Research Article

Biased Maximum Power Extraction from a PV during Low Irradiation and a Highly Stiffed Grid Condition

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Growing electrical demand is to be met dynamically through conventional and nonconventional power sources. PV power generation plays a vital role. Because of low irradiation and overcast weather condition, the installed PV sources are not fully utilized. Many research papers were presented to extract maximum power from PV using various MPPT techniques. This paper presents a new idea of implementing a biased transformer to extract maximum power during the above condition. The proposed method uses three winding transformers to give sufficient biased voltage and current. The biased current and voltage were obtained from the grid that is fed to the primary winding—two of the three winding transformers through the controller. A 10 kW panel is checked for low irradiation and overcast weather condition using the biased MPPT technique. The proposed method is compared with the conventional incremental conductance method with power, cost, and efficiency analysis. Simulation was carried out in MATLAB/Simulink software and experimentally evaluated through a suitable hardware setup.

1. Introduction

Rapid usage of energy from nonfossil fuel is increased in the modern world. This photovoltaic (PV) sourced power plays a significant role. The PV panel at a specific point delivers maximum power for which a technique has been developed to improve the effective utilization of PV called the maximum power point tracking (MPPT) techniques in [1]. Power electronic converters are used for these techniques due to the PV panel's nonlinear characteristics in [2]. Researchers developed many MPPT techniques as discussed in [3] to extract maximum power from PV cells. Factors considered by most existing MPPT techniques include the number of unique sensors used, technology implementation method, speed of operation, utilization method, complexity of algorithm, and the cost of controller [4–6]. Many existing MPPT methods concentrate on standalone operations with single-source PV power utilization systems. Grid-connected PV operations using MPPT methods are comparatively less in the market due to constant grid voltage at the common coupling point. Perturb and observe (P&O) method, incremental conductance method (IC) [7], and constant voltage method (CV) are basic MPPT techniques, while methods of soft computing combining intelligent techniques are tuned to the basic methods [8]. The constant voltage method tracks only the nearby original maximum power point (MPP; within boundary) and not the exact MPP position [9], which can lead to energy loss from the PV. The incremental conductance (IC) method fits MPPT at specific positions but varies due to variable load impedance [10]. The algebraic sum of conductance across the terminal of the PV array is equal to the conductance of PV \( \frac{I_{pv}}{V_{pv}} \), and then maximum power is transferred from the PV to the load [11]. The PV source is connected to the load through single- or dual-stage converters for both standalone or grid-connected modes [12]. Most-grid connected systems consist of a dual stage for the MPPT process and for DC-to-AC inversion in [13]; however, the system are tracked to the nearby original MPP [14, 15]. Pulse with modulated converters are used to achieve MPPT by varying the PWM conductance value in
As the load impedance changes, the actual MPP deviates from its original value, causing the PV to lose energy supply to the load in relation to the current irradiation [17]. Analysis of MPPT with fixed step size IC based on direct control method was tested in [18] without load variations. IC method with variable step size method MPPT was implemented in [19], but the variable load was not considered. Dynamic variation of irradiations was traced by fast varying step size IC method with output oscillation. This will be suppressed by partial varying step size IC MPPT algorithm introduced in [19] along with the standalone mode with a fixed and concentrated load. Grid-connected single-stage PV power generation with INC-based MPPT system was used in [20]. This may lead to power loss during utilization. One-cycle cost-effective MPPT control for grid-connected PV system was attempted in [21] with a 4.5% error in peak power performance during low irradiation. Fuzzy-based MPPT was established in [22] with the inputs of duty ratio and charger power through PIC microcontroller, but on the other hand, dynamic irradiation change was not realized. PV power error and change in error were fed to the input of fuzzy-based cognitive maps MPPT controller in [23]. This controller requires historical data for training. Also, variable load conditions were not considered. The temperature along the irradiation parameter was the input of the PI fuzzy MPPT method simulated in [24] with the change of output load. Visualization of the change of irradiation was missed. Grid-connected dual-stage PV system with self-organizing fuzzy MPPT was evaluated through software in [25]; DC link voltage of the inverter was not properly regulated; and hence, the change of duty ratio and hardware implication could result in complex work. Real-time optimal power point of the PV array was achieved through historical-data-focused neural network controller in [26] with the common power source. High-speed computational digital controllers or PCs' are required for these controller implementations. The system may also fail due to drastic changes in weather. The next level approach of neural network MPPT methods for standalone and grid-connected PV schemes are discussed in [27] with electrical and nonelectrical inputs. Implementation and training of these controllers require complex hardware with highly knowledgeable persons are required. Also, the actual MPP works at the boundary of the original operating point. Further improvement of fuzzy-neural with optimization of MPPT schemes was discussed in [27] as this suits MW-level power plants with large investment and reduces power utilization from PV during low-level irradiation. This paper proposes the biased MPPT method that allows the user to extract and use power during low irradiation. Most existing MPPT methods for grid-connected PV systems achieve MPP by adjusting the pulse duty ratio of power converters [28]. The PWM duty ratio can change the input and output conductance of DC/DC power converters to attain MPPT in a dual-stage grid integrated PV setup [29]. Simultaneously, if the input is maintained for MPP, then output conductance changes, and so it is not possible to regulate the DC link voltage of the grid integrated inverter. Similarly, if we tuned the output conductance of the power converter to regulate the DC link voltage, then MPP input is lost. However, the proposed system can exactly work in MPP with effective utilization of PV during low irradiation [30]. Additionally, the proposed biased MPPT scheme helps significantly reduce low voltage problems faced by residential consumers and imbalance in the loading effect of Indian distribution transformers [31], for which a detailed explanation is given in Section 2. Globally, renewable energy utilization analysis and installed capacity factual data were revealed in the Renewables 2019 Global Status Report [32]. The various irradiation data are utilized from the standard journals [33]. The efficiency analysis of the proposed system is compared with the existing efficiency analysis report [34, 35].

