Detection of partial shading and tracking of PV arrays' maximum power point under PSC

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Abstract: Photovoltaic (PV) systems need to get the most power out of their array even when partially shaded; this can be especially problematic in partially sunny conditions (PSC). PV arrays' P–V characteristics will have numerous peak values under PSC. Only one of the points is the global maximum. " An MPPT approach can't harvest the greatest amount of electricity in this situation. An entirely new concept is presented in this work. Two-stage MPPT is proposed to address this issue. First, a method for determining the presence of PSC is proposed, and in the second stage, a new algorithm is used to identify PSC is based on ramping up the duty cycle and sampling indefinitely based on the array's P–V characteristic, the maximum global power The array's midpoint (MPP) has been achieved. Observe and disrupt the algorithm. reactivated to monitor the new MPP's tiny adjustments. The proposed method's open-loop operation makes it easier to implement. inexpensive and straightforward. The approach is adaptable in the face of a changing environment. Environmental factors, such as array characteristics, and the linked power system. Simulations in MATLAB/Simulink show that the proposed methods function as expected.

Keywords: Photovoltaic (PV), Partial shading conditions (PSC), Maximum power point tracking (MPPT)

I.INRODUCTION

A growing number of people are considering photovoltaic (PV) systems as a viable alternative to coal and other fossil fuels. PV systems can either be connected to the grid or operate independently. When it comes to photovoltaic (PV) systems, the PV array is the most important part, which comprises several individual PV modules linked together in series and parallel. PV arrays have a nonlinear relationship between voltage and current, and only in one operational voltage does the maximum power output occur. Therefore, the primary goal of PV system control is to maximise the amount of electricity extracted from the system at all times. There has been a slew of MPPT methods proposed and put into practise so far. P&O, IC, short-circuit current, and open-circuit voltage are some of the more traditional and widely used methods. Fuzzy logic and neural networks, both based on artificial intelligence, are also discussed, but they require more computing [1]. It's called partial shade when all of an array's modules aren't getting equal amounts of sunlight (PSC). If you have solar panels, put in metropolitan locations or areas where low-moving clouds are abundant, you're going to get PSCs. Because of a lack of detection and response from the control system, the PV system will operate in a less efficient mode. With the usage of bypass diodes, several peak points can be seen in the P–V characteristic of the array. To locate the global maximum power point (GMPP) in PSC, conventional MPPT algorithms often track local peaks. As a result, new MPPT strategies must be developed to deal with PSC. MPPT under PSC has been the subject of numerous studies in recent years [4–21]. For the most part, these methods require two steps to achieve GMPP. The GMPP is determined in the first step, and the exact GMPP is determined in the second step using conventional MPPT methods such as P&O. After the PSC detection in [4], the operating point moves to the vicinity of the GMPP and then converges to it in the second step by moving on the load line based on short-circuit current and open-circuit voltage of the array. The GMPP cannot be tracked using this method in all PSCs, as demonstrated by the results [5]. A P&O algorithm with voltage step sizes determined by dividing rectangles has been proposed in [6]. The GMPP is not guaranteed by using this method. [7] shows how a neural network can be trained to work with a variety of PSCs based on the amount of solar irradiance and temperature. In order to solve the PSC problem, Abdalla and his colleagues [8] have devised a multilevel converter and a new control algorithm. Each module's current is reduced by connecting a fly-back dc–dc converter in parallel with a regulator that regulates its voltage at its respective maximum power point (MPP) value, as proposed in [9]. [10] proposes a controllable current transformer (CCT) at the end of each PV module, allowing a PV string to have compatible current. According to the MPPT algorithm, the output current of the CCT can be controlled by a dependent current source. However, despite the fact that these methods are highly accurate and reduce PS's impact on array power, their implementation is prohibitively expensive. As soon as the PV power changes above a certain threshold, the proposed method begins sampling the P–V characteristic of the array at 60–70 percent of Voc–mod (open circuit voltage of module) intervals, and at each sample, in the event of a change in dP/dV, the proposed method uses the P&O technique to determine the local peak. Finally, the GMPP is determined by comparing all peaks. Similarly, to [13], [12] proposes a similar method based on the method proposed in [11]. These algorithms' flaws include their reliance on the variable Vocmod and their sluggish performance as a result of the large sampling number. While [14] has good performance, it requires that each module be measured for its voltage. To sample the array's P–V characteristics at distances of 0.8 Vocmod, the approach described in [15] uses IC. As in [11], it restricts the search area for GMPP to a reasonable extent but requires a high sample number. Both Wang et al. [12] and Wang et al. [13] propose sampling the P–V curve and restricting their search to areas with the lowest short-circuit currents and the highest local powers, respectively This approach, as described in [12], provides great precision while operating at a modest speed. Since local MPP power is estimated by monitoring the currents of bypass diodes of modules, a second approach is proposed. Even though tracking is now more rapid, the implementation costs are still somewhat significant. It was found that applying evolutionary approaches like particle swarm optimization, simulation annealing and colony of flashing fireflies to locate the GMPP helped to shed light on MPPT's role as an optimization problem. GMPP is obtained by sampling the array P–V characteristic at various locations in these approaches. Even though these strategies are largely effective, they require a large sample size. It is imperative that initial sampling cover the full P–V curve, as the GMPP can occur at any point along this line. In order for the PV array's voltage to be stabilised, a few transients occur in the boost converters. MPPT's processing speed degrades as the number of samples grows. Particle Swarm Optimization (PSO) is employed in a standard, slow version in [16–19]. It is shown in [18] how to speed up and complicate the PSO approach. In comparison to PSO-based algorithms, an approach based on the firefly algorithm is proposed in [20]. The simulated annealing approach is used in [21] for MPPT under PSC. GMPPT's sample rate and speed are both significantly lower than the PSO-based technique, but its accuracy is higher, as shown by the results. To be effective in the PSC, a good MPPT algorithm should have these characteristics: 1) fast tracking of the MPP to achieve high efficiency; 2) simple implementation with low computing load; and 3) using fewer and less expensive sensors are some of the goals (removing current sensors of boost converter reduces the cost dramatically). Inflicting as little damage as possible on the connected grid. The detection of PS incidence is another subject that has received less attention in the literature. It is required to detect the occurrence of MPPT before implementing any MPPT method under PSC. This problem has yet to be addressed by a specific technique, and the most prevalent indicator of PS occurrence is a sudden large change in array power [11], [12]. It's not easy to determine a threshold for a substantial power change to distinguish between PSC and UIC correctly. Also, it's possible that no significant shift in power is seen when the PS pattern is altered, especially in rare cases. As an alternative approach, there is a mechanism that takes advantage of the large differences in array current at low and high voltages in PSC [18]. This method necessitates taking current samples at low and high voltages from the array, which causes significant disruption to the PV system and the grid it is linked to. In this study, a new MPPT algorithm based on ramping the duty cycle and continuous sampling from the P–V characteristic of the array is proposed. As a result of its open-loop operation and changeable speed, the proposed technology is simple to implement, inexpensive, resilient, and guaranteed to perform in any environment. It's also shown that a novel PV array PSC detection algorithm provides a performance advantage over current methods.

