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Adaptive perturb and observe MPPT technique for Grid-connected Photovoltaic Inverters

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Abstract

In this paper, a single-phase based Cuk converter topology for grid-connected photovoltaic inverters is used, which has a wide voltage range for PV array voltage. An adaptive perturb and observe maximum power point tracking (MPPT) method for the converter is proposed. The used MPPT algorithm can fast and accurately track the maximum power point (MPP). All control functions are implemented in software with a single-chip microcontroller. Experimental results obtained on a 2.5-kW prototype, which demonstrate that the proposed method provides effective, fast, and perfect tracking.

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Keyword: Cuk converter, grid-connected photovoltaic inverters, adaptive perturb and observe, MPPT;

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1. Introduction

Growing concerns about environmental issues and the word energy crisis have attracted a great deal of interests for the available sustainable energy sources. Among them, photovoltaic (PV) application has received a great attention because of distinctive advantages such as simplicity of allocation, high dependability, low maintenance, absence of fuel cost and lack of noise. In addition to these factors, there are other advantages such as the declining cost and prices of solar modules, an increasing efficiency of solar cells and manufacturing technology improvements[1]-[3].

The voltage-power characteristic of a photovoltaic (PV) array is nonlinear and time varying because of the changes caused by the irradiance and temperature conditions. The task of a maximum power point (MPP) tracking (MPPT) in PV power systems is to continuously tune the power system in order to draw maximum power from the PV array. In recent years, the grid-connected photovoltaic inverters have been

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more and more popular because they do not need battery backups. Various methods of maximum power tracking (MPPT) have been presented in photovoltaic power conditioning system. Of these, the perturbation and observation (P&O), which moves the operating point toward the maximum power point by periodically increasing or decreasing the PV array output voltage, is often used in many photovoltaic power applications[4],[5]. Although the implementation of this method is simple, the method itself is not very accurate and fails to quickly track the maximum power point. The incremental conductance method (INC) also applied in photovoltaic systems. The INC method tracks the maximum power point by comparing the incremental and instantaneous conductance of the solar array. However, it is a more advanced algorithm, and its hardware and software implementation is reasonably complex. It seldom reaches the maximum power point in practical situation. When adopting a MPPT, the major job is to choose and design a highly efficient converter. Among dc-dc converters available, the Cuk and buck-boost converters have the ability either higher or lower output voltage compared with the input voltage. Although the buck-boost converter is cheaper than the Cuk converter, some disadvantages, such as discontinuous input current, high peak currents in power components and poor transient response make it less efficient. On the other hand, the Cuk converter has the highest efficiency among nonisolated dc-dc converters.

The paper proposes an adaptive perturb and observe MPPT for a single-phase photovoltaic grid-connected inverter based the Cuk converter. The photovoltaic system using a 32 bit digital signal processor (TMS320F2808) is implemented. Experimental results obtained on a 2.5-kW prototype show high performance, such as wide range of the PV array voltage (100V-600V), high MPPT efficiency (99%), high power conversion efficiency(96.5%), a near-unity power factor (99.996%), and low current total harmonic distortion (THD)(1.889%).

2. System description and modeling

2.1. System description

Fig.1 shows the basic structure of a two-stage single-phase grid-connected photovoltaic inverter studied in this paper. The PV system consists of a PV array, Cuk converter (DC-DC), DC-AC converter, an output filter inductor L and a filter capacitance C, and grid. The PV modules are connected in a series-parallel configuration to match the power rating. The Cuk converter converts the PV array voltage into another required dc voltage. The DC-AC converter with an output filter inductor and a filter capacitance convert the Cuk output voltage into an ac sinusoidal voltage by means of appropriate switch signals to make the output current in phase with the grid voltage and obtain a unity power factor.