From the inference of the literature survey, there is no biased control attempted to use to track maximum power so far. This paper presents a novel approach to obtaining MPPT using a biased unit.

In this section, a brief introduction of various PV systems and their MPPT techniques available in the literature are explained. Various methods adopted to attain maximum efficiency and problems faced while connecting the PV system to the grid are discussed. The merits and demerits given in the reference papers are specified briefly. The concept of the biased MPPT technique and implementation of three winding transformer is introduced.

2. Overture of the Proposed System’s Methodology

2.1. Functional Block Diagram of the Proposed System. In the proposed system, a 1kW PV panel is connected to the microgrid through the biased MPPT transformer. The biased transformer contains two primary winding $S_{pv}^1$ and $S_{pv}^2$ and one secondary winding $S^S$. During irradiation, the biased transformer adds the voltage and produces the power with the help of the feedback power from the grid through the inverter.

2.1.1. Description of the Proposed System. Figure 1 shows a functional block schematic of the proposed biased MPPT method for PV source power generation. The photovoltaic array is connected to the biased transformer through a reverse blocking diode. The biased transformer consists of two input windings with a center-tap terminal and one output winding. One input winding center tap is connected to the positive terminal of the PV source, while the other two ends are connected through a power electronic switch to the negative terminal of the PV source. The second input winding center tap point is connected to the positive terminal of biased DC that is derived from the grid supply. The DC negative is connected through power electronics switches to the other two terminals of the second input winding of the biased transformer. The secondary winding of this biased transformer is connected to the grid. The DC source voltage is controlled by a bidirectional TRIAC switch. Nonlinear load and grid are integrated at the point of common coupling (PCC). Voltage and current sensors are interfaced at suitable locations. These values are fed into the physical controller unit through a signal conditioner and ADC. PWM pulses are connected to the power switch gate.
2.1.2. Proposed System Methodology. (a) A photovoltaic array’s equivalent model depicted in [3, 33]. PV array with compensations for the photovoltaic light-triggered current source is connected with a parallel diode representing the P–N junction of the cell. One resistance is connected in series, and another is connected in parallel. The relationship between the PV array voltage and current equations is obtained through Kirchhoff’s law given in (1) and (2). These equations clearly indicate the nonlinear performance of PV output. PV voltage and current vary widely with respect to a fall in irradiation and temperature. Hence, the PV delivers peak power at a specific point called maximum power point (MPP); conductance of a PV array equal to load conductance is connected across the PV terminal. Power generated by the PV array is given in the conventional equation (3). Continuous change of environmental conditions solar irradiations and temperature change affects the MPP of the PV array, and hence, many algorithms were developed to track the MPP called maximum power point tracking (MPPT). The work of MPPT is to create a conductance match between load and source during the change of irradiation and temperature. DC-to-DC converters (such as transformers) are widely used in this application. This device works perfectly at high irradiation levels but lags at low irradiation levels to attain the MPPT due to low load voltage and grid variations in the grid-connected PV generation systems. Hence, we need an MPPT scheme that suits all situations. (b) Biased transformer and the equivalent circuit model of the proposed system are depicted in Figure 2. The given equation is utilized by the biased system.