II.PROPOSED SYSTEM

SYSTEM DESIGN

Figure 1 depicts a grid-tied solar system with two stages. The dc/dc boost converter is critical in the first stage because it regulates the voltage of the PV array, which is where the bulk of the power is absorbed. inverter controls output voltage of dc/dc converter and generates AC voltage to connect solar system to the grid in the second stage. Since there is no direct coupling between the two stages due to a dc link capacitor, each stage can be investigated in isolation. There are generally two ways to regulate a PV array using a boost converter: closed loop and open loop. When the array works in the constant current area with low irradiance, the dynamic resistance of the array has its maximum negative value, as demonstrated by Weidong et al. in a PV array coupled to a boost converter. There is no way to control the array voltage properly using a single-loop PI voltage controller in a close-loop fashion because the dynamic response of the system is dependent on the operating point and environmental conditions. Another inner control loop (boost converter inductor current loop) is required to achieve the desired dynamic response of the system (high-speed, low-transient, and zero steady-state error). Two PI controllers and a costly current sensor are required for this two-loop control approach. There is no feedback in an open-loop control system, which is a typical technique for managing boost converters. Instead, the converter's input voltage (vin) and output voltage (vo) are used to generate a suitable input voltage, as in (1)

$$v_{\text{in}} = v_{\text{pv}} = (1 - D)v_o. \qquad 1$$

The boost converter inductor current does not have to be measured with this method, saving the cost of a current sensor. The system response, on the other hand, may have more transients and steady-state errors than the close-loop strategy. The sample time is a crucial MPPT parameter for a PV system. Before sampling from the array voltage and current, it is necessary to settle the system's transient response when a fresh command voltage (vref in) is applied to the converter. This settling time necessitates a longer sampling time span. A simulation in the MATLAB/Simulink environment is used to investigate the response of a PV array coupled to a boost converter with open-loop control. Table I lists the converter settings, including Vocarr = 130 V and Isc = 8A for the simulated PV array. The boost converter's output voltage is also taken to be constant at 250 volts. Figure 1 depicts the open-loop response of the system's switching and averaging state-space models to step and ramp command signals. Based on the system's response, the following inferences can be drawn:

