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# A MODIFIED P&O MPPT ALGORITHM FOR SINGLE-PHASE PV SYSTEMS BASED ON DEADBEAT CONTROL

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**Keywords:** maximum power point tracking (MPPT), perturb and observe (P&O), photovoltaic (PV), deadbeat control

## Abstract

A modified perturb and observe (P&O) algorithm is presented to improve maximum power point tracking (MPPT) performance of photovoltaic (PV) systems. This modified algorithm is applied to a single-phase PV system based on deadbeat control in order to test the tracking accuracy and its impact on the reliability of the whole system. Both simulations and experimental results show that the proposed algorithm offers a fast response as well as smaller steady-state oscillations even under low irradiance condition compared with classical methods.

## 1 Introduction

Solar energy gains more and more attention and is increasingly utilized in power generation systems as an alternative to fossil energy resources. The high penetration of single phase grid-connected PV systems also causes a negative impact on power availability, reliability and quality. It is a must that the grid-connected PV generation system should have the ability to extract energy from the PV panels under a given operation condition as much as possible, also known as maximum power point tracking.

As known, the volt-ampere characteristic of a PV panel is nonlinear and it is time-varying under changing solar irradiance and ambient temperature [1,2]. Therefore, as aforementioned, the MPPT techniques should be developed in PV systems in order to maximize the output power of PV systems. Nowadays, there have been a lot of MPPT methods reported in the literatures, such as hill climbing method, perturb and observe method, incremental conductance method (INC), constant voltage/current method, and ripple correction method [1-8]. Among them, the perturb and observe method and incremental conductance method are very commonly used in PV systems due to their easy implementations.

In this paper, an overview of the two popular MPPT methods- P&O and INC algorithms is presented. Subsequently, a coarse analysis of the relationship between the step-size and the performance is done, and a modified P&O MPPT technique is proposed in order to get a better dynamic and steady-state performance. In order to evaluate its tracking accuracy, tracking response and its impact on the reliability of the whole system, a deadbeat-controlled single-phase PV system is set up based on dSPACE and MATLAB/Simulink.

## 2 Modified P&O MPPT Algorithm

### 2.1 Overview of P&O and INC Algorithms

It is easy to obtain the *I-V* and *P-V* characteristics of a PV array, as shown in Fig. 1. Obviously, the *P-V* curve is of the "hill" form with a maximum power point (MPP). A large number of MPPT algorithms are developed according to the fact that the power-voltage characteristic has the maximum point, like the peak of a hill, such as two most commonly used methods- P&O method and INC method. Some modified methods have also been proposed in recent years based on that characteristic [1-6,11,13].

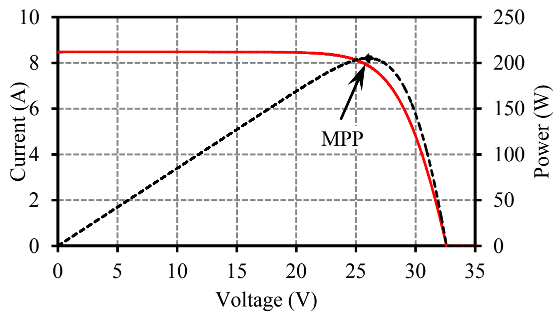


Fig. 1. Typical *I-V* (solid line) and *P-V* (dashed line) curves of a PV array.

As for the P&O method, in steady state, the operating point does not keep steady but oscillates around the MPP because of the perturbation. Another disadvantage of this method is that the rapidly changing atmospheric conditions may lead to failure of MPPT. This is because of the fact that this algorithm cannot determine the power changes caused by perturbing variations or by irradiance changes [1].

The performance of the P&O technique is affected by the perturbing step (step-size), $V_{stp}$, as illustrated in Fig. 2. Clearly, the MPP is reached when the power difference is equal to zero, $\Delta P$=0. Thus the choice of a large $V_{stp}$ can provide a fast tracking response but the tracked voltage at MPP, $V'_{MPP}$, is far from the theoretical one, $V_{MPP}$, which means that there will be more oscillations. If $V_{stp}$ has a small value, the MPPT is slower, but it still has small oscillations. Because of the perturbing steps, the tracked voltage at MPP cannot be equal to the theoretical one. The oscillations cannot be eliminated by decreasing the step-size.

