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Original article

A Multiple-Band Golden Section Search Strategy for Maximum Power Point Tracking in Solar Water Pumping Systems

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Abstract

This study proposes a novel multiple-band Golden Section Search (GSS) strategy for maximum power point tracking (MPPT) in photovoltaic (PV) systems, specifically designed to enhance the detection of the global maximum power point (GMPP) under dynamic operating conditions. The method is applied to control a brushless DC (BLDC) motor driving a single-stage solar water pumping system (SWPS). The power-voltage (P-V) curve of the PV array is optimally divided into sequential bands, within which the proposed GSS-MPPT algorithm identifies all local peaks and determines the global peak. The proposed design further increases search density compared to the conventional GSS-MPPT, ensuring GMPP capture within an acceptable time frame, reducing power oscillations, and eliminating the randomness and complexity of meta-heuristic MPPT methods. This enhanced strategy also improves reliability under shading conditions by enabling more efficient GMPP extraction. An indirect MPPT control structure, employing a proportional-integral-derivative (PID) controller, provides smooth motor speed regulation and precise PV voltage adjustment at each setpoint. MATLAB simulations under varying irradiance and temperature conditions demonstrate that the proposed system achieves stable motor operation with high dynamic responsiveness, tracking an MPPT efficiency exceeding 99%. These results confirm the method's suitability for high-performance solar water pumping applications.

Keywords. Solar PV, Single-stage Solar Water Pumping, BLDC Motor, Soft Switching.

Introduction

The features of solar PV panels make them a highly suitable renewable energy source for both small- and large-scale power applications. They are reliable, clean, cost-effective, have no moving parts, and are easy to install. Additionally, power electronics technology is continually advancing, and the cost of PV panels is gradually decreasing [1,2]. Operational challenges in renewable energy systems require efficient power converter designs combined with robust global MPPT control strategies [3,4]. Water and energy are essential for life. The SWPS offers a reliable, efficient, economical, and sustainable solution, capable of effectively tracking the GMPP. It includes PV panels, an embedded control circuit, a motor pump, and a water tank or batteries. However, batteries add cost, increase complexity, and reduce efficiency [5, 6].

An embedded control circuit is required to drive the motor of the SWPS. Its design should be low-cost, compact, lightweight, and highly efficient. Single-stage and two-stage power converters are the main types used for AC loads in PV systems. A two-stage converter comprises a DC-DC converter and an inverter, whereas a single-stage converter utilizes only an inverter. As a result, two-stage designs are larger, heavier, and less efficient. Therefore, if the PV voltage matches the motor's operating voltage, a single-stage converter is a simpler and more efficient choice [7,8]. BLDC motors are widely used in modern applications due to their high power density and efficient electronic control [9]. These motors are ideal for single-stage converters and small-scale SWPSs, saving energy, reducing costs, and improving efficiency [10].

Solar energy output varies continuously due to factors such as PV panel tilt angle, sunlight intensity, surface temperature, dust accumulation, water droplets, and partial shading [11]. MPPT control is a renewable energy technology that maximizes the output power of solar PV panels by continuously adjusting the operating voltage to its optimal value. The goal of MPPT control is to optimize energy conversion efficiency, enhance PV system reliability, reduce power loss, increase tracking speed, and improve performance with minimal power perturbation. Hence, addressing operational challenges and improving PV system efficiency requires an effective power converter design combined with a robust and fast global MPPT control strategy [12,13].

Previous studies have introduced various MPPT approaches aimed at accurately determining the maximum power point (MPP) and improving overall efficiency. Most of these methods employ direct or indirect MPPT control strategies with a regulator. The regulator smoothly adjusts the duty cycle, making the control structure ideal for PV motor applications due to its stability, robustness, accuracy, and effective speed regulation [14,15]. Classical MPPT algorithms are powerful under uniform weather conditions. They rely on PV power variations or gradient-based searches and target the first peak, since they often operate on the high-voltage side of the P-V curve rather than the full curve. As a result, classical algorithms such as the perturb and observe (P&O) and incremental conductance (INC) MPPT methods are robust and effective under

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uniform weather conditions [16,17]. The performance of these methods strongly depends on the values of the initial reference voltage and step size [18].