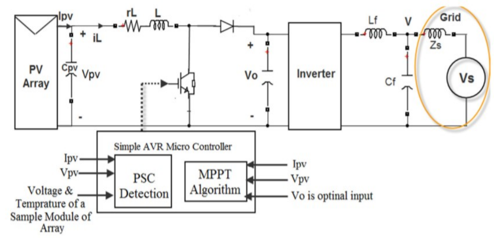

Fig. 1 Detailed diagram of a two-stage grid-tied PV system

Averaging the averaged state-space model and the correct switching model produce nearly equal results. There is a steady-state inaccuracy in the system's responsiveness to step and ramp commands. MPPT algorithms that sample from specific locations in the array's P–V characteristic may suffer from this issue. As a result, the system is susceptible to oscillation, overshoot, and settling time, especially when the PV array is operating at a constant current level, which results in higher switching stress and losses. The ramp response, on the other hand, exhibits very little transitory activity. 4) The system step response settles in at a rate of roughly 15 ms. As a result, sampling duration must be more than 15 ms for MPPT applications. Notably, while rL is deemed high, it is actually lower and has a higher settling time in practise for improved efficiency.

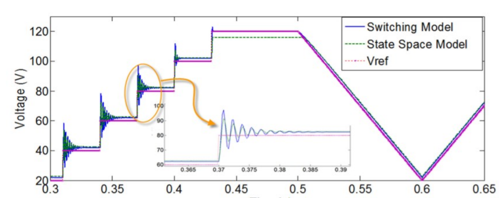

Fig.2 Step and ramp commands in a PV system's boost converter can be modelled using switching and averaging state space models.

III. PROPOSED ALGORITHM FOR MPPT UNDER PSC

The P–V characteristic of the array must be sampled in different voltages in order to use heuristic algorithm-based approaches such as PSO, as well as most other methods for MPPT in PSC. In GMPPT, these approaches have a slow settling time for the boost converter to step orders. When solving a numerical optimization problem, the objective function is evaluated numerically and places a heavy burden on the processor; in contrast, when solving an MPPT problem, the objective function is evaluated physically, i.e., by applying specific voltages to an array and then measuring its output power. The MPPT sampling interval must be longer than the boost converter's settling time, as discussed in Section III. The amount of time it takes for a PV array to settle depends on its design and operating point. The boost converter used in the experiments and simulations for this paper has a maximum settling time of roughly 20 ms. Section II of the PSC manual states that the GMPP can be found in the voltage range shown below.

$$V_{\mathrm{mpp-mod}} < V < V_{\mathrm{oc-arr}}. \quad \mathbf{2}$$

GMPPT can be solved with minimal steps by sampling just at certain locations in the P–V characteristic of the array [13]. GMPPT cannot be guaranteed by these approaches because they rely on estimates. The array voltage experiences all voltages between V1 and V2 when sampling is done in V1 and V2, respectively. Due to the fact that the parallel capacitor's voltage cannot fluctuate drastically, this is the reason why the voltage of the array can't change. Consequently, in practically all MPPT systems, the array experiences the full range of voltages that can be generated (11). In light of the foregoing, two key reasons motivate the use of ramp voltage as the converter's command signal for searching the voltage range of (11) for GMPPT. While the boost converter's response to step orders is quite slow, its settling time and transient to ramp commands are almost zero. There are no significant dynamics in PV arrays, hence they can be considered static. This means that the measured power at any given time is directly proportional to the array voltage at that same time, unlike in dynamic systems. Consequently, this work proposes the idea of a scanning I–V characteristic of the array with an adjustable high-speed command voltage (or ramp change in duty cycle). In addition to this ramp input, the voltage and current of the array are continually sampled at the correct rate.