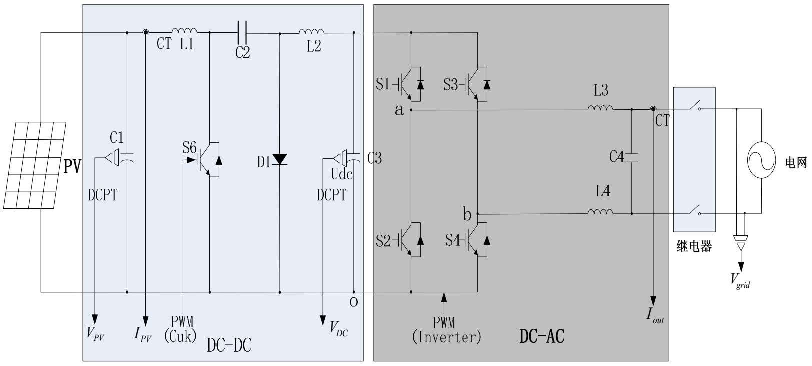

Fig. 1. The basic structure of a two-stage single-phase grid-connected photovoltaic inverter

2.2. Solar cell and PV array

The basic structure unit of a solar module is the PV cells. A solar cell converts energy in the photons of sunlight into electricity by means of the photoelectric phenomenon found in certain types of semiconductor materials such as silicon and selenium. A single solar cell can only generate a small amount of electric power. In order to increase the output power of systems, solar cells are generally connected in series or parallel to form PV arrays. The PV array is considered as an exponential and nonlinear relation between the output voltage and current of a PV array, and there exists one operating point where the PV array generates maximum power.

If the internal shunt resistance is ignored, the characteristic of the PV output current I_{PV} can be written as

$$I_{\mathrm{PV}} = I_{\mathrm{Ph}} - I_{\mathrm{sat}} \left\{ \exp\left[\frac{q(V_{\mathrm{PV}} + I_{\mathrm{PV}} R_s}{AKT} \right] - 1 \right\} \tag{1}$$

where I_{Ph} is the PV array photocurrent that is proportional to solar irradiation, I_{sat} is the PV array reverse saturation current that mainly depends on temperature, q is the charge of an electron, A is the ideality factor of the p-n junction, K is Boltzmann's constant, R_s is the intrinsic series resistance of the PV array. Once the series resistance R_s can be ignored, (1) can be derived as

$$I_{\mathrm{PV}} = I_{\mathrm{Ph}} - I_{\mathrm{sat}} \left\{ \exp\left(\frac{qV_{\mathrm{PV}}}{AKT} \right) - 1 \right\} \tag{2}$$

3. MPPT control

PV strings are known to be nonlinear, and there exists one operation point where the PV string generates maximum power. One of the problems in the PV generation systems is that the amount of electric power by the PV arrays is always changing with weather conditions. An MPPT control strategy, which has quickly response characteristics and is able to make good use of the electric power generated in any weather, is needed to solve the aforementioned problems. The most commonly used MPPT algorithm is the Perturb and Observe (P&O), due to its ease of implementation in its basic form. In Fig.3(a), if the operating voltage of the PV array is perturbed in a given direction and dP/dV > 0, it can be concluded that the perturbation moved the array's operation point to the maximum power point. The P&O algorithm will then continue to perturb the PV array voltage in the same direction. If dP/dV < 0, then the change in operating point moved the PV array away from the maximum power point, and the P&O algorithm will reverse the direction of the perturbation. The incremental conductance uses the PV array's incremental conductance dI/dV to compute the sign of dP/dV. The incremental conductance can track rapidly increasing and decreasing irradiance condition with higher accuracy than P&O. However, because of noise and errors due to measurement and quantization, this method also can produce oscillation around MPPT, and it also can be confused under rapidly changing atmospheric conditions. Another disadvantage of the method will increase complexity compared to P&O. In this paper, the an adaptive perturb and observe MPPT method is used to extract maximum power from the PV arrays and deliver it to the inverter. The reference voltage for the PV arrays is calculated as

$$V_{\text{ref},k+1} = V_{\text{ref},k} + M\,\frac{\Delta P_k}{\Delta V_k} \tag{3}$$

where k and $k+1$ are the sampling instants, M is the step size, $\Delta P_k / \Delta V_k$ is the instantaneous power slope at the PV array output.