Partial shading significantly reduces PV array output and can cause multiple peaks in the P-V curve [19]. Extracting the GMPP from a multi-peak P-V curve requires a dense search across the entire solution space. A practical and efficient approach to address this challenge is to use a sweeping and segmented search over the full PV voltage range. Although a large number of search iterations or random searches—such as bio-inspired and meta-heuristic techniques—often lead to long search times and power oscillations. Since measuring PV power at each voltage point takes time, dense scanning of the full P-V curve can be slow, especially for PV motor applications [16,20]. Meanwhile, significant PV power loss can occur if the MPPT controller fails to track the GMPP quickly and efficiently [21]. Hybrid MPPT algorithms with partial shading detection are designed to respond rapidly and accurately track the GMPP, while minimizing PV power fluctuations and enhancing overall system efficiency [17,22].

The main challenge is implementing an advanced indirect MPPT control structure for GMPPT, equipped with a robust regulator to ensure fast and accurate tracking of the GMPP in PV motor systems. Besides, using a cost-effective converter to drive motors and implement advanced MPPT control is challenging, as the inverter is responsible for both motor operation and speed control [12]. Careful control of duty cycle changes ensures smooth and accurate motor speed, avoiding fluctuations and instability [23]. Meanwhile, a low number of iterations is a critical requirement for global searching in PV motor applications [12].

This study presents an innovative enhancement to the classical GSS-MPPT technique, improving reliability under shading conditions by increasing search density for efficient GMPP extraction. To achieve this, a novel multiple-band GSS-MPPT algorithm is proposed, combined with a PID voltage controller to drive a single-stage SWPS using a BLDC motor. Accordingly, it addresses the power converter structure and robust indirect GMPPT control of a power-dense motor. The study applies the well-known conventional GSS-MPPT as a robust MPPT control method, enhanced with a novel approach for efficient global searching. The proposed multiple-band approach improves on the classical single-interval GSS-MPPT. The multiple-band (multiple-interval) approach automatically increases search density, reliably finding the GMPP within an acceptable time. This proposed approach divides the PV search space into an optimal number of bands to achieve effective global search density. Instead of continuously scanning the entire PV range, the proposed GSS-MPPT searches each specific band separately, starting from the high-voltage side near the open PV voltage (V_{OC}). It achieves a robust and thorough search across all optimal bands with fewer iterations. The optimal voltage (V_{MPP}) and power (V_{OC}) values for each band are identified and stored in variables. As a result, the obtained V_{MPP} and P_{MPP} are updated and identified as the global values of the full PV range. The MPPT controller then jumps to the global V_{MPP} and forces the PV array to transfer the corresponding power, while partial shading detection (based on a power threshold) monitors significant power changes to repeat the global searches.V_{MPP}) and power (P_{MPP}) values for each band are identified and stored in variables. As a result, the obtained V_{MPP} and P_{MPP} are updated and identified as the global values of the full PV range. The MPPT controller then jumps to the global V_{MPP} and forces the PV array to transfer the corresponding power, while partial shading detection (based on a power threshold) monitors significant power changes to repeat the global searches.

A multiple-band search using the GSS-MPPT enables rapid scanning across the full range of operating voltages with efficient GMPP tracking. It divides the search space into multiple bands, reducing the interval eliminated in each iteration and thereby increasing the search density to accurately confine the GMPP. The GSS-MPPT is a robust technique that searches the voltage range between the endpoints of the interval. The proposed multiple GSS-MPPT searches the voltage range between the endpoints of each band, sequentially scanning all bands of the interval. It confines the GMPP within a small tolerance in just a few iterations. The proposed algorithm efficiently detects sudden and significant power changes using two modified PV power conditions to restart the global search. This approach aims to speed up the global search, reduce PV power oscillations, and enhance the GMPP capture process. It also seeks to improve overall PV performance by employing a cost-effective converter combined with a robust indirect MPPT controller structure to regulate motor speed effectively. Results confirm the effectiveness of the proposed MPPT approach for global search.

The Proposed SWPS

(Figure 1) shows a simplified solar water pumping system model with the proposed MPPT approach.

