Self-learning Maximum Power Point Tracking with Environmental Adaptation for Photovoltaic Power Systems

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Abstract. A novel self-learning method is proposed for maximum power point tracking (MPPT) in photovoltaic (PV) system. A simple control circuit is designed to make its implementation effective, in which the super capacitor is used to charge and discharge to achieve fast control. Furthermore, the proposed method is implemented with hardware experiments and MATLAB/Simulink for simulations. The experimental results verify the feasibility of this method for MPPT, while simulations in MATLAB/Simulink indicate that the proposed PV system can react quickly within milliseconds under enormous changes of atmospheric conditions.

1. Introduction

MPPT is an important function in all PV power systems. At present, there are two kinds of widely used conventional MPPT control algorithms known as perturb and observe (P&O) and incremental conductance (IC) methods. These methods are excellent in adaptability to slowly varying irradiance, temperature, however they are prone to failure at sudden changing irradiance [1-3]. Although some methods have been developed to overcome partly the problem based on artificial intelligence or improvements of P&O and IC techniques [3-6]. Nevertheless, most of them are relatively complex. Another method can determine the maximum power point (MPP) directly by using available database tables [1], meanwhile, its operation mode is relatively simple, but it suffers in terms of portability because the data in the database tables is dependent to the model of modules. As a consequence, this letter proposes a novel self-learning MPPT algorithm for photovoltaic power system with dynamic lookup table, which makes the MPPT system provide a quick response speed to rapidly changing atmospheric conditions.

Figure 1. The typical power-voltage characteristic of solar cell
2. Control mode

The typical power-voltage characteristic of solar cell is shown in Fig. 1. Accordingly, in order to track the MPP effectively, the schematic diagram as shown in Fig. 2 is designed to draw the output voltage VPV of the solar panel to approach the corresponding voltage (VM) of the MPP. Based on the assumption that the diode is ideal, the equation of VPV and I can be written by

\[ C \frac{dV_{PV}}{dt} = I - SI_R \]  

(1)

Where S = 0 or 1 denotes switch open or closed, respectively. In addition, IR=VPV/R. According to (1), VPV (t) and ΔVPV can be described as, respectively

\[ \begin{align*}
V_{PV}(t + \Delta t) &= V_{PV}(t) + \frac{I}{C} \Delta t, (S = 0) \\
V_{PV}(t + \Delta t) &= [V_{PV}(t) - IR]e^{-\frac{I}{RC}} + IR, (S = 1)
\end{align*} \]

(2)

\[ \Delta V_{PV} = \left( I - SI_R \right) \Delta t / C \]  

(3)

Where Δt represents the sampling time of the MPPT system. According to (3), if S=0, ΔVPV=I·Δt/C >0, which indicates VPV will increase as the capacitor is charging. In contrast, the capacitor is discharging and VPV will decrease if S=1 and R<= V2M / PMPP. Here, a small resistor should be chosen to satisfy the latter inequality constraint and ensure I<IR. Such control mode is similar to the mode in [7].

![Figure 2. Schematic diagram of proposed MPPT](image)

3. Irradiance and temperature discretization

Irradiance and temperature can be discretized into a series of intervals uniformly as shown in TABLE1. Additionally, PM_TEMP and VM_TEMP are used to store maximum power and corresponding voltage of the PV panel under different intervals of irradiance and temperature, respectively. And the initial values of PM_TEMP and VM_TEMP are both set to 0.
Table 1. A dynamic lookup table of the MPP in different environments

| \( \text{Ir}_0 \sim \text{Ir}_1 \) (W/m²) | \( T_0 \sim T_1 \) (deg. C) | \( T_1 \sim T_2 \) (deg. C) | \( \ldots \) | \( T_{m-1} \sim T_m \) (deg. C) |
|--------------------------------|-----------------|-----------------|-------|-----------------|
| \( P_{M, \text{TEMP}}[1,1] \) | \( V_{M, \text{TEMP}}[1,1] \) | \( P_{M, \text{TEMP}}[1,2] \) | \( V_{M, \text{TEMP}}[1,2] \) | \( P_{M, \text{TEMP}}[1,m] \) |
| \( P_{M, \text{TEMP}}[2,1] \) | \( V_{M, \text{TEMP}}[2,1] \) | \( P_{M, \text{TEMP}}[2,2] \) | \( V_{M, \text{TEMP}}[2,2] \) | \( P_{M, \text{TEMP}}[2,m] \) |
| \( \ldots \) | \( \ldots \) | \( \ldots \) | \( \ldots \) | \( \ldots \) |
| \( P_{M, \text{TEMP}}[n,1] \) | \( V_{M, \text{TEMP}}[n,1] \) | \( P_{M, \text{TEMP}}[n,2] \) | \( V_{M, \text{TEMP}}[n,2] \) | \( P_{M, \text{TEMP}}[n,m] \) |

