A NEW METHOD TO IDENTIFY OPTIMAL OPERATING POINT FOR PHOTOVOLTAIC POWER SYSTEMS BASED ON COMPLETELY MATHEMATICAL MODEL

MỘT PHƯƠNG PHÁP MỚI XÁC ĐỊNH ĐIỂM VẬN HÀNH TỐI ƯU CHO NGUỒN PIN MẶT TRỜI DỰA TRÊN MÔ HÌNH TOÁN HỌC ĐẦY ĐỦ

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ABSTRACT

This paper proposes a method to identify the optimal operating point for a photovoltaic power system. With the information on the power's solar irradiance, the temperature at P-N junction, and the generated power limit, an algorithm is proposed to calculate points on the voltage-power curve based on an utterly mathematical model of the generation, iterative, and bisectional techniques. A control system using an average voltage control technique is represented to drive the generation to one of the calculated points, including the maximum power point, left and right sides, to evaluate its response and identify the optimal operating point. Simulation results in Matlab/Simulink showed that the optimal operating point is the maximum or right side point because these points can help reduce power fluctuation and state perturbation. This study can be applied in systems limiting power interaction at buses with the presence of the generation to ensure power balance for the whole system.

Keywords: *Control loop, maximum power point, photovoltaic power system, power limit, power balance, voltage-power curve.*

TÓM TẮT

Bài báo này đề xuất một giải pháp xác định điểm vận hành tối ưu cho nguồn pin mặt trời. Thông qua việc sử dụng thông tin về công suất của bức xạ mặt trời, nhiệt độ của lớp tiếp giáp P-N và giới hạn của công suất phát ra, một thuật toán sẽ được đề xuất để tính toán các điểm trên đường cong điện áp - công suất dựa trên mô hình toán học đầy đủ nguồn pin mặt trời, kỹ thuật lặp và chia đôi. Một cấu trúc điều khiển sử dụng kỹ thuật điều khiển điện áp trung bình được xây dựng để vận hành nguồn pin mặt trời ở các điểm tính toán, bao gồm điểm công suất cực đại, điểm bên trái và bên phải để đánh giá phản ứng của nguồn pin mặt trời và chỉ ra điểm vận hành tối ưu. Các kết quả vận hành được thực hiện trên phần mềm Matlab/Simulink để khẳng định điểm vận hành tối ưu là điểm công suất cực đại hoặc điểm ở bên phải đường cong điện áp - công suất vì các điểm này có thể giúp giảm dao động công suất và nhiễu trạng thái. Nghiên cứu này có thể được áp dụng trong các hệ thống có sự giới hạn công suất phát vào nút của nguồn pin mặt trời để đảm bảo cân bằng công suất trong toàn hệ thống.

Từ khóa: *Mạch vòng điều khiển, điểm công suất cực đại, nguồn pin mặt trời, giới hạn công suất, cân bằng công suất, đường cong điện áp - công suất.*

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1. INTRODUCTION

Photovoltaic power systems (PVs), a series and parallel coupling system of cells, are among the most popular distributed power generation in power systems. Power converters regulate power generated from PVs to harness maximum power or a part at some specific times [1-4]. In cases of sizeable total capacity and no storage, power generated from PVs must be regulated to adapt to maintain instantaneous power balance to overcome the slow inertia of thermal and hydro generators [1, 2].

At modes harnessing a part of power, the response of PVs affects the ability to release heat in power converters and perturbation in measurement devices that can cause adverse reactions in actual operating conditions [5]. At each time, it depends on the power of solar irradiance (G), temperature (T) at P-N junction, and the variation of electric load [6]. In cases of not using DC/DC converter, the voltage value at terminals of PVs can be regulated by DC/AC converter to adjust the generated power that adapts to the power requirements of the dispatch center [7]. This structure can also help to reduce implementation costs. Still, it isn't easy to synchronize with the grid due to the variation of voltage at DC side of DC/AC converter or not harnessing the maximum power point (MPP) of PVs. In cases of both using DC/DC and DC/AC converters, DC/DC converters can regulate PVs, and grid-connected control can be executed by the DC/AC converters [8]. This structure can help regulate PVs flexibly and more stably than the above solution due to the capability to harness all or a part of the power from this generation as the dispatch center's requirements and not affect the synchronous process.