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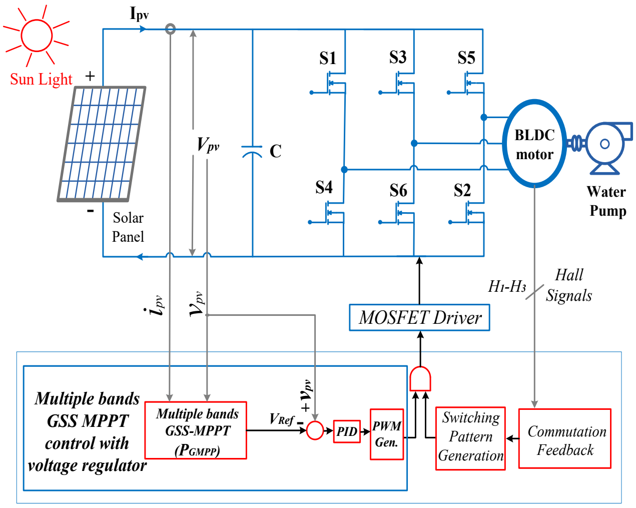

Figure1. SWPS Model with the proposed MPPT approach

The multiple-band GSS-MPPT, combined with a PID regulator, controls the voltage source inverter (VSI). The proposed MPPT approach is conceptually simple to implement. However, its operational strategy ensures that the GSS-MPPT technique effectively tracks the global MPP. It accelerates the global search and reduces the number of MPPT iterations compared to meta-heuristic methods. Moreover, it enhances performance and ensures optimal power transfer through the VSI to the BLDC motor.

As an indirect MPPT control structure, the proposed approach determines the optimal reference voltage (V_{ref}), which is then compared with the actual voltage in a feedback loop. The resulting error is compensated using a PID controller. This controller smoothly regulates the duty cycle of the pulse-width modulation (PWM) signals to accurately adjust the PV voltage as needed. The PWM signal controls the VSI load to apply V_{MPP} and maximize the output power of the SWPS. The rotor position of the BLDC motor is detected using Hall-effect sensors, which determine the switching pattern required for accurate VSI operation.V_{ref}), which is then compared with the actual voltage in a feedback loop. The resulting error is compensated using a PID controller. This controller smoothly regulates the duty cycle of the pulse-width modulation (PWM) signals to accurately adjust the PV voltage as needed. The PWM signal controls the VSI load to apply V_{MPP} and maximize the output power of the SWPS. The rotor position of the BLDC motor is detected using Hall-effect sensors, which determine the switching pattern required for accurate VSI operation.

PV Output Characteristics

PV power output exhibits a nonlinear relationship with voltage and current. Identifying and tracking the MPP on the P-V curve is critical for optimizing the performance of the PV system. The MPP location and power depend on sunlight intensity, surface temperature, and shading. To handle this, the PV array must operate at the global optimal voltage, which allows maximum power extraction [24,25]. Since PV power continuously changes under variable weather conditions, real-time monitoring is needed to quickly detect partial shading. Depending on the shading distribution across the PV array, the GMPP occurs at any local peak (LMPP). Analyzing the P-V curve characteristics indicates that the patterns and peaks do not exhibit randomness in their distribution. Predicting the GMPP location is possible, and it can be extracted using segment search [26,16].

The Proposed MPPT Control

This study introduces a novel global MPPT strategy based on the GSS optimization technique. The proposed multiband GSS-MPPT strategy is employed to control a BLDC motor that drives a water pump. It leverages the strengths of GSS to overcome key challenges in GMPP tracking. Additionally, the proposed multiband approach systematically enhances search density toward the GMPP, accelerating convergence by starting the search near the open-circuit voltage. It quickly and reliably extracts the GMPP with higher efficiency than meta-heuristic methods, which use random searching and often take much longer. This multiband GSS-MPPT method addresses two main issues: rapidly capturing and accurately tracking the GMPP, while also reducing power perturbations, search time, and increasing the average MPPT efficiency.

The proposed multiple bands across the P-V curve represent an effective search strategy for MPPT control. The idea is to systematically divide the search space into multiple bands or segments, thereby increasing the order and density of the search. The algorithm then employs the GSS-MPPT to search across each band, capturing the GMPP more quickly and accurately. This helps speed up convergence and reduce oscillations around the true GMPP. A key feature of the proposed algorithm is its ability to efficiently detect shading and restart the initial global search. As a result, it improves tracking performance under rapidly changing environmental conditions. It can avoid being trapped in LMPPs, which is especially useful in systems like

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partially shaded PV arrays where the power-voltage curve may have multiple peaks. Since it divides the P-V curve into zones (bands), the algorithm briefly scans each zone before focusing its effort on where the GMPP appears to be.
Figure 2 shows the P-V curve divided into three bands that will be searched separately using the GSS-MPPT technique, resulting in a higher search density.