2.1.3. Equation of the Biased Transformer Model. Here, R: resistance, L: inductance, M: mutual inductance, P: primary winding, and S: secondary winding.

\[
\begin{align*}
    v_{p1} &= R_{p1}i_{p1} + j\omega \left[ L_{p1}i_{p1} + M_{p11}i_{s} + M_{p12}i_{p2} \right], \\
    v_{p2} &= R_{p2}i_{p1} + j\omega \left[ L_{p2}i_{p2} + M_{p11}i_{s} + M_{p12}i_{p2} \right], \\
    v_{s} &= R_{s}i_{s} + j\omega \left[ L_{s}i_{s} + M_{p11}i_{p1} + M_{p21}i_{p2} \right].
\end{align*}
\]

Solving this equation reveals the following model:

\[
\begin{align*}
    \begin{bmatrix}
        i_{p1}^i \\
        i_{p2}^i \\
        i_{s}^i
    \end{bmatrix} &= j\omega \begin{bmatrix}
        1/L_{p1}L_{p2}M & M_{p11} & M_{p12} \\
        M_{p11} & R_{p1} & M_{p21} \\
        M_{p12} & M_{p21} & R_{s}/M
    \end{bmatrix} \begin{bmatrix}
        i_{p1} \\
        i_{p2} \\
        i_{s}
    \end{bmatrix}, \\
    v_{p1} &= \begin{bmatrix}
        1/L_{p1} \\
        1/L_{p2} \\
        1/M_{s}
    \end{bmatrix} v_{p1}, \\
    v_{p2} &= \begin{bmatrix}
        1/L_{p1} \\
        1/L_{p2} \\
        1/M_{s}
    \end{bmatrix} v_{p2}, \\
    v_{s} &= \begin{bmatrix}
        1/L_{p1} \\
        1/L_{p2} \\
        1/M_{s}
    \end{bmatrix} v_{s},
\end{align*}
\]

\[
M = M_{p11}M_{p21}M_{p12}.
\]

Here, the biased transformer (BT) has two primary winding and one secondary winding. One primary winding terminal through a proper driver isolation circuit. The entire system operation is detailed in Section 4.
The primary winding voltage \( v_{p1} \) is connected to the PV source. The second primary winding voltage \( v_{p2} \) is obtained from the biased circuit derived from the grid source. Secondary winding voltage \( v_s \) is connected to the grid-integrated systems. The power balance of the BT is given in (5):

\[
v_{pp} = v_{pp} i_{s}. \tag{6}
\]

PV source output voltage and current are maintained at a particular point to extract maximum power from the PV source. \( v_{pp}^m \) and \( i_{pp}^m \) are maximum power point voltage with the corresponding irradiation due to changes in irradiation, \( v_{pp}^m \) and \( i_{pp}^m \) values deviate from \( v_p^1 \) and \( i_p^1 \), resulting in complicated problems in maintaining grid integration. To compensate for this situation, additional biased source is added in parallel to the PV through BT. In order to achieve an output power balance between the PV and the grid (full extracted power pumped to the grid), the grid-integrated transformer maintains voltage and current as per (6). BT primary voltage is divided by two sources, one from the PV panel and another biased source derived from the grid. The primary power equation is given in (6):

\[
v_p = v_{pp}^m v_b, \tag{7}
\]

\[
i_p = i_b, \tag{8}
\]

\[
i_p = i_{pp}^m + i_b. \tag{9}
\]

Solving the above equation results in the value of \( i_b \) as follows:

\[
i_b = \left(\frac{i_b}{k}\right) - i_{pp}^m. \tag{10}
\]

The main objective of this work is to increase the maximum extracted PV power to the grid with low irradiations and cloudy weather conditions. Hence, the power balance equation is given in (10):

\[
P_p = P_{pp} + P_b, \tag{11}
\]

\[
P_p = (i_{pp}^m)^2 Z_b^m + i_b^2 Z_b. \tag{12}
\]

\( z_b \) is obtained by substituting the value of (10) in (12) along with BT primary power with computed maximum PV power values \( (P_{pp}^m) \) as follows:

\[
Z_b = \left[ P_{pp} - P_{pp}^m \right] \left[ (i_b/k) - \frac{i_{pp}^m}{i_{pp}^m} \right]^2. \tag{13}
\]

BT primary winding has the same turns and similar parallel voltage, and hence, we write (13):

\[
v_{pp}^m \sin(\omega t) = v_b \sin(\omega t + \delta), \tag{14}
\]

\[
\sin(\omega t) = \left(\frac{v_b}{v_{pp}^m}\right) \sin(\omega t + \delta), \tag{15}
\]

\[
\theta_2 = \sin^{-1}(kv \sin(\sin(\theta_i))). \tag{16}
\]