With the power, anxious and observed techniques have often been used to maintain the operating point at the desired point corresponding to each value of reference power [5, 9, 10]. This technique is easy to control and implement at a low cost. Still, it also causes fluctuation, loses control signal in cases of fast variation of (G, T), and can not help with evaluations about operating points. Ref. [6] proposed a new solution to accurately determine MPP on V-P curve to provide reference values for controllers based on an utterly mathematical model of PVs. This solution uses a system of equations to convert parameter values from standard test conditions to any operating condition, n(T) function, and iterative and bisectional techniques to determine value pairs of voltage and power with the smallest number of calculating steps. It also can be used to assess value pairs of voltage and power at any point on the voltage-power (V-P) curve if it continues to develop.

This paper will focus on evaluating the response of PVs to suggest optimal operating points corresponding to different requirements. With this purpose, the next section will represent a method to determine operating points based on a completely mathematical model of PVs. The third section will propose a method to drive PVs to the desired point. The two last sections will show some simulation results and conclusions.

2. DETERMINATION THE OPERATING POINTS OF PVs BASED ON COMPLETELY MATHEMATICAL MODEL

Voltage (V_{pv}) and power (P_{pv}) values specify each PV operating state. These values establish operating points on each V-P curve corresponding to (G, T) value pair [5, 6]. As depicted in Fig., operating point movements are caused by the control process, variation of electric load, or the change of (G, T).

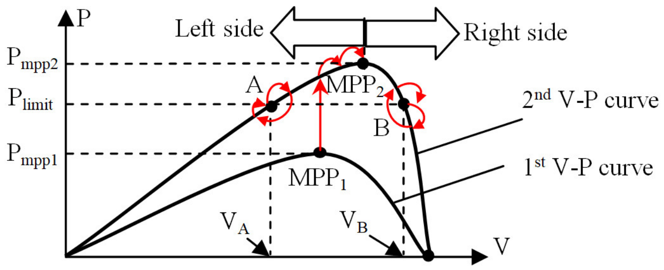

Fig. 1. Operating points on V-P curve

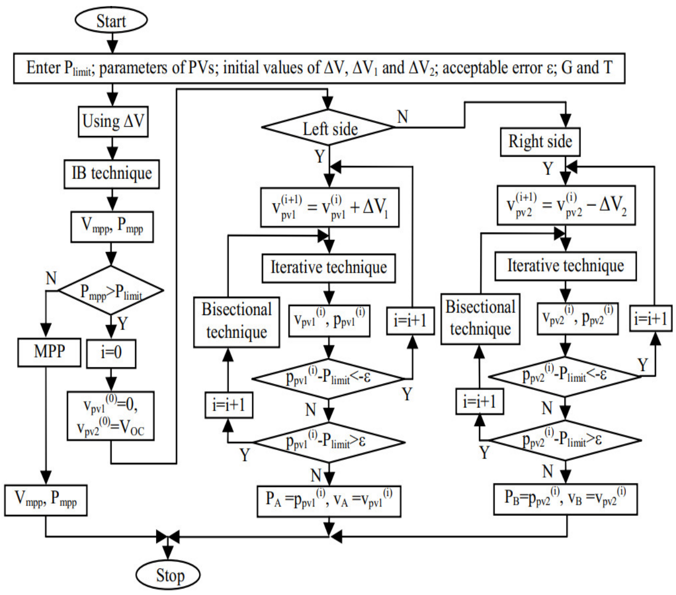

Fig. 2. Calculation block to determine operating points

The movement from MPP_1 to MPP_2 has been analyzed in almost all studies about PVs to represent the purpose of harnessing maximum power. With the interaction of the dispatch center, the value of power limitation P_{limit} makes PVs work at point A (on the left side of MPP_2) or point B (on the right side of MPP_2), as depicted in Fig. 1 [5]. These points can be determined by iterative and bisectional techniques [6]. The difference in voltage value between point A and point B makes different PV responses and affects the stability of state parameters. An algorithm to determine operating points for PVs based on an utterly mathematical model is proposed in Fig. 2.

The above algorithm provides voltage values (V_{pvref}) about operating points to the control system in the next section to drive PVs to desired points.

3. THE SOLUTION TO CONTROL PVs TO DESIRED POINTS

Using V_{pvref}, the method to evaluate the response of PVs is represented in Fig. 3.

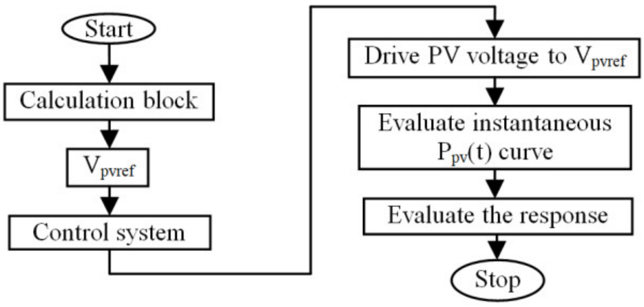

Fig. 3. The method to evaluate the response of PVs

To drive the current operating point to the desired operating point (specified by V_{pvref}), a control system, as depicted in Fig. 4, combines an inner current loop and an outer voltage loop.