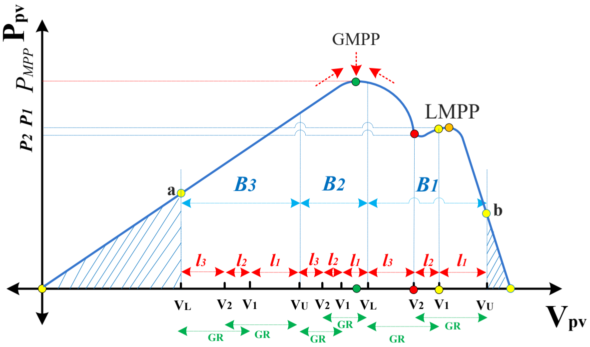

Figure 2. Division of the P-V curve into three bands for GSS

The multi-band GSS-MPPT technique starts searching sequentially from band 1 (B_1) to band 3 (B_3), near B_3 V_{OC} A detailed explanation of the GSS technique follows.

Golden Section Search Technique

In 1953, the American mathematician Jack Kiefer introduced a numerical optimization technique based on the golden ratio (GR), which rapidly locates the maximum or minimum point of a function within a desired tolerance. The GR $((\sqrt{5}-1)/2)$ often appears in mathematics, nature, art, and architecture.
The golden-section search is a simple, easy, and versatile technique that ensures efficient search interval reduction. It is a robust technique that does not require derivatives. Its mechanism depends on the comparative value of two specific points estimated inside the search interval. The GR (61.8%) is a mathematical constant commonly utilized in the GSS method to divide intervals efficiently. (Figure 3) shows the interval between its endpoints, divided into three sections using the GR. The GSS technique evaluates the function at the two points, x_1 and x_2, to decrease the search interval and confine the optimal solution. Its search mechanism repeatedly decreases the search interval to confine the solution within a satisfied tolerance (ε). The GSS stops narrowing down the interval once the solution is within the specified tolerance range [27,28].

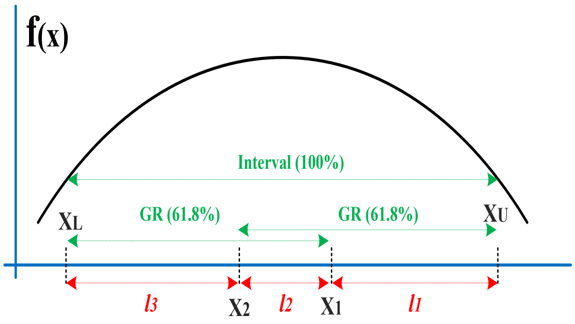

Figure 3. Fundamental principle of the GSS technique mechanism

GSS-MPPT Technique

The GSS-MPPT technique effectively captures the MPP in PV systems. The GSS-MPPT technique can deal with the effect of partial shading and confine the GMPP effectively [29,7]. (Figure 4) shows a simple flowchart of the GSS-MPPT technique with a partial shading detection condition. Once the GSS-MPPT technique confines the GMPP within the predefined tolerance, it frequently checks the PV power to detect partial shading or consider power changes.

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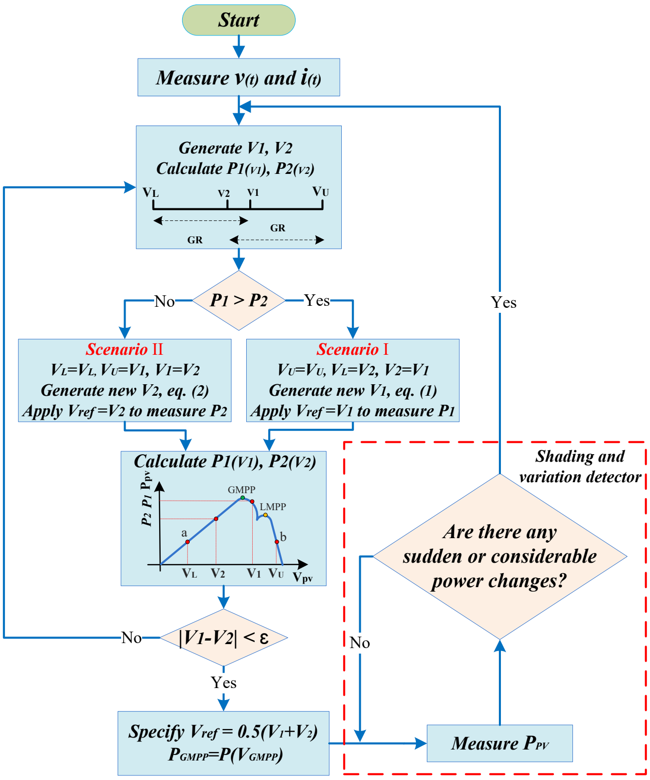