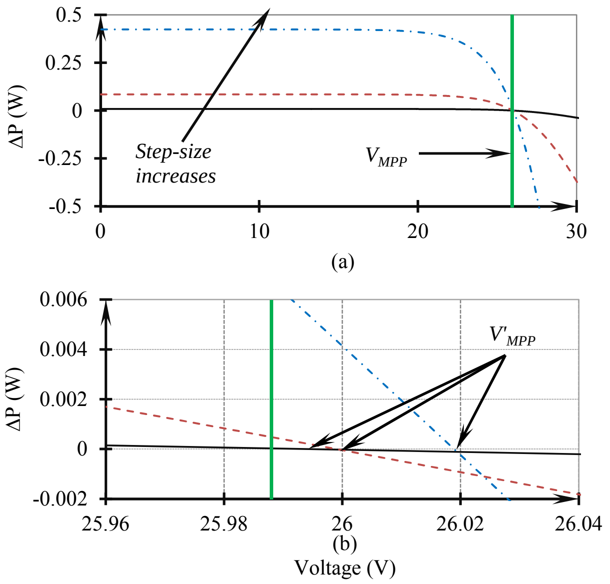


Fig. 2. Relationship between $\Delta P$ and the perturbing step, $V_{stp}$.

Furthermore, the sampling period of the system should be set properly; otherwise an inappropriate sampling period will lead to instability of this method and cause more variations around the MPP [1,7]. This relationship is discussed thoroughly in [1], which can be the guidance for the modified P&O algorithm design and optimization in this paper.

Similar to the P&O method, the steady-state operating point of INC oscillates around the MPP in steady state and the tracking accuracy and the tracking response also depend on the step-size, $V_{stp}$, as shown in Fig. 3. But INC can rapidly track the irradiance changes with higher accuracy than the P&O method [5]. The increased complexity is another disadvantage of this method, when it is compared to P&O method [1,5].

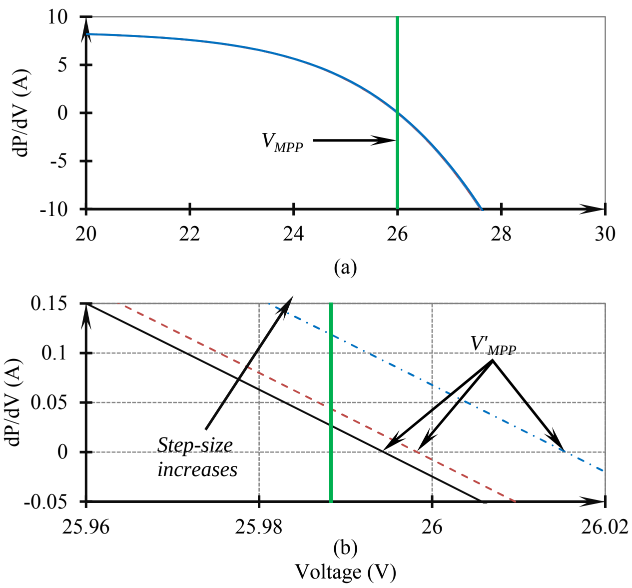


Fig. 3. Relationship between $dP/dV$ and the perturbing step, $V_{stp}$.

## 2.2 Modified P&O Algorithm

As mentioned, the P&O method may become unstable under rapid irradiance changes and the step-size has a strong impact on the tracking performance. In this part, a coarse explanation to the relationship between step-size and MPPT performance is presented first. The *P-V* characteristic curves are plotted again in Fig. 4 under different irradiance levels.

It is supposed that the PV system is delivering the power $P_k$ at $t=kT_s$ ($T_s$ is the sampling period) before perturbed by the voltage $\Delta V$ and that the irradiance will change within the next sampling interval. Therefore, when $t=(k+1)T_s$ , the output power is shifted to $P_{k+1}$ as shown in Fig. 4. Consequently, the classic P&O MPPT algorithm will make an error and enter the decreasing-voltage operation. This is the main drawback of P&O method.