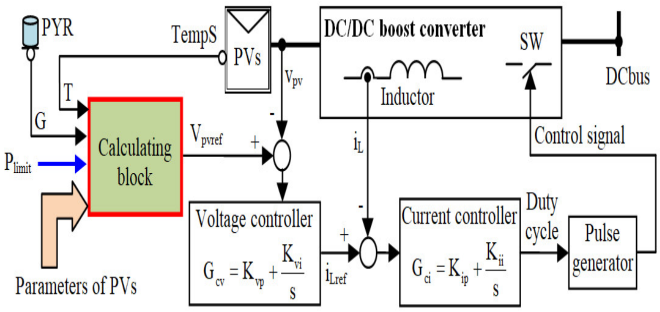

Fig. 4. Control system to drive PVs voltage to V_{pvref}

Parameters in Fig. 4: K_{vp} and K_{vi} are proportional and integral factors of voltage controller; K_{ip} and K_{ii} are proportional and integral factors of current controller;

Calculating block collects information about G from a pyranometer (PYR), T from a temperature sensor (TempS), V_{pv} from a voltage sensor to measure voltage at two terminals of PVs, i_L from a current sensor to measure current through the inductor in the DC/DC converter. For PVs, G and T are discrete values with fast variation for G and constant for T in a short time.

4. SIMULATION RESULTS

The parameters of PVs provided by the manufacturer (calculated from the parameters of each PV panel) and parameters calculated by the Newton-Raphson algorithm [6] are shown in Table 1.

Table 1. Parameters of PVs

Parameters provided by the manufacturer	Value	Calculated parameters	Value
Short-circuit current (A)	117.76	Reversed saturation current (A)	1653×10^{-6}
Open-circuit voltage (V)	456		
Voltage at MPP (V)	363	Thermal voltage at P-N junction (V)	25.215
Current at MPP (A)	109.28		
Temperature coefficient of V_{OC} (mV/^{0}C)	-0.346	Series resistor (Ω)	0.2354
Temperature coefficient of power (%/^{0}C)	-0.478	Photo-generated current (A)	117.79
Temperature coefficient of I_{SC} (%/^{0}C)	0.057	Parallel resistor (Ω)	109.84

n(T) function is defined by (1) [6]:

$$n(T)=1-0.008017(T-T_{stc})+\frac{9}{400000}(T-T_{stc})^2 \quad (1)$$

where T_{STC} = 25°C is value of temperature at standard test condition (STC); n is function of P-N junction temperature.

G is considered in a scenario as presented in Fig. 5 while T = 40^{0}C (constant). Due to only considering three seconds and much change of G, the dispatch center limits power generated from PVs at 35kW (P_{limit} = 35kW).

The DC/DC boost converter and controller parameters are represented in Table 2.

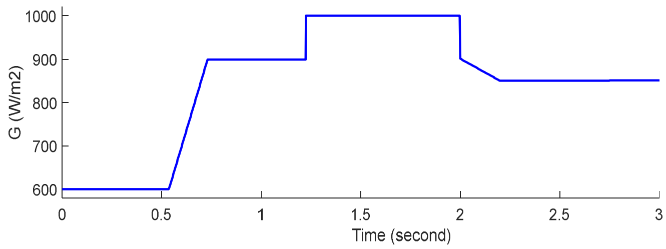

Fig. 5. Variation of G

Table 2. Parameters of DC/DC boost converter and controllers

DC/DC boost converter	Value	Controllers		Value
The inductance of inductor (H)	0.02	Current controller	K_{ii}	1.825
Resistance inductor (Ω)	0.1		K_{ip}	0.83
Capacitance (F)	5×10^{-3}	Voltage controller	K_{vi}	66.1
Voltage at DCbus (V)	804		K_{vp}	2.68
		Switching frequency		50kHz

The simulation process is carried out in Matlab/Simulink. Simulation results about power curves (including $P_{pv}(t)$ and $P_{mpp}(t)$) with no power limit are shown in Fig. 6.