Figure 4. GSS-MPPT flowchart with the detection condition of partial shading

The GSS-MPPT technique compares a P_1 with a P_2 according to the operating voltage of a V_1 and a V_2, as shown in (Figure 4). The GSS selects two sections within the search interval that contain the GMPP and eliminates the third section to reduce the interval. It can clearly narrow the interval progressively until the GMPP is confined with sufficient tolerance accuracy. In every iteration of GSS software, a new operating voltage is generated to apply as a V_{ref}, while the other remains predefined [8,27]:

$$V_1 = V_L + 0.618\,(V_U - V_L) \qquad (1)$$
$$V_2 = V_U - 0.618\,(V_U - V_L) \qquad (2)$$

Accordingly, the operating mechanism of the GSS-MPPT can be summarized as follows: First, the voltage values (V_1, V_2) must be applied respectively to evaluate their power values (P_1, P_2). Then, comparing the evaluated values of the P_1 and P_2 within the specified range decreases the search range to confine the GMPP. The GSS-MPPT technique searches rapidly across the specified operating voltage range, including both voltage sides (lower and higher voltage). Its operating mechanism reduces approximately 38.2% of the search interval $(100\% - 61.8\% = 38.2\%)$ in each iteration of the GSS algorithm.

Multiple Band Search with GSS-MPPT Technique

The GSS-MPPT is a robust method; however, dividing the interval into multiple bands increases search density, as the GSS eliminates 38.2% of the interval per iteration. With three bands, this elimination ratio corresponds to approximately 38.2% of one-third (one band) of the full interval. This higher search density ensures the GMPP is captured with fewer iterations compared to meta-heuristic methods. It is a simple and intelligent strategy that efficiently covers the full range of operating PV voltages in just a few iterations. (Figure 5) shows the main flowchart of the proposed multiple band search with the GSS-MPPT technique.

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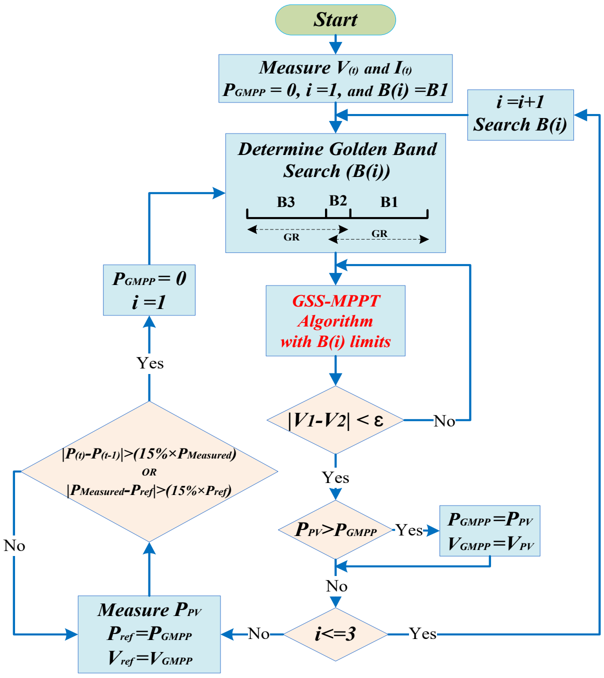

Figure 5. Main flowchart of the proposed multiple band search with the GSS-MPPT algorithm

The flowchart of the proposed MPPT algorithm includes a single loop that sequentially applies the three bands of the P-V curve up to $B_{i=3}$. The algorithm detects the peak (or highest point) within each band and increments i until $i = 3$, matching the total number of bands. It identifies all peaks, then jumps to the global one and tracks it using a constant V_{ref} to avoid PV power oscillation. A simple loop stores the values of V_{MPP} and P_{MPP}, updating them to obtain the P_{GMPP}. The MPPT controller jumps to V_{GMPP}, forcing the PV array to transfer the corresponding PV power, while two power thresholds monitor changes to repeat the global searches. Any significant PV power change, such as partial shading, begins a new global search to extract the new P_{GMPP}. The power thresholds detect sudden and considerable weather changes by monitoring the PV power change value in every MPPT software iteration.