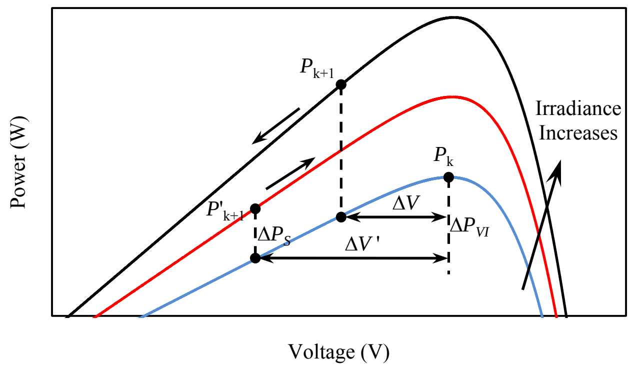


Fig. 4. MPPT performance under rapidly changing irradiation.

If the step-size is large enough, for example $\Delta V'$ as shown in Fig. 4, the power difference $\Delta P_S$ caused by the irradiance change will be smaller than the power change $\Delta P_{VI}$ resulting from the MPPT algorithm perturbation, and the next perturbing direction will be correct. Actually, if the irradiance keeps stable or changes slightly and high resolution sensors are used, the MPPT method could go back to the correct condition after only one sampling period ($t=(k+2)T_s$). However, due to measurement noise and the non-linear systems, this could not happen. In order to avoid the above problem, the following inequality should be fulfilled in order to design an effective MPPT algorithm [1].

$$|\Delta P_s| \le |\Delta P_{VI}| \quad (1)$$

However, too large step-size will lead to more power losses in steady state especially under strong solar irradiance conditions. One solution to this is to use variable step-sizes. But too many step-sizes need to be tuned in order to avoid confusion under rapid irradiance change, which can be another big challenge. In this modified MPPT algorithm, two step-sizes and a power threshold are adopted. These variables also need to be chosen properly.

When it comes to the choice of power threshold, the output power oscillations should be taken into consideration. Assuming that the step-size is sinusoidal with the amplitude $V_{stp}$, thus, the PV operating voltage can be given by,

$$\tilde{V}_{PV} = V_{MPP} + V_{stp}\sin(\omega t)\,. \qquad (2)$$

Then, the power variation can be obtained as,

$$\Delta P = \tilde{V}_{PV}\tilde{I}_{PV} - P_{MPP}\,. \qquad (3)$$

where $\tilde{V}_{PV}$ and $\tilde{I}_{PV}$ are the instantaneous voltage and current of the PV panel, $P_{MPP}$ is the maximum power under a given irradiance. The power variation is plotted as shown in Fig. 5. In order to reduce the power variation in steady state, the step-size will become smaller when the following inequality is satisfied,

$$|\Delta P| > P_{th},$$

where $P_{th}$ is the power threshold. It can be concluded from Fig. 5 that the power threshold should be chosen larger than $\Delta P_1$ in order to achieve the goal: quick and accurate tracking response.

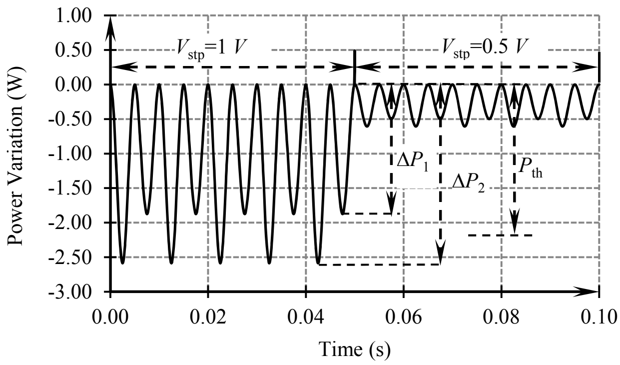


Fig. 5. Power variation due to step-size.