Voltage \( v_{p2} \) angle is obtained by (16). This angle of deviation that may act as a current sharing control component of \( i_b \) is given in (8)

\[
v_{pp}^m = v_{pp} + v_{p2}, \text{ where } v_{pp} = \text{primary winding 1 voltage.} \]

This is the output voltage of the PV panel. In the normal irradiation condition, value of \( v_{p1} \) is almost equal to the value of \( v_{pp} \), \( v_{p2} = \text{primary winding 2 voltage. Due to low irradiation and overcast condition. This voltage is fed back from the grid to the three winding transformer. Hence, } v_{p2} \text{ is called biased voltage. Its value depends on } v_{p1}. \text{ For ideal transformer, } K = 1, v_s = 230v, i_{pp}^m \text{ and } i_s \text{ values are varied depending upon the irradiation.}

2.2. Working Methodology of the Proposed System

2.2.1. Flow Chart. The execution steps for the proposed scheme are pictorially depicted in Figure 3.

2.2.2. Biased Current and Biased Voltage. Generally, power is unavailable from the PV panel between 7:00 am and 9:00 am, 4:00 pm to 5:30 pm, and during cloudy and overcast weather due to low irradiation. So approximately 250 W/m² power is wasted during low irradiation. Our proposed method successfully obtains power during low irradiation.

The MPPT and DC link voltage between the PV and grid should be maintained to retrieve maximum power from the PV panel. In most conventional methods, MPPT power is obtained using DC/DC converters. But the main issue with the converter is improving output voltage \( (v_o) \) as then input current \( (i_i) \) will decrease. Similarly, when improving output current \( (i_o) \), the value of \( (v_o) \) will decrease.

The condition for maximum power point tracking is as follows:

\[
v_{pp}^m \times i_{pp}^m = P_{pp}^m. \tag{17}
\]

But the problem is that during low irradiation, DC/DC converters are unsuitable to achieve MPPT. Also, converters cannot maintain the maximum Z value. During low irradiation, the voltage across the PV Panel is low, due to which it cannot feed the PV power from the panel to the grid.
Approximately, power wasted is 3 kW for a 10 kW panel. MPPT is also not maintained due to low voltage.

In our proposed method, we extract power from the PV panel at low irradiation with the help of biased current \( (i_b) \) obtained from the transformer connected in series with the PV. Only when biased current \( (i_b) \) is added can we maintain MPPT. The \( v_{pv} \) and \( i_{pv} \) values were also maintained at the maximum. The biased current is feedback from the grid with the help of a voltage controller, rectifier, and transformer. The value of the biased current \( (i_b) \) is obtained by varying the firing angle of the voltage controller.

Maintaining the MPPT of a PV requires satisfying the following conditions: \( v_{pv} = v_{pv}^m \) \( i_{pv} = i_{pv}^m \). But, during low irradiation, the value of \( v_{pv}^m \) is less than the value of required \( v_{pv} \). To retrieve power from the PV, biased voltage \( v_{pv}^b \) should be added to the PV panel voltage \( v_{pv} \).

Now, \( v_i = v_{pv} + v_{pv}^b \). \( \text{(18)} \)

The amount of biased current \( (I_b) \) fed back from the grid is approximately equal to 15% to 20% power utilized through the proposed system. The proposed hardware setup includes a 10 kW panel. Obtained power from the PV during low irradiation is 3 kW. Around 15% to 20% of loss is due to biased current \( (I_b) \). 0.5 kW. In the proposed method power obtained per hour is near to around 2.5 kWh.

2.3. Power and Cost Analysis for the Proposed System. The power extracted from the 10 kW PV panel is investigated and compared with the existing incremental conductance MPPT method. The investigation is based on two categories:

(i) Low irradiation: during low irradiation period, power extraction per hour and cost analysis for the existing system in comparison with the proposed system are given in Table 1

(ii) Irradiation due to overcast weather conditions: during overcast period, power extraction per hour and cost analysis for the existing system in comparison with the proposed system are given in Table 2.

2.3.1. Low Irradiation

2.3.2. Overcast Condition

2.3.3. Extracted Power Analysis. Annual power extraction analysis of proposed and existing MPPT methods energy value is given in Table 3.