Search Density of Multiple Band GSS-MPPT

(Figure 6) shows a comparison of search density between the classical and multi-band GSS-MPPT techniques, with the search density increasing by approximately threefold.

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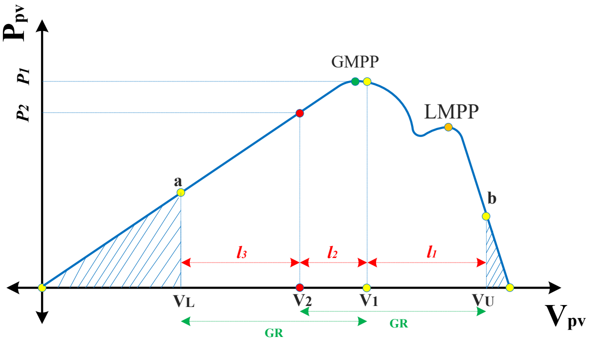
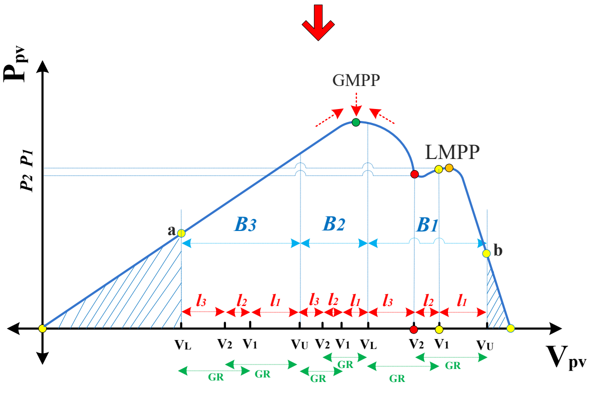


a) GSS-MPPT with one interval



b) GSS-MPPT with multiple-bands

Figure 6. Comparison of search density between classical and multi-band GSS-MPPT techniques

Comparison of Classical and Multi-Band GSS-MPPT

The multi-band GSS-MPPT algorithm first identifies all peaks and then determines the global peak with sufficient search density, whereas the classical GSS-MPPT directly seeks the global peak. Table 1 shows the key comparison between classical and multi-band GSS-MPPT.

Table 1. Comparison of classical and multi-band GSS-MPPT

MPPT technique	**GSS-MPPT**	**Multi-band GSS-MPPT**
Required sensors	I_{PV}, V_{PV}	I_{PV}, V_{PV}
Software complexity	Low	Low
Power perturbing	Without perturbing	Without perturbing
Step size	Adaptive	Adaptive
Reliability of GMPP extraction	Medium	High
Response to weather change	High	High
Search density	Low	Satisfying
Global efficiency	Satisfying	High

Partial Shading Detection

This study proposes two power threshold values that work together to detect significant changes, as illustrated in (Figure 5) and explained in detail below.

Detecting Sudden Power Change

The P-V characteristics curve shws that the power slope (dP/dV) value in steady-state operation at the MPP is nearly zero, so he absolute power change $|dP|$ and (dP/dV)ow. In this mode, the GSS algorithm applies a constan voltage and montors power change values. The $\left|dP = P_{(t)} - P_{(t-1)}\right|$ is the absolute value of the difference between the actual power and its instant previous power. This $|dP|$ value will increase rapidly if the weather changes suddenly, and it can give sudden power change information. It is modified by utilizing the real-time data of the PV power variation rate during the tracking loop (around the GMPP) to acquire an adequate response and detect the notable sudden change caused by such variable shading. A quick response is generated almost if the weather changes suddenly.$|dP|$ and the slope are low. In this mode, the GSS

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algorithm applies a constant voltage and monitors power change values. The $|dP = P_{(t)} - P_{(t-1)}|$ is the absolute value of the difference between the actual power and its instant previous power. This $|dP|$ value will increase rapidly if the weather changes suddenly and it can give the sudden power change information. It is modified by utilizing the real-time data of the PV power variation rate during the tracking loop (around the GMPP) to acquire an adequate response and detect the notable sudden change caused by such variable shading. A quick response is generated almost if the weather changes suddenly.

During the local tracking, the power limitations control the operation mechanism of the MPPT loops. If any considerable change is detected, it restarts the multiple band search with the GSS-MPPT technique. The first condition recognizes the sudden change, which occurs when the power change $|dP|$ value exceeds 15% of the instant power (P_{MPP}). This means a significant power change occurred, which requires to restarting the multiple band search.