Based on the MPPT method reported in [8], the proposed modified MPPT method can be described as the following: when $|\Delta P|>P_{th}$, the step-size is $V_{stp1}$; and it could rapidly track the MPP; when $|\Delta P|\leq P_{th}$, the step-size becomes $V_{stp2}$ (smaller) and the proposed method should be able to offer a more accurate tracking response. The flow-chart of this modified MPPT method is shown in Fig. 6.

However, if the solar irradiance is very low, using the above step-sizes may also lead to more power losses. In order to solve this problem, a power ratio, $P_r$, is plugged into this MPPT control algorithm as also shown in Fig. 6. This power ratio is defined as the following:

$$P_r \triangleq \frac{P_{ins}}{P_{mn}}, \qquad (4)$$

where $P_{ins}$ is the instantaneous power under different solar irradiance conditions and $P_{mn}$ is the nominal maximum power under standard test condition (solar irradiance: 1000 W/m$^2$, ambient temperature: 25 ℃, air mass of 1.5 solar spectral irradiance distribution).

Due to these variable steps, accurate and high resolution sensors are required in order to achieve these goals. Therefore, when compared to the traditional one, the required high resolution sensors increase the complexity of this modified MPPT algorithm. A tradeoff should be made between the complexity and the performance.

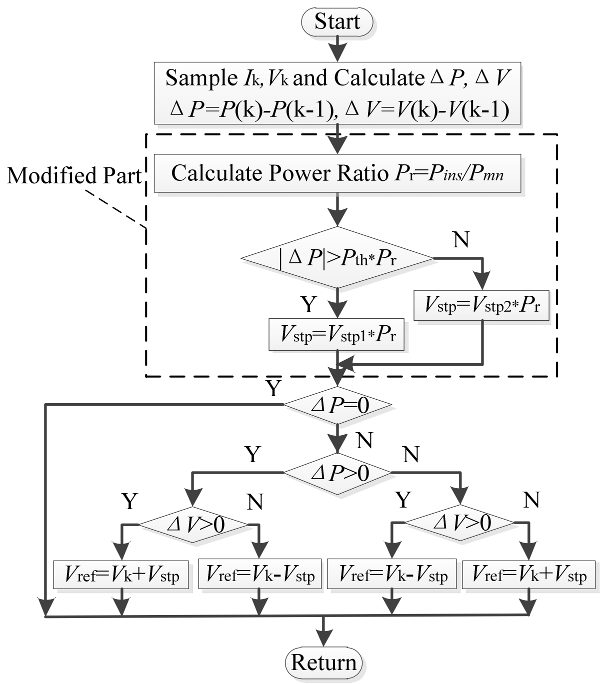


Fig. 6. Flow-chart of the modified P&O MPPT algorithm.

## 3 Deadbeat Control Algorithm

As a digital PWM control method, the deadbeat control algorithm is used in this system in order to evaluate the proposed modified MPPT algorithm. The deadbeat method calculates the state equation of the inverter system with filter and feedback signal from the voltage in order to predict the pulse width of the next switching period [14-16].

The deadbeat control scheme can be derived using Kirchhoff's law on the grid-side circuit of the single-phase system as shown in Fig. 7. In this case, the voltage equation can be expressed as (6) at the $k$-th sampling period interval.

$$L\frac{i_f(k+1)-i_f(k)}{T_s} + Ri_f(k) = u_{in}(k) - u_s(k)\,, \qquad (6)$$

where $i_f(k)$, $u_{in}(k)$ and $u_s(k)$ are the instant values at the sampling instant $t=kT_s$, and $T_s$ is the sampling period, and $L$ and $R$ are the total inductance and resistance down-steam of the inverter.