The step size M is chosen according to the system stability requirement. The main job is to choose and design a highly efficient converter when the variable step P&O method is used, which is considered as the main part of the MPPT.

4. Experimental results

To verify the performance of the proposed method, the proposed MPPT method is applied to the dual stage grid-connected photovoltaic inverter rates as 2.5kW. The developed prototype is composed of a Cuk converter and single-phase full-bridge inverter. Fig.2 shows the control scheme for the system. As shown in Fig.2, the Cuk converter performs MPPT. The full-bridge inverter performs the dc-link voltage control and out-put current control. In this system, the DSP TMS320F2808 of Texas Instruments is used as the main controller. The system parameters are presented as followings: Input voltage range:100V-600V; Dc-link voltage: 380V; Output voltage: 230V (rms); Cuk converter frequency: 20kHz; Full-bridge converter frequency: 15kHz.

In the experiment, the Topcon Quadro 6 K programmable DC power supply is used as the PV array. The equipment can simulate the PV array. The PV array characteristic curve and operating point can be graphically monitored using communication between this equipment and a PC. Fig.3 (a) shows the PV array simulator used in this experiment. Fig.3(b) shows waveforms of the PV array voltage and the output current by oscilloscope in the initial operation for grid-connected photovoltaic inverters used in this experimental. First, the inverter starts grid interconnection, after the dc-link voltage has reached 360V, then, the converter performs the MPPT. Fig.4 (a) shows the steady-state waveform after the converter has reached the MPP. It is confirmed that the output current is synchronized with he grid voltage. The rms output current is about 11A, hence, the transferred power from the PV simulator to the grid is about 2.5kW. Fig.4 (b) shows the spectrum result of output grid current for grid-connected condition. The THD is 1.889% and the power factor is 99.996%. This is within the 4% bounds of the IEEE standard. The THD does not exceed the limit (5%).

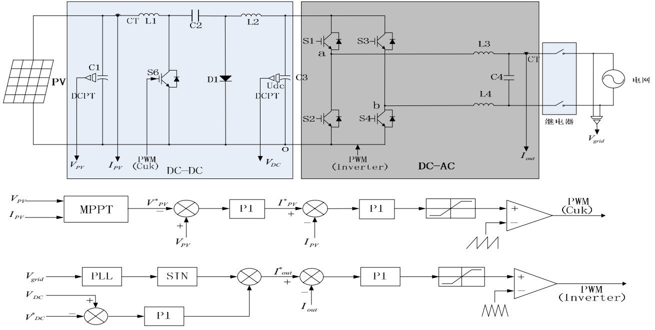

Fig. 2. The control scheme for single-phase grid-connected inverters

5. Conclusion

In this paper, an adaptive perturb and observe MPPT based on Cuk converter was employed. The proposed system was constructed, and the functionality of the suggested control method was proven. From the experimental results obtained on a 2.5-kW prototype, it was confirmed that, with a well-designed system including a proper converter and selecting an efficient algorithm, the implementation of MPPT is simple and can be easily constructed to achieve an acceptable efficiency level of the PV array. The results also indicate that the proposed system is capable of MPPT and has a very good steady-state performance.