Detecting Considerable Power Change

This study proposes a simple solution to recognize the considerable PV power change using the second power condition. It occurs when the solar power value of the difference between the actual power and the specified reference power ($|P_{MPP} - P_{ref}|$) exceeds 15% of the P_{ref}. This means a significant power change occurred, which requires restarting the multiple-band search for high tracking efficiency.

The mechanism of the algorithm action simplifies the global convergence process and reduces oscillation and tracking time, using the advantages of the GSS MPPT method. The multiple-band search of GSS-MPPT is restarted if there is a sudden or considerable power change. The GSS optimization is used for a robust search across the full range of operating PV voltages and rapidly confines the GMPP. Once the GMPP is extracted, the GSS control adopts a constant reference voltage to reduce power oscillations.

As explained previously, the MPPT algorithm generates a suitable V_{ref}. The PID controller compensates for voltage error by adjusting the duty cycle value of the PWM signals to apply the desired voltage and reduce the error voltage ($V_{ref} \cong V_{PV}$). That may require more than one iteration loop of the controller to acquire soft motor speed by smoothly controlling the duty cycle. Thus, the PID controller is employed to regulate motor speed. Then, the algorithm generates the new V_{ref} value, and the PID controller applies this voltage carefully using its loop. (Figure 7) shows a simple diagram of generating the control signals.

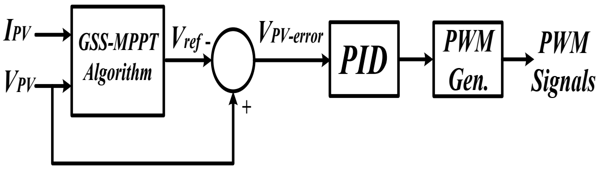

Figure 7. Indirect MPPT control scheme with PID controller

The PWM duty cycle is constrained between 5% and 97% for safety reasons and practical soft motor operation. The duty cycle of signal control is initially set to 5% during startup operation and gradually increased until it reaches the optimal value. In every iteration, the output of the voltage regulator represents the rate change of the duty cycle, which is tuned to be between 0 and 10%. Thus, the PID controller is employed to regulate motor speed smoothly.

Validation and Results Discussion

The proposed multiple-band GSS-MPPT algorithm is tested on a single-stage PV water pumping system driven by a BLDC motor using MATLAB/Simulink. The PV array consists of three parallel strings, each containing two PV panels. Each PV panel has a rated power of 219.876 Wp, with the following specifications under standard test conditions: $V_{MPP} = 30.12\ V$, $I_{MPP} = 7.3\ A$, $V_{OC} = 36.06\ V$ and $I_{SC} = 7.95\ A$. The PV array supplies PV power to the BLDC motor via a VSI that includes capacitors. The sensored BLDC motor then drives the water pump model. Six-step commutation is used to drive the VSI switches (S1 to S6) based on trapezoidal control. The MPPT algorithm determines the optimal V_{ref}, which enables the PID controller to drive the PV system to track the P_{MPP}. The proposed SWPS model is tested under varying irradiation levels of $300\ W/m^2$, $600\ W/m^2$, and $1000\ W/m^2$, with a constant temperature of 25°C. Figure 8 shows the P-V curves of the used PV array at three solar irradiances, including the V_{MPP} and P_{MPP} values.

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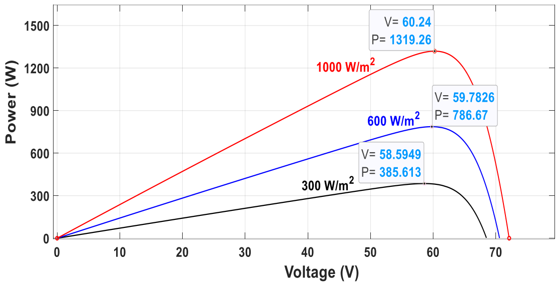

Figure 8. P-V curves of the used PV array

The P_{MPP} of the PV array must be extracted when the system operates at the corresponding optimal voltage (V_{MPP}). (Figure 9) shows the output of the PV system using the multiple-band GSS-MPPT algorithm, which successfully tracks the P_{MPP}. The results confirm that the obtained values are completely identical to the expected outcomes. The blue line represents the output power of the PV array, while the green line indicates the system's PV output power. The array transfers power outputs of 385.6 W at 300 W/m^2, 786.6W at 600 W/m^2, and 1319.2 W at 1000 W/m^2 irradiance levels.

