Yang Yong[1,*]
Zhu Binbin
Wu liang

J. Electrical Systems 9-4 (2013): 392-400

Regular paper

Multistring Power Conditioning System For Grid-connected Photovoltaic Inverters

JES
Journal of Electrical Systems

In this paper, a single-phase multistring based Cuk converter topology for grid-connected photovoltaic inverters is proposed. It consists of two strings of PV arrays connected to their own dc-dc Cuk converter. An improved maximum power point tracking (MPPT) method for the multistring converter is used. The used MPPT algorithm can fast track the maximum power point. All control functions are implemented in software with a single-chip microcontroller. Experimental results obtained on a 3-kW prototype, which demonstrate that the proposed method provides effective, fast, and perfect tracking.

Keywords: Multistring, Cuk converter, Grid-connected, Maximum power point tracking

1. Introduction

As conventional sources of energy are fast depleting and the cost of energy sources is rapidly rising. The need of having available sustainable energy sources for gradually replacing conventional ones demands the change of structures of energy supply based on clean and renewable resources[1-4]. 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.

Series-connected PV modules are called a string. A string power conditioning system uses a single string of modules to obtain high voltage. However, the single string power condition system has a power limit because of a limited number of series connections once increasing the nominal power. The multistring inverter is a further development of the string inverter, where several strings are interfaced with several dc-dc converter to a common dc-ac converters. Compared with the central power conditioning system, it is beneficial, because every string can be independently controlled and it can eliminate the drawbacks such as nominal power limitation, mismatch problem of parallel-connected string, severe partial shading problem and etc. 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 ne point by periodically increasing or decreasing the PV array output

[*] Corresponding author: Yang Yong1,*Zhu Binbin Wu liang
Yang Yong, School of Urban Railway Transportation, Soochow University, Suzhou, China,
E-mail: yangy198102@126.com or yangy1981@sina.com

voltage, is often used in many photovoltaic power applications. 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. The paper proposes a single-phase multistring based Cuk converter topology. It consists of two strings of PV arrays connected to their own dc-dc Cuk converter. The photovoltaic system using a 32 bit digital signal processor (TMS320F2808) is implemented. The variable step P&O method is implemented in a software program, which automatically adjusts the PV array voltage reference and voltage step size to achieve the maximum tracking under rapidly changing environment conditions. Experimental results obtained on a 3-kW prototype show high performance, such as wide range of the PV array voltage (100V-500V), high MPPT efficiency (99%), high power conversion efficiency(96.5%), a near-unity power factor (99.9%), and low current THD (2.5%).

2. PV module and MPPT

2.1 PV module

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 generate maximum power as shown in Fig.1.

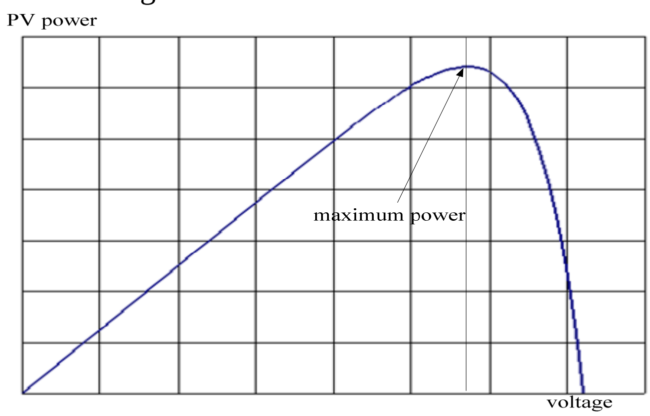


Fig. 1. Characteristic of PV array.

If the internal shunt resistance is ignored, the characteristic of the PV output current I_{PV} can be written as[5,6]

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

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

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

2.2 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.1, 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[7-10]. 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[7-10]. Another disadvantage of the method will increase complexity compared to P&O. In this paper, the variable step P&O 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

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

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. The efficiency of the switch-mode dc-dc converters is widely discussed. Among all the available topologies, both buck-boost and Cuk converters can provide the ability to have either higher or lower output voltage compared with the input voltage. Although the buck-boost converter is cheaper than the Cuk converter, some disadvanges, such as discontinuous input current and high peak currents in power switches, make it less efficient. On the other hand, the Cuk converter has low switching losses and high efficiency among nonisolated dc-dc converters. Thus, the Cuk converter is employed in designing the MPPT.