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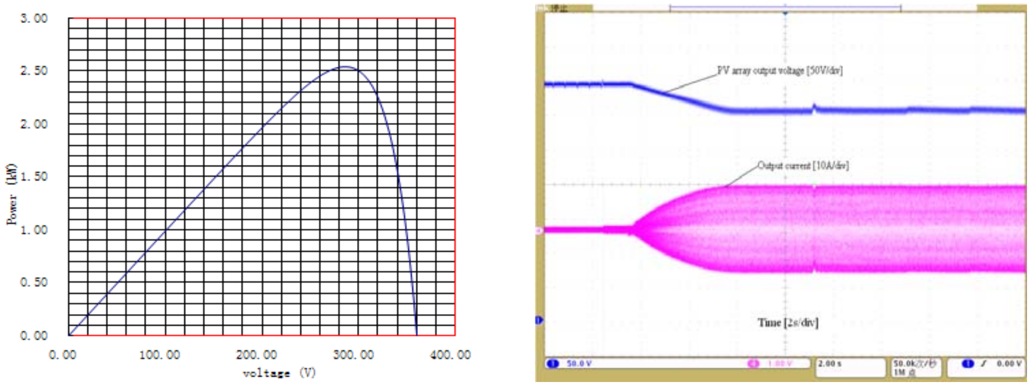
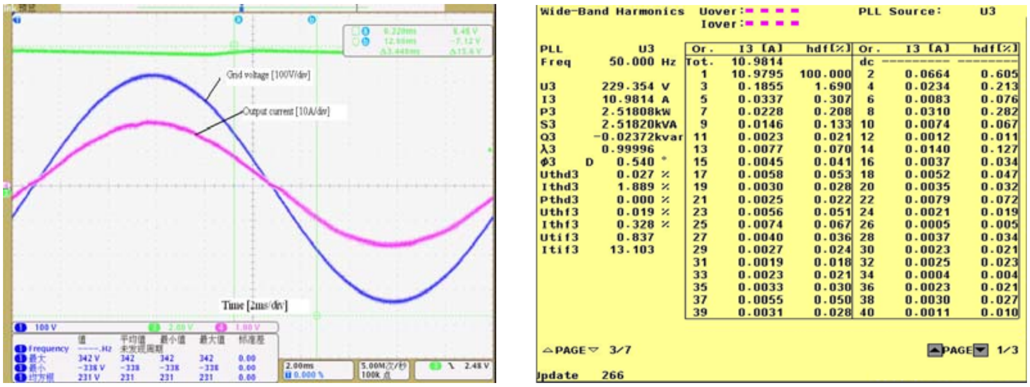


(a) (b)

Fig. 3. (a) PV array simulator output; (b) the PV array voltage and the output current in initial operation



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Wide-Band Harmonics  Uover:- - - -          PLL Source:    U3
                     Iover:- - - -

PLL         U3         Or.   I3 [A]    hdf[%] Or.   I3 [A]    hdf[%]
Freq     50.000 Hz     Tot.  10.9814          dc    ---------  -------
                         1   10.9795  100.000  2    0.0664    0.605
U3      229.354 V        3    0.1855    1.690  4    0.0234    0.213
I3      10.9814 A        5    0.0337    0.307  6    0.0083    0.076
P3      2.51808kW        7    0.0228    0.208  8    0.0310    0.282
S3      2.51820kVA       9    0.0146    0.133 10    0.0074    0.067
Q3     -0.02372kvar     11    0.0023    0.021 12    0.0012    0.011
λ3      0.99996         13    0.0077    0.070 14    0.0140    0.127
φ3    D   0.540 °       15    0.0045    0.041 16    0.0037    0.034
Uthd3     0.027 %       17    0.0058    0.053 18    0.0052    0.047
Ithd3     1.889 %       19    0.0030    0.028 20    0.0035    0.032
Pthd3     0.000 %       21    0.0025    0.022 22    0.0079    0.072
Uthf3     0.019 %       23    0.0056    0.051 24    0.0021    0.019
Ithf3     0.328 %       25    0.0074    0.067 26    0.0005    0.005
Utif3     0.837         27    0.0040    0.036 28    0.0037    0.034
Itif3    13.103         29    0.0027    0.024 30    0.0023    0.021
                        31    0.0019    0.018 32    0.0025    0.023
                        33    0.0023    0.021 34    0.0004    0.004
                        35    0.0033    0.030 36    0.0023    0.021
                        37    0.0055    0.050 38    0.0030    0.027
                        39    0.0031    0.028 40    0.0011    0.010

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(a) (b)

Fig. 4. (a) The waveforms of the output current and gird voltage in steady-state; (b) spectrum result of output grid current

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