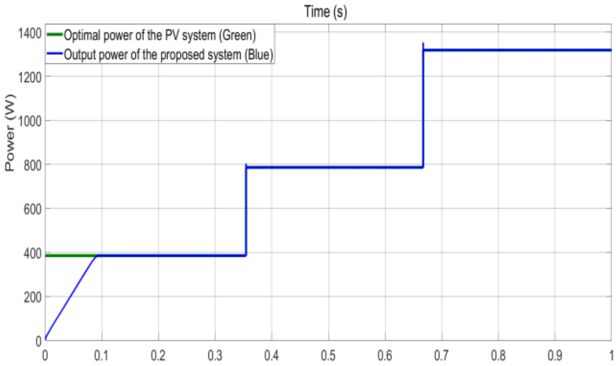

Figure 9. PV power tracks the P_{MPP} using the multiple-band GSS-MPPT

The obtained output PV power closely corresponds to the three power points on the P-V curve shown in (Figure 8). However, the irradiance level is rapidly changed to simulate worst-case shading conditions and evaluate the effectiveness of the proposed model. The results confirm that the proposed control system achieves high power-tracking efficiency, with an MPPT efficiency exceeding 99%.

The proposed SWPS has been successfully tested under rapidly changing irradiation levels of 200, 800, 300, 900, 500, and 900 W/m^2. The solar irradiation levels were chosen and rapidly changed to simulate shading and worst-case radiation drops, demonstrating the effectiveness of the multi-band GSS-MPPT control. (Figure 10) shows the PV power tracking results using the multi-band GSS-MPPT method, confirming its reliability under rapidly changing weather conditions.

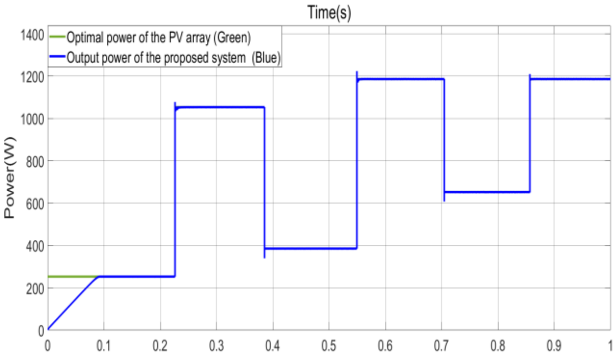

Figure 10. Power tracking of the SWPS under rapidly varying irradiance levels

The results confirm that the output power matches the optimal power of the PV array. In (Figure 10), the green line represents the optimal power, and the blue line shows the system's output power. MPPT efficiency (η_{MPPT}) is calculated using the following equation [30]:

$$\eta_{MPPT} = \frac{P_{output}}{P_{MPP}} \times 100\,\% \qquad (3)$$

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Where the P_{output} is the output power of the PV array and the P_{MPP} is the optimal PV power (theoretical power). Several tests were performed, and the results show the advantages of the multiple-band GSS-MPPT, including simplicity, robustness, accuracy, and high reliability. They also verify that the MPPT efficiency exceeds 99%.

Conclusion

This study proposes a multiple-band GSS-MPPT algorithm combined with a PID regulator to control a single-stage solar water pumping system driven by a BLDC motor. The proposed algorithm utilizes the robust features of the GSS-MPPT technique, dividing the P-V curve to optimize search density. Its features enable the detection of sudden and significant weather changes, reducing power oscillations and efficiently tracking the GMPP. A multiple-band search based on the GSS-MPPT technique is introduced to accelerate the global search process and enhance efficiency. The GSS-MPPT mechanism reduces the PV voltage search range by approximately 38.2% in each iteration, rather than using a fixed step size. Additionally, the GSS confines the GMPP by searching both its left and right sides, thereby reducing search time and improving efficiency. The proposed multiple-band search concept is simple and can be easily integrated with other MPPT methods for global search. Tests confirm that using a 15% power change threshold effectively detects partial shading under varying weather conditions in the proposed SWPS. A lower number of MPPT iterations is essential for PV motor applications and global tracking, as it significantly reduces search time and ensures high tracking efficiency. Several tests were performed, showing that the proposed control drives the motor efficiently and performs well with a cost-effective driver. The MPPT efficiency reached 99% or higher.

Conflict interest. Nil

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