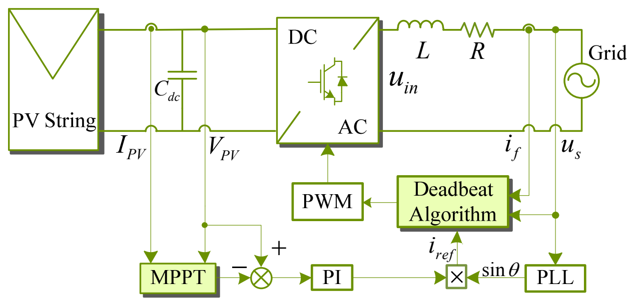


Fig. 7. Simulation structure of single-stage single-phase systems.

Taking into account the relationship between the voltage of the DC capacitance $V_c$ (in single-stage PV systems, there is $V_c=V_{PV}$) and the inverter-side voltage $u_{in}$ under unipolar modulation condition, Equation (7) can be obtained as:

$$L\frac{i_f(k+1)-i_f(k)}{T_s}+Ri_f(k)=\frac{\Delta T(k)}{T_s}V_c-u_s(k), \quad (7)$$

where $\Delta T(k)/T_s$ is the duty cycle at the sampling time $t=kT_s$.

Replacing $i_f(k+1)$ with the reference signal $i_{ref}(k)$, the deadbeat control law can be obtained as given in (8),

$$u(k)=\frac{\Delta T(k)}{T_s}=\frac{L\left[i_{ref}(k)-i_f(k)\right]+T_sRi_f(k)+T_su_s(k)}{T_sV_c}. \quad (8)$$

# 4 Simulation and Experimental Results

## 4.1 Simulation Results

The simulation structure of the single-phase PV system is shown in Fig. 7. This system consists mainly of a PV string, which is modelled via MATLAB/S-Function using the data of a virtual PV array and a single-phase full-bridge inverter. The MPPT algorithm is also implemented using S-Function.

The simulation results are shown in Fig. 8 and the irradiance change starts from 400 W/m$^2$, stops at 1000 W/m$^2$, lasts for 2 seconds at this level, and goes back to 400 W/m$^2$ in two seconds with a constant slope.

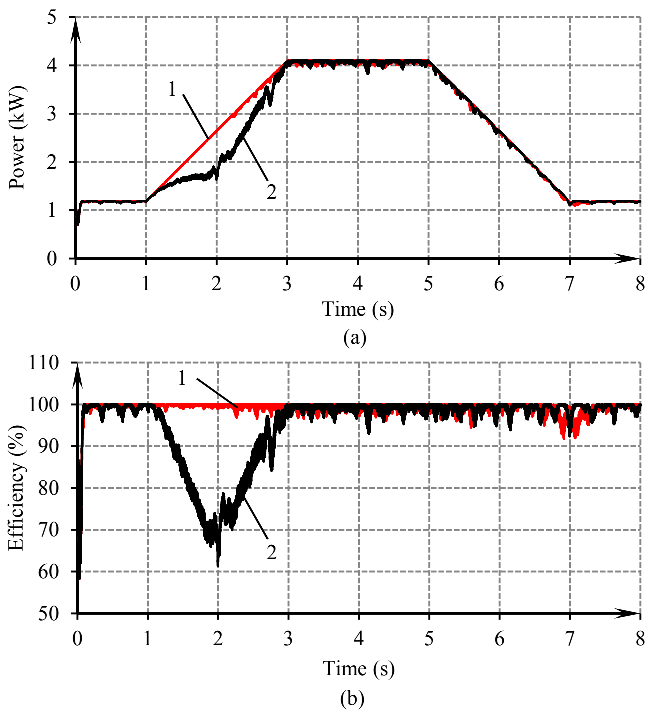


Fig. 8. Simulation results of grid-connected PV system with modified P&O method (line 1) and classical P&O method (line 2) under trapezoidal irradiance change: (a) tracked power; (b) instantaneous efficiency.