2.3.4. Cost Analysis. Annual cost analysis of proposed and existing MPPT methods energy value are given in Table 4.

This section explains the proposed methodology. The choice of selecting the transformer is carried out. The biased transformer was chosen to add the required voltage to maintain the voltage profile. The strategy to implement the biased MPPT technique is presented. A functional block diagram of the proposed system is given. The dynamic equation of the biased MPPT method is derived. The algorithm and flow chart of the model are also shown. Investigation between the existing and proposed methodology is developed in terms of power and cost analysis.

3. Simulation and Analysis of the Proposed Method

Simulated system parameters of the proposed approach are given in Table 5.

3.1. Explanation of Simulink Block Diagram and Resultant Waveforms. The proposed system simulation base model of biased MPPT contains three blocks. They are PV array block, control circuit, and power circuit that are pictorially represented in Figure 5.

3.1.1. Implementations of the Simulink Block Diagram. The simulation of the proposed system is shown in Figure 6. It is divided into three major parts. The first one is a 10 kW PV array system. The power circuit comprises three winding transformer and grid-integrated circuits. The control circuit contains all biasing control units and elements.

3.2. PV Array Block. In the proposed method, the PV module contains 10 cells connected in parallel and 5 connected in series. A single module produces 24.3 V and
7.35 A. The entire arrangement of a PV section is mentioned in Figure 7. Here, the irradiation input variable is fed into the PV-simulated system. A total power produced from the panel is 10 kWh. By the filter capacitor is connected across the PV panel and the inverter to reduce ripples and improve voltage smoothening. By this inverter output is given to an input winding of the biased transformer.

Table 6 describes the varying radiation from the sun between 7:00 am and 5:30 pm.

3.3. Power Circuit. The power circuit consists of two input windings and one output winding biased transformers. One input winding is from the PV panel through the inverter and another input winding is fed back from the single-phase AC grid through the AC voltage controller, rectifier, and inverter. This section is called the biased block. The second winding produces the biased current that is used to improve the output voltage of the transformer. LC filter is used for smoothening the voltage. The above-stated arrangement is shown in Figure 8.

In the simulation power circuit is shown in Figure 9, the filter circuit is used to remove the unwanted signal. A mathematical algorithm of MPPT is developed. Computation block is used to find out the value of biased voltage. In this section, the error values are computed and given to the PID controller. The output of the PID controller is given to the VSI through the PWM generator. The computed biased voltage is finally given to the secondary winding.

**Algorithm 1:** The algorithm of the working methodology.

Table 1: Power and cost analysis during low irradiation.

| Type      | Irradiation value (W/m²) | Max possible power per hour (kWh) | Power extraction per hour (kWh) | Power extraction per year (kWh; 3.5'365) | Cost per year (Rs.; 1 unit, Rs. 8) |
|-----------|--------------------------|-----------------------------------|-------------------------------|----------------------------------------|----------------------------------|
| IC method | 250                      | 2.167                             | 1.620                         | 2,069.55                               | 16,556                           |
| Biased MPPT |                          |                                   |                               |                                        |                                  |

Table 2: Power and cost analysis during overcast conditions.

| Type      | Irradiation value (W/m²) | Minimum possible days per year (days) | Possible power extraction in existing IC method per hour (kWh) | Power extraction in existing IC method (60°6 hrs) per year (kWh) | Cost per year (Rs.; 1 unit, Rs. 8) |
|-----------|--------------------------|--------------------------------------|---------------------------------------------------------------|-----------------------------------------------------------------|----------------------------------|
| IC method | Up to 300                | 60                                   | 1.167                                                         | 420.12                                                          | Rs. 3,360                        |
| Biased MPPT |                          |                                       | 2.125                                                         | 765                                                             | Rs. 6,120                        |

Table 3: Overall extracted power analysis.

| Type      | Power extraction during low irradiation (kWh) | Power extraction during overcast condition (kWh) | Overall power extraction (kWh) |
|-----------|----------------------------------------------|--------------------------------------------------|--------------------------------|
| IC method | 2,069.55                                      | 420.12                                           | 2,489.67                       |
| Biased MPPT | 2,714.68                                    | 765                                               | 3,479.68                       |

Table 4: Overall cost analysis.

| Type      | Low irradiation (Rs.) | Overcast (Rs.) | Overall (Rs.) |
|-----------|-----------------------|----------------|---------------|
| IC method | 16,556                | 3,360          | 19,916        |
| Biased MPPT | 21,717                | 6,120          | 27,837        |
3.4. Control Circuit. Terminal voltage and current of the PV panel are measured, and ripples are removed by a suitable filter. The changes in conductance values are instantaneously derived from the PV terminal voltage and current. By the changes in conductance values, the biased voltage is a function of instantaneous PV power availability. The required biased voltage is determined through the control circuit with the difference between actual and reference voltage as shown in Figure 10. The proposed system is grid-connected, and so the synchronization part plays a significant role in grid integration. In this method, the single-phase PLL is used to attain the frequency tracking of the value of $\theta$. This $\theta$ value is taken as a reference to generate the modulating signal in the proposed inverter system.
The simulation control circuit shown in Figure 11 plays a vital role in the proposed system methodology. Its control output of the system through the particular computational block.