The suggested method for GMPPT works as follows in two separate PV array scenarios: After a PS (V2 = V1, P2) occurs, the array's operational point goes back to (V1 = V1, P1) while it is under UIC. PSC detection algorithms are activated by this power change and identify whether or not the array is still at UIC or has gone through PSC. PS detection fails, and then P&O is brought in. Otherwise, the MPPT algorithm under consideration is put into action. The maximum array power (Ve, Pe) and its related voltage (Ve, Pe) are initialised using the proposed MPPT approach (V2, P2). The boost converter is then given the following positive ramp voltage command, starting at V1: (4). Changing the duty cycle without having to know the boost converter's output voltage (vo) is also possible using the ramp function. As a result, the voltage of the array is shown in Fig. 10 to alter ramp-like (a). The command voltage (t) and the array voltage (t) are simultaneously sampled as (Vs = V (t), Ps = P (t)). As long as Ps exceeds Pe, (Ve, Pe) is updated to (Ve = Vs,Pe = Ps) at any given time. When the array voltage hits Vocarr, the process repeats itself. As a result, the command voltage ramp sign is reversed and the array voltage is reduced ramp-likely. There is no stopping the updating process till the voltage hits Vmppmod.

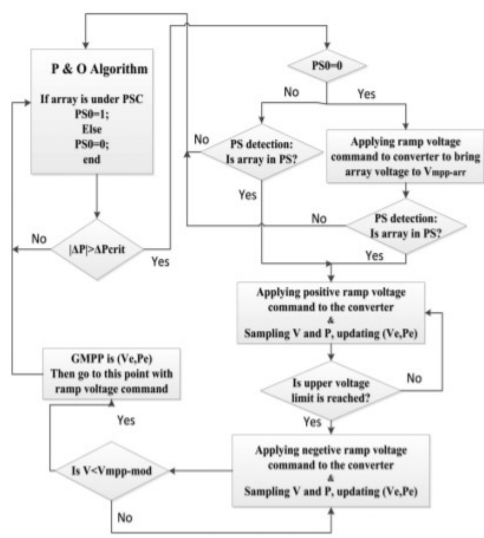

Fig. 3 Flow chart of the suggested MPP tracking methods under PSC

After that, the GMPP of the array will be the final value (Ve, Pe). It then resumes MPPT around this operating point by bringing array voltage up to Ve and then using the P&O algorithm. There is a shift in the shade pattern because the array is under PSC. A ramp voltage instruction is applied to the converter to lower the array voltage down from Vmpparr to Vmpp Checking for UIC or PSC status is done using PS detection criteria at this point. PS detection fails, and then P&O is brought in. Otherwise, the converter is given a positive ramp voltage command to begin the MPPT process. The following analyses are offered in order to narrow down the scope of the search for GMPPT. Assume that the array is functioning at a typical operating point (Vs, Is). We already know that as the array voltage rises, the current flowing through it drops. V > Vs results in a reduced array current (Iarr). Hence

$$P_{\text{arr}}(V > V_s) = V I_{\text{arr}} < V I_s \quad 3$$

In addition, because the maximum voltage of the array is Voc−arr

$$P_{\text{arr}}(V > V_s) < V_{\text{oc-arr}} I_s. \quad 4$$

The array power will be less than Pe at all higher voltages if the above arguments are true during positive ramp commands while VocarrIs is less than the most recent updated value for MPP (Pe). As a result, it's unnecessary to keep giving the positive ramp command. To put it another way, the search area will only include Vs that

$$V_{\text{oc-arr}} I_s < P_e. \quad 5$$

The negative ramp of the MPPT process is bound as follows when a PS occurs following a UIC. There is no need to look for voltages where VIsc Pe because the array power is less than Pe. As a result, the lower search region voltage will be Vs.

$$V_s < P_e / I_{\text{sc}}. \quad 6$$

MPP current for PV arrays under UIC is also about 0.9Isc [3], hence Isc is roughly known in terms of Impparr. Under any PSC, the suggested MPPT approach ensures that the GMPP would be reached. For this reason, sampling of voltage and power from the array is done across the voltage area (11) rather than just at a few specific spots. In addition, the suggested MPPT approach does not require any electrical properties of the PV array other than Vocarr, which is utilised to define the search zone. For the search region to be known by all MPPT methods, Vocarr must be known. Another reason why Vocarr does not need to be exact is that Vmpparr provides an approximation. It is demonstrated in Fig. 8 that the proposed MPPT algorithm for PSC can be implemented. Both an analogue rate limiter and a digital one can be used to execute the ramp voltage.