The single-phase PV system with modified MPPT algorithm has been tested in the simulation with the following system parameters: sampling period of the system $T_s$=0.1 ms, the MPPT algorithm sampling period $T_m$=0.05 s, and perturbing sizes $V_{stp1}$=0.5 V and $V_{stp2}$=0.1 V. The PV string consists of twenty serial PV arrays (205 W for each panel), and thus the rated maximum power is $P_{nm}$=20×205 W=4100 W. The rated voltage and current are $V_{nm}$=20×25.8 V=516 V and $I_{nm}$=7.95 A, respectively. The other parameters are selected as $L_f$=5 mH, $C_{dc}$=1100 $\mu$F, $U_s$=220 V, grid frequency $f$=50 Hz, switching frequency $f_c$=10 kHz, and PI controller proportional gain $k_p$=2, integral gain $k_i$=110.

As it can be seen in Fig. 8, compared to classical P&O method, the modified MPPT algorithm can go back to steady state quickly and operate around MPP with smaller variations. Thus, there should be less power losses and the amplitude of the injected current should be more stable.

## 4.2 Experimental Results

In order to verify the proposed MPPT method, a dSPACE based experimental platform was set up as shown in Fig. 9 to test its performance. This laboratory setup mainly consists of the following parts:

- a solar simulator or virtual PV panels;
- an industrial PV inverter, Danfoss VLT 5000 5KW 3-phase inverter, is used in single-phase mode with unipolar modulation;
- a DS 1103 dSPACE control system.

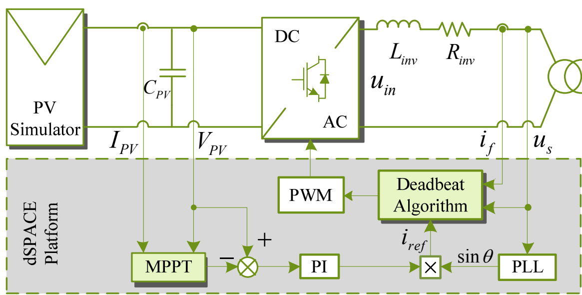


Fig. 9. Experimental setup for the test PV system.

The deadbeat current controller is first tested. In this test, a constant Delta Electronika DC voltage is used, $V_{dc}$=400 V. The other parameters of this experiment are as followings: $L_{inv}$= 8.7 mH, $R_{inv}$=0.1 Ω, $L_g$=2 mH, $R_g$=1.4 Ω, which are in the transformer. The sampling frequency and switching frequency are the same, $f_s$=$f_c$=15 kHz. The results are shown in Fig. 10. Due to the weather in Aalborg in winter, it is difficult to test the MPPT algorithm using virtual panels. A simulator will be used to verify this algorithm and the results will be available in the presentation.

As it can be seen in Fig. 10, the deadbeat controller performance is good. However, it is quite sensitive to the system parameters, such as the filter inductance and the sampling frequency. In order to solve this problem, a method was proposed in [15] to increase the robustness of the deadbeat controller.

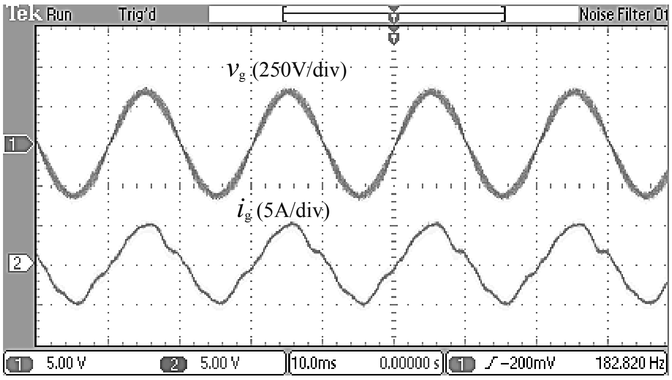


Fig. 10. Deadbeat current controller experimental results at $t$=10 ms/div: (1) grid voltage $v_g$ [250V/div]; (2) grid current $i_g$ [5A/div].

## 5 Conclusion

In this paper, a modified P&O method is proposed in order to achieve a better MPPT performance. This modified algorithm is implemented and experimentally tested in a single-phase PV system based on a dSPACE platform in order to verify its performance. A deadbeat control algorithm is used in this experiment when the PV string is connected to the utility grid. In the future work, a thorough analysis of the relationship between the MPPT performance and the step size, as well as sampling rate will be investigated.

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