3.5. Performance Analysis of the Proposed System through the Simulated Output

3.5.1. PV Panel and IV Characteristics. Figures 12 and 13 describe the PV and IV characteristics of the PV module and the array of PV modules utilized in the proposed simulation system.

3.5.2. Case 1: Low Irradiation (7:00 am to 9:00 am and 4:00 pm to 5:30 pm; 150 w/m² to 400 w/m²). Performance analysis of the proposed biased MPPT method was compared with the existing incremental conductance MPPT method. In the proposed system, the irradiation level from the 1,000 watts panel at 0 to 1 sec is 250 w/m² and 1 to 2.5 is 750 w/m². \( v_m \) and \( i_m \) values should be maintained at maximum for retrieve power from the PV panel. If the loading condition is greater than 0.5 sec, the PV terminal voltage and current deviate from the maximum power point voltage in the existing method. However, the proposed biased MPPT scheme maintains the \( v_{mp} \) and \( i_{mp} \) with respect to corresponding irradiation and is shown in Figures 14 and 15.

During low irradiation, grid-connected condition is significantly reduced by the existing method. But the proposed method retains the \( v_{mp} \) and \( i_{mp} \) in the required value as per instantaneous irradiation. Hence, the proposed technology that enhances power extraction from the PV is a remarkable improvement as shown in Figure 16.

For the proposed three winding biased transformers, the primary voltage is 135 V, and the secondary voltage is 230 V. In low irradiation or overcast weather, the primary voltage is less than 135 V. Due to less irradiation in a grid-connected condition, the system cannot extract maximum power from

![Figure 6: Simulation block diagram of proposed biased MPPT.](image)

![Figure 7: Simulation base diagram of the PV block.](image)

**Table 6: Irradiation level.**

| S. no. | Duration                  | Irradiation (kWh) |
|-------|--------------------------|-------------------|
| 1     | 7:00 am to 9:00 am       | 3                 |
| 2     | 9:00 am to 4:00 pm       | 7.5–10            |
| 3     | 4:00 pm to 5:30 pm       | 3                 |
| 4     | Cloudy (overcast) weather condition | 0–2.5             |
the PV panel. To attain maximum power at low irradiation, biased current $i_b$ is fed back from the grid through the second input winding. In the proposed system biased current value is increased from 1 to 3 A than the IC MPPT method as shown in Figure 17. When the value of the input current increases, the voltage of the secondary side of the transformer also increases. Now available power is obtained from the source.

Time duration from 0 to 0.5 sec our proposed method is not implemented. So the current value is minimum. From the duration 0.5 to 1 sec (low irradiation period), the proposed method is implemented. The maximum available power is produced with the help of the biasing current fed to the primary winding 2.

Biased current ($i_b$) fed back from the grid is approximately equal to 15% of the power utilized. Power obtained from the 10 kW panel during low irradiation is approximately 3 kW. 15 percentage of loss due to biased current ($i_b$) is 0.5 kW. Comparatively, the loss is very low from the 3 kW output.

In the proposed biased MPPT method, power spent is approximately 300 to 400 watts. From Figure 18, 0 to 0.5 sec
is a no-load condition, and 0.5 to 1 is the loading condition at low irradiation. Around 2.5 kW maximum power is extracted during that time.

During low irradiation, from the above Figure 19, no-load condition is from 0 to 0.5 sec, and 0.5 to 1 sec is a loading condition when the terminal voltage of the BMPPT method improves gradually. During low to high irradiation, 250 w/m² to 750 w/m² (1 sec to 2 sec), the biased voltage $b_v$ is reduced and becomes zero, as sufficient primary voltage is produced from the PV panel during normal radiation. So the controller does not produce the biased voltage.

During low irradiation, the RMS value of the terminal voltage of the proposed method increases after 0.5 to 1 sec compared to the IC MPPT method as shown in Figure 20. Power from the source is successfully extracted during that time; once the irradiation level becomes normal (after 1 sec), the controller does not produce any biased voltage.

The value of the biased current ($i_b$) is obtained by varying the firing angle of the voltage controller. If the current of the primary winding is improved during low irradiation, the voltage of the secondary side is improved to attain maximum power. The PLL value of power value and its angle is shown in Figure 21. The power angle is improved at low irradiation after 0.5 sec than during the unloading condition.