The following points are taken into consideration while selecting a ramp rate. 1) The ramp rate of the command voltage must be coordinated with the sampling rate of the array voltage and current. It's possible to imagine a PV array that has Vocarr = 200 V. The voltage ramp is set at R = 200/0.05 = 4000 V/s in order to reach the GMPP voltage in around 50 ms. At least one sample is required for every two-volt period in order to reach the GMPP voltage with a maximum 1-volt inaccuracy. Because of this, the minimum sample rate is required to be

$$f_{\text{sam}} > \frac{4000}{200} * \frac{200}{2 * 1} = 2 \text{ kHz}. \quad 7$$

As micro-controllers have significantly faster sampling capabilities, this element does not have a significant impact on voltage ramp. Because of their current leakage to the ground, PV arrays exhibit extremely fast dynamics, which are inconsequential and ignored in the MPPT process. To the best of our knowledge, the proposed technique may suffer if excessive ramp rates are used in the range where these fast dynamics are occurring. It would be ideal; however, this is impossible, and as previously said, the PV arrays are treated as static systems. There may be some steady state inaccuracy and very little transients when a ramp voltage is applied to the boost converter. Its voltage fluctuates proportionally to the ramp rate of the command voltage. The suggested approach, on the other hand, continuously samples voltage and current from the array, therefore the array voltage need not match the command voltage. As a result, the proposed technique is unaffected by the boost converter's imprecise reaction. During GMPPT, excessive ramping can cause high dPpv /dt during GMPPT, which can disrupt the connected grid. This is the final worry. The next part shows that selecting a voltage ramp of 4000 V/s leads in quick MPP tracking and minimal disturbance.

IV.SIMULATION RESULTS

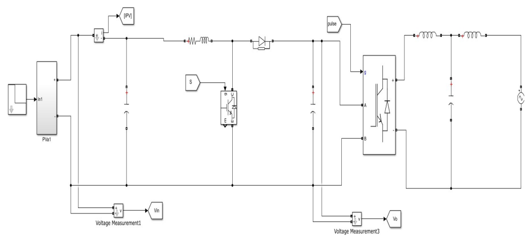

Fig.4 MATLAB/SIMULINK circuit diagram of the proposed system

Results of MPPT process with the proposed method in different PSC patterns

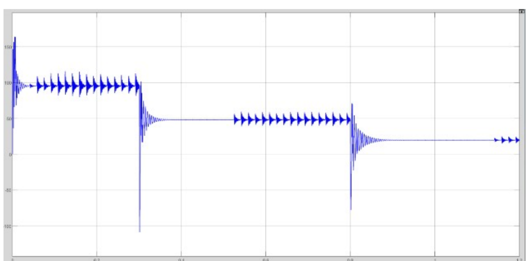

Fig. 5 Array voltage

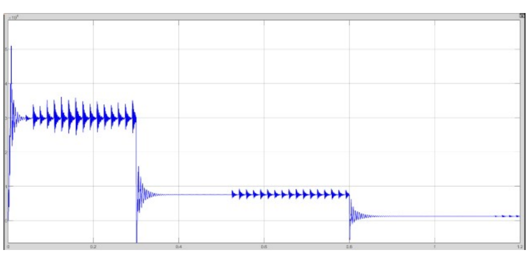

Fig.6 Array power

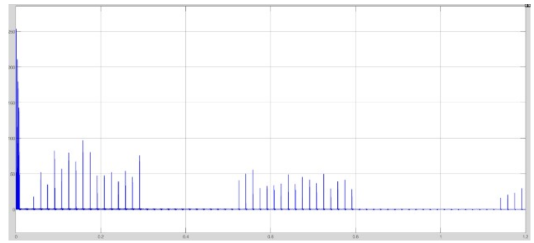

Fig.7 Grid voltage

CONCLUSION

One of these algorithms is provided and its performance tested in various scenarios in this paper. If the system does not operate at a uniform irradiance, then the suggested algorithm determines this. It is then proposed that an MPPT algorithm under PSC can be implemented using a direct control method, which does not require any feedback control of current or voltage. In this technique, the PV array voltage is ramped up and down constantly while simultaneously measuring its voltage and current. The proposed method's speed and accuracy have been shown by simulation results. The advantages of the GMPPT approach include the following: A simple microcontroller like the AVR can be used to implement it, and it has a high adjustable speed, a smooth shift in power, and no negative impact on the associated power system. Its efficiency is also guaranteed and is not reliant on the model of modules it is attached to.

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