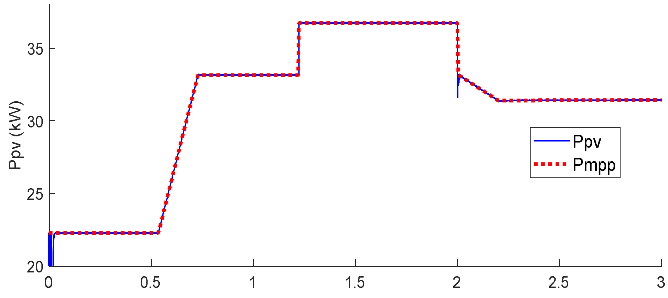

Fig. 6. Power curves with no power limit

Corresponding to the scenario in Fig. 6 and simulation results in Fig. 7, PVs were regulated at MPP from 0 to the 1.22th second and from the 2th second to the 3rd second. Power generated from PVs exceeded P_{limit} from 1.22th second to the 2nd second. Using the algorithm in Fig. 2 with P_{limit} = 35kW, calculated voltage values are V_A = 300V (at point A) and V_B = 355V (at point B). To limit power at P_{limit}, PVs should be regulated at point A or point B from 1.22th second to the 2nd second. Regarding power limits, simulation results of power curves are shown in Fig. 7 for point A and Fig. 8 for point B.

From simulation results in case of no power limit (Fig. 6), the control system helped to harness the power at MPPs, although G varied very fast (blue line tracked red line accurately). In the case of power limit and point A (Fig. 7), power generated from PVs fluctuated very much, from 34.5kW to 35.5kW (±1.43% around stable value). Besides power fluctuation in this case, instantaneous voltage and current values at PV terminal terminals also fluctuated, affecting the ability to work accurately for sensors and the control system and causing heat release in the DC/DC converter. In the case of the power limit and point B (Fig. 8), the power curve was stable, the same as no power limit (Fig. 6).

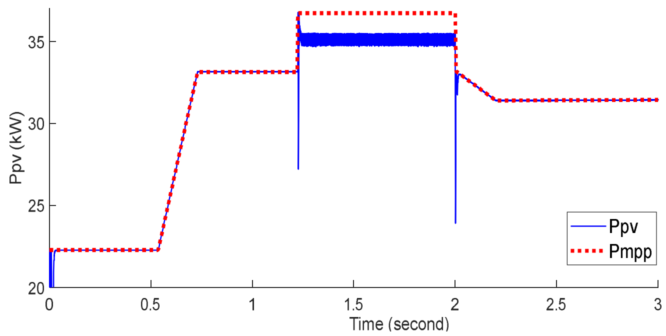

Fig. 7. Power curve with power limit and point A

From all simulation results (from Fig. 7 to Fig. 8), MPP is the best point to harness maximum power and ensure the stability of generated power. If there is a command about the power limit from the dispatch center, the right-side point of MPP can bring a better response of PVs than the left-side point of MPP because it can help reduce the fluctuation of state parameters.

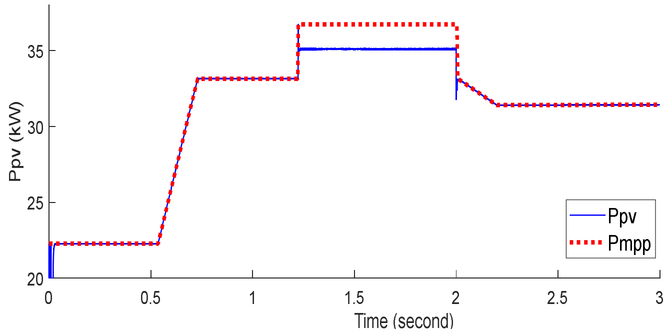

Fig. 8. Power curve with power limit and point B

5. CONCLUSION

This paper proposed a new method to identify the optimal operating point for PVs. On each V-P curve specified by (G, T) value pair and in cases of P_{mpp} larger than P_{limit}, three points including MPP and points at left and right sides of MPP were calculated by a proposed algorithm using the entirely mathematical model, iterative and bisectional techniques. Voltage values at points are used as reference values to drive PVs to a desired operating point using a control system with voltage and current control loops. With the proposed algorithm and control system combination, the response of PVs can be evaluated by observing $P_{pv}(t)$ curve corresponding to each above point.

Simulation results in Matlab/Simulink identified the optimal operating point. Simulation results showed that MPP is always the best operating point due to harnessing maximum power and stability. In cases of being regulated at P_{limit}, the left side point provides $p_{pv}(t)$ curves less stable than the right-side point with ±1.43% power fluctuation. It means points with voltage values from Vmpp to VOC are suitable for regulating PVs to reduce power fluctuation in DC/DC converters and perturbation for measurement devices.

The optimal point in each operating case can be determined using the proposed mathematical tools, a pyranometer, and a temperature sensor. Contributions in this paper can be applied to regulate PVs in grid-connected systems without ESS. This generation can be coupled to many buses in the grid and limited to power at any time to ensure a power balance between generations and electric loads.

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THÔNG TIN TÁC GIẢ

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