Total harmonic distortion (THD) analysis for the proposed system was carried out, and the results are depicted in Figures 22–24.
**Figure 12:** PV and VI characteristics of the single PV module.

**Figure 13:** PV and VI characteristics of PV array of the module.

**Figure 14:** PV terminal voltage.

**Figure 15:** PV terminal current.
The THD value of current in IC MPPT method was 3.77%. However, the proposed biased MPPT system’s THD value was significantly improved. The THD value of current was 1.24% (Figure 23), and the THD value of voltage was 0.24% (Figure 24).

If the fundamental value is raised up to 100%, the other harmonics values are invisible. A fundamental component of the AC voltage 100% value is shown in Figure 24(b).

3.6. Comparative Analysis of Power Extraction during Varied Irradiation. Table 7 describes the improvement of power developed using the proposed methodology (10 kW panel).

A detailed simulation of the proposed method is explained in Section 3 where simulation parameters and their corresponding values are given. The simulation block module, control strategy, and power circuit of the method are explained. The VI and PV characteristics of the PV array are presented. Simulation results for the biased MPPT method are obtained and compared with IC MPPT. The merits of the biased MPPT were proven by the results. The simulated output waveforms and data values ensured that the proposed system’s extracted power daily from the PV was a significant improvement.

4. Experimental Evaluation of the Proposed System

4.1. System Setup. The focused prototype physical model was fabricated with a reduced simulation model. Rating of the experimental system’s components is given in Table 8. This circuit consists of two single-phase inverters built with a power module of SEMIKRON’s IGBT. A biased transformer (BT) has a dual input primary winding and a secondary winding. The secondary winding is connected to the grid in parallel with one voltage smoothing capacitor. One primary
BT winding is connected to the PV source through the inverter circuit, and another is connected to the biasing supply. The biasing supply source is derived from the grid through SEMIKRON’s IGBT-based AC voltage control circuit. PV source and the biased source’s voltage and current values are measured by Hall effect sensors, and the respective sensor ratings are given in Table 4. The proposed control method was developed in the domain of MATLAB/Simulink with Simulink coder depicted in Figure 25 and deployed in the TI LaunchPad F28379D Texas board controller to produce the biasing current from the grid as shown in Figure 25.

4.3. Control Circuit Implementation Using the SIM Coder. The driver circuit shown in Figure 27 includes an Optocoupler TLP250 and bridge rectifier to mainly control the voltage.

4.4. Hardware Result. Current and voltage values during low irradiation shown in Figure 28 (0.5 to 1 sec in simulation, 7:30 am to 9:00 am and 4:00 pm to 5:30 pm in hardware) and normal radiation (1 to 2 sec in simulation, 9:00 am to 4:00 pm in hardware) are almost similar to the simulation waveform shown in Figures 17 and 20. Input current is increased due to $i_b$.

The results in Figure 29 show improved output power during low irradiation and overcast weather condition.

In Figure 30, the PLL value of power output from the proposed output system’s hardware is exactly equal to the simulation output shown in Figure 21. Angle variation and power values are the same in both results.

There are two primary windings in the proposed biased transformer. The PV output is linked to one primary winding. Biased voltage is given to another input winding. The above Figure 31 shows both input voltages during low irradiation.

Hardware output of biased voltage shown in Figure 32 is more suitable in the simulation result shown in Figure 19. Free biased AC voltage is produced with a filter. THD analysis of the proposed system is carried out. The THD obtained for voltage in simulation and hardware is 0.24% shown in Figure 24(a) and 0.9% shown in Figure 33, respectively. For current, it is 1.47% shown in Figure 24(b) and 1.8% shown in Figure 34. A small variation is inferred in THD of simulation and hardware results. From the above assessment, the THD obtained in the system is less than the fundamental THD values of existing methods.

The efficiency analysis of the system is developed through the experimental evaluation; also the efficiency of the system is compared with the existing IC MPPT method shown in Table 9.