4. System operation

The overall execution of the proposed MPPT method is illustrated in Fig. 3. In the initial state, the switch \( S \) is open. While the initial operating point of the PV cell is on the left of the MPP (point A) in Fig. 1, if \( P_A (P_{PV} = P_A) \) is greater than \( P_{M, \text{TEMP}}[i, j] \) (\( i = 1, 2, 3 \ldots n, j = 1, 2, 3 \ldots m \)), then \( (V_{M, \text{TEMP}}[i, j], P_{M, \text{TEMP}}[i, j]) \) is updated with \( (V_{M, \text{TEMP}}[i, j] = V_A, P_{M, \text{TEMP}}[i, j] = P_A) \) and the switch stays unchanged, which makes \( V_{PV} \) keep on increasing. This process will continue until the voltage \( V_{PV} \) of the PV cell reaches to \( V_M \). Subsequently, \( P_{PV} < P_{M, \text{TEMP}}[i, j] = P_{MPP} \), then the switch changes to closed state in order to make \( V_{PV} \) decrease. Then, the voltage \( V_{PV} \) finally wanders around \( V_M \). By contrast, while the initial operating point of the PV cell is on the right of the MPP (point B), the control process is similar to the above. During this course the \( P_{M, \text{TEMP}} \) and \( V_{M, \text{TEMP}} \) are updated in such self-learning way without requiring any knowledge of the PV cell. In particular, the size of \( C \) and \( R \) determines the response time of tracking the MPP. Fast tracking can be achieved with a smaller \( C \) and \( R \) while the oscillation will be larger. However, the oscillation can be minimized by reducing the sampling time within reason. It should be noted that when the operating point of the PV cell reaches the MPP exactly (\( I = P_{MPP}/V_M, I_R = V_M/R \)), if \( R = V_M^2/P_{MPP} \), then the system achieves a static equilibrium state.

![Flow chart of the proposed self-learning algorithm for MPP tracking](image-url)
5. Experimental verification
To verify the performance of the proposed method, hardware experiments and simulations in MATLAB/Simulink have been conducted respectively.

5.1. Hardware experiments
A 58×58 mm Si PV panel (nominal voltage 2V) is illuminated by an incandescent light (nominal power 95W) in the experimental PV system. Besides, the proposed method is implemented with a microcontroller. The parameters used are: \( C=1F, R=150\Omega \). And the sampling time \( \Delta t \) is set to 1s. When the surface temperature of PV panel is 31deg.C and the illuminance is 952lux, experimental waveforms of PV panel voltage \( V_{PV} \) and output power \( P_{PV} \) as well as \( P_{M\_TEMP} \) and \( V_{M\_TEMP} \) are illustrated in Fig. 4. It can be seen that when \( t=750s \), the switch is forced to disconnect to make \( V_{PV} \) keep increasing. And \( P_{M\_TEMP} \) and \( V_{M\_TEMP} \) will not be updated until the MPP has been tracked in the PV system, which approves the feasibility of this method for MPPT.

![Figure 4](image-url)

**Figure 4.** Experimental waveforms of PV panel voltage \( V_{PV} \) and output power \( P_{PV} \) as well as \( P_{M\_TEMP} \) and \( V_{M\_TEMP} \)

5.2. Simulink simulations
A new PV system has been built in MATLAB/Simulink, in which PV array is realized by the model with array type of Sun Power SPR-315E-WHT-D, 1Series modules, 1Parallel strings in MATLAB. The parameters used in the circuit diagram are: \( C=0.005F, R=2\Omega \) and \( \Delta t = 10\mu s \). The simulation results of PV cell output power \( P_{PV} \) and output voltage \( V_{PV} \) under various constant irradiance and temperature conditions respectively are shown in Fig. 5a and b. When a steep change in irradiance occurs, as shown in Fig. 6a, the waveforms of \( P_{PV} \) and \( V_{PV} \) are illustrated in Fig. 6b and c respectively. A comparison between Fig. 5 and Fig. 6 indicates that the proposed PV system tracks effectively the MPP of PV cell for different normal operating atmospheric conditions, meanwhile the settling time is less than 1ms under enormous changes of atmospheric conditions. Hence, the proposed system tracks the MPP successfully with the feature of the strong ambient adaptability.
Figure 5. The waveforms of PV cell output power $P_{PV}$ and output voltage $V_{PV}$ under various constant irradiance and temperature (a Power $P_{PV}$ b Voltage $V_{PV}$).

Figure 6. The waveforms of PPV and VPV under steeply changing irradiance a steeply changing irradiance curve (b Power PPV, c Voltage VPV)
6. Conclusion
A novel self-learning MPPT method for PV system is presented, which can react to environmental saltation within milliseconds. In particular, the response speed can be further accelerated by reasonably reducing the capacity of the super capacitor $C$ and the resistance $R$. Additionally, a control circuit that is far simpler than most MPPTs is proposed to the method. Moreover, there are no other parameters to be set in the proposed algorithm except the sampling time, so the algorithm is transplanted conveniently.

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