3. Phase Locked Loop (PLL)

Phase, amplitude and frequency of the grid are critical informations for the operation of the grid-connected inverter systems. In order to get an accurate and fast detection of the phase angle, amplitude and frequency of the utility voltage, PLL is usually used. Recently, there has been an increasing interest in PLL topologies for grid-connected systems. The general structure of a single-phase PLL including the grid voltage monitoring is shown in Fig.2 [11-12]. Usually, the main difference among single-phase PLL methods is the orthogonal voltage system generation structure. An easy way of generating the orthogonal voltage for a single-phase grid-connected inverter is using a transport delay block, which is responsible for generating a phase shift of 90 degrees with respect to the fundamental frequency of the input grid voltage. However, the orthogonal voltage will be frequency dependency and poor filtering. The paper adopts a new method of single-phase PLL structure based on SOGI. The proposed method is a good alternative for creating an orthogonal system in single-phase systems compared to a transport delay method. The PLL structure using SOGI has been chosen as the most promising candidate for the single-phase grid voltage monitoring. The structure of the SOGI is shown in Figure 3. The input signal V_{grid} is the voltage signal measured at the Point of Common Coupling (PCC). As output signals, two sine waves (V_α and V_β) with a phase shift of 90 degree are generated. The component V_α has the same phase and magnitude with the fundamental of the input signal (V_{grid}). The SOGI acts like an infinite gain band-pass filter. The closed-loop transfer functions ($F_\alpha = V_\alpha / V_{grid}$ and $F_\beta = V_\beta / V_{grid}$) of the SOGI presented in Figure 3 are obtained as follows:

$$F_\alpha = \frac{V_\alpha}{V_{grid}} = \frac{k\omega_g s}{s^2 + k\omega_g s + \omega_g{}^2} \tag{4}$$

$$F_\beta = \frac{V_\beta}{V_{grid}} = \frac{k\omega_g{}^2}{s^2 + k\omega_g s + \omega_g{}^2} \tag{5}$$

where ω_g is the nature frequency of the SOGI which is equal to the estimated frequency ($\omega_g = \omega^*$); k represents the gain which affects the bandwidth of the SOGI.

Using the SOGI, the input voltage signal (V_{grid}) is filtered and two clean orthogonal voltage signals will be get due to the resonance frequency of the SOGI at ω^*.

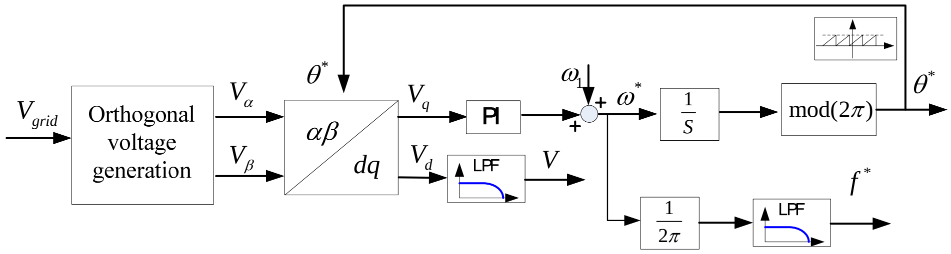


Figure 2. General structure of a single-phase grid-connected inverter PLL

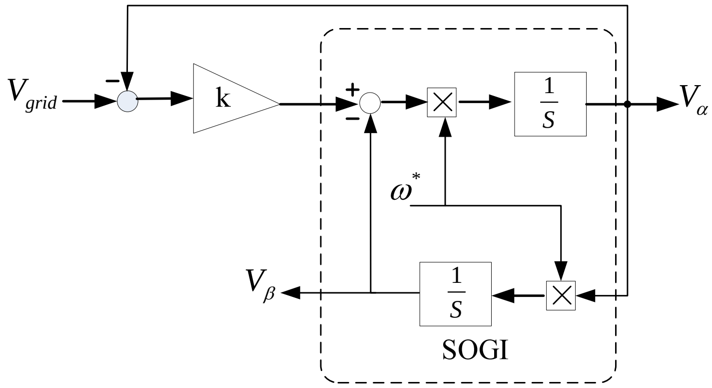


Figure 3. Structure of SOGI

4. Control scheme and experimental results

The control scheme for two string input in grid-connected PV system is shown in Fig.4. There are two stages. In two stages, the first is to used to boost or buck the PV array voltage and track the maximum power; the second stage allows the conversion of the power into high quality ac current. The common dc voltage of two Cuk circuits is the same. The MPPT is implemented by using current inner loop and voltage outer loop. In order to verify the previous analysis, some experiments have been carried out on a laboratory setup to test the performance of the PV system with the proposed MPPT. The hardware setup consists of the following equipment: programmable dc voltage source to simulate PV arrays, a PV inverter, and the digital processor (DSP), type TMS320F2808 is used to implemented the control scheme, including MPPT and grid-connected inverter control. The PV converter is connected to the grid through an *L* filter and *C* filter, whose values are 2mH and 10uF respectively, The two Cuk inverter inductances are the same value, which is 1.2mH and the Cuk inverter capacitor is 20uF. The Cuk circuit PWM frequency is set to 20kHz and the inverter circuit PWM frequency is set to 15kHz. For all laboratory tests, the nominal grid voltage is 230V, and the nominal grid frequency is 50Hz. The MPPT step size M is 4. A PV array emulator is necessary for the operational evaluation of system components. The dynamic of the PV array emulator is of particular importance in order to avoid any significant impact on the MPPT. The current and voltage relationship of the PV array are preloaded into a lookup table, and the programmable dc voltage source is iteratively converging to the solution. The power curve of PV array emulator for the PV string 1 is shown in Fig.5, and the power curve of PV array emulator for the PV string 2 is the same with the PV string 1. The open voltage of the PV string is set to 350V and the short current of the PV string is set to 6A.

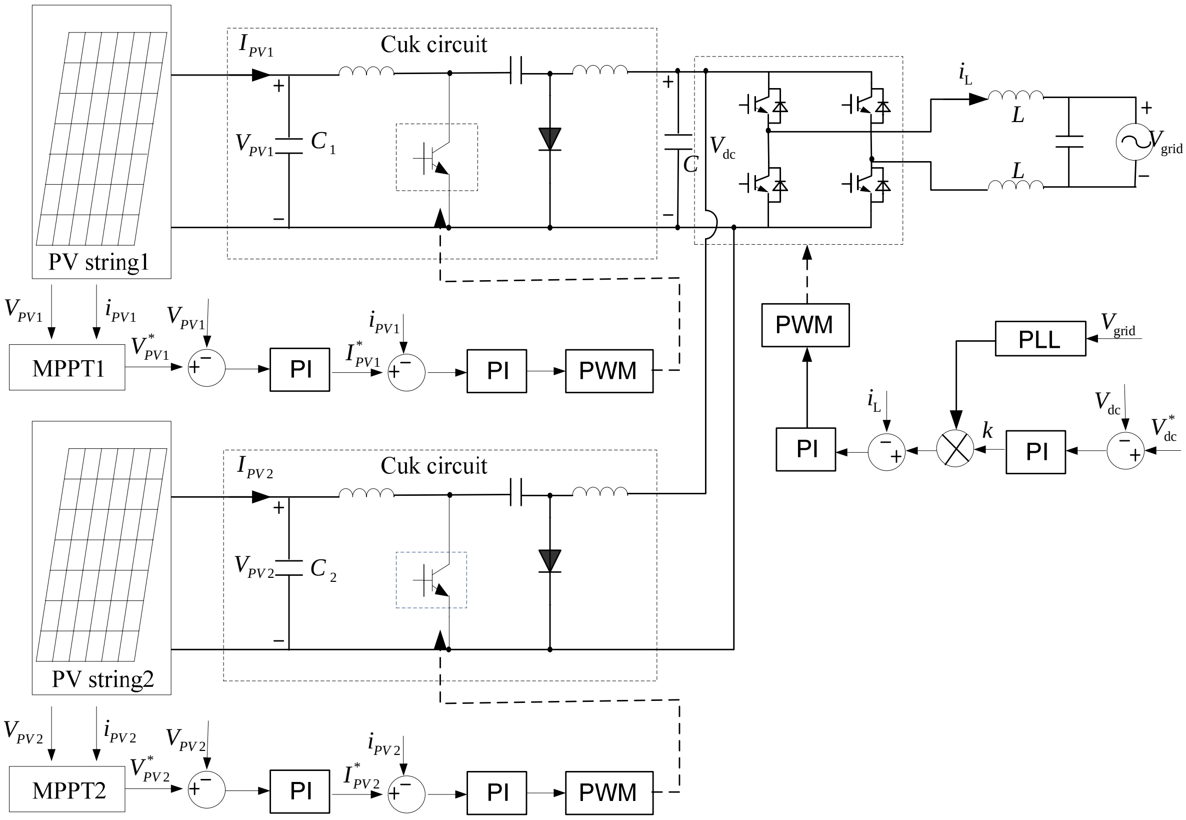