The hardware of the proposed system is developed. Voltage and current of the biased MPPT technique were obtained. Extraction of continuous power irrespective of the change in irradiation was presented. Hardware results justify the implementation of the biased MPPT technique as it ensures maximum power extraction under varied environmental conditions. Efficiency analysis and THD analysis of the Experimental evaluation are developed.
Table 7: Comparative analysis of power development.

| S. no. | Type of irradiation                      | Existing INC MPPT method (per kWh) | Proposed biased MPPT method (per kWh) |
|--------|-----------------------------------------|-----------------------------------|--------------------------------------|
|        |                                         | Per hour | Per day | Per month | Per year | Per hour | Per day | Per month | Per year |
| 1      | Normal irradiation                      | 7.5      | 70      | 2,100     | 25,200   | 7.5      | 70      | 2,100     | 25,200   |
| 2      | Low irradiation                         | 0–0.5    | 1.75    | 52.5      | 630      | 2.5      | 8.75    | 262.5     | 3,150    |
| 3      | Cloudy (overcast) weather condition     | 0–1      | 3.5     | 105       | 1260     | 2.5      | 8.75    | 262.5     | 3,150    |

Figure 23: AC current THD value in the proposed biased MPPT method.

Figure 24: THD value of system AC voltage.

Table 8: Hardware components parameter.

| S. no. | Name of components | Component’s spectrum |
|--------|--------------------|----------------------|
| 1      | PV panel           | 25Wp, 17.5V/m, 1.54A-Isc |
| 2      | Biased transformer | (0–15) V and (0–15) V/230V |
| 3      | Power switch       | SKM75GB12T4; 1,200 V; 75 A |
| 4      | Hall effect voltage sensor | LV 25-P; up to 500V |
| 5      | Hall effect current sensor | LA 25-P; up to 25A |
| 6      | Controller         | TI LaunchPad F28379D |
| 7      | Diode              | 5KP30A               |
| 8      | Capacitor          | 25V 2200uf           |
| 9      | Optocoupler        | TLP250               |
Figure 25: Experimental evaluation setup of the proposed method.

Figure 26: Control circuit implementation using SimCoder.

Figure 27: Driver circuit for the power module.
Figure 28: Biased MPPT voltage and current.

Figure 29: Power extraction during irradiation.

Figure 30: PLL value of power.

Figure 31: Biased transformer primary winding 1 and 2 voltages.
5. Conclusion

The proposed biased MPPT achieved the task of power extraction from the solar PV panel during low irradiation. This process was proved through analysis and simulation modeling and with appropriate hardware results. Compared to the conventional method, this novel proposed biased MPPT method extracts 3 MW power additionally in a year. The final goal was achieved by designing the proposed three winding biased transformer that provides the proper output. The biased current required for the primary winding was successfully controlled by the Texas board controller. In the proposed biased MPPT model, additional studies are possible as there is also a lot for interpretation regarding the

| Irradiation condition          | Irradiation value (W/m²) | Max possible power per hour (kWh) | Power extraction in existing IC method (kWh) | Energy extracted efficiency of IC method (%) | Power extraction in proposed biased MPPT (kWh) | Energy extracted efficiency of biased MPPT method (%) |
|-------------------------------|--------------------------|----------------------------------|---------------------------------------------|---------------------------------------------|-----------------------------------------------|---------------------------------------------------|
| Low irradiation               | 250                      | 2.167 kWh                        | 1,620 kWh                                   | 74.75                                       | 2,125 kWh                                      | 98.06                                             |
| Cloudy (overcast) weather     | Up to 3,000              | 65,010 kW/month                  | 36,600 kW/month                             | 56.29                                       | 59,100 kW/Month                                | 90.9                                              |
| condition                     |                          |                                  |                                             |                                             |                                               |                                                   |
future scope in this area. This methodology is considered more suitable for the power demand and the current economy.

**Abbreviations**

- $v_{p1}$: First primary winding voltage
- $v_{p2}$: Second primary winding voltage
- $v_{pv}$: Photovoltaic terminal voltage
- $i_{pv}$: Photovoltaic terminal current
- $p_{pv}$: Power from the PV panel
- $i_{b}$: Basing current
- $v_{b}$: Basing voltage
- $v_{pm}$: Maximum PV voltage
- $i_{pm}$: Maximum PV current
- $p_{pm}$: Maximum PV power
- $z_{bi}$: Biased impedance
- MPPT: Maximum power point tracking
- IC: Incremental conductance
- PV: Photovoltaic
- CV: Constant voltage
- ADC: Analog to digital
- PCC: Point of common coupling
- PWM: Pulse width modulation
- BT: Biased transformer
- PLL: Phase-locked loop
- THD: Total harmonic distortion.

**Data Availability**

The data used in the manuscript were taken from the following textbooks: (i) Global Renewable Energy usages data from “Raturi, A. K. (2019). Renewables 2019 global status report” and (ii) the irradiation data from “Rekioua, Ernest Matagne, Modelization, Simulation and Control; Springer Science and Business Media.”

**Conflicts of Interest**

The authors declare that they have no conflicts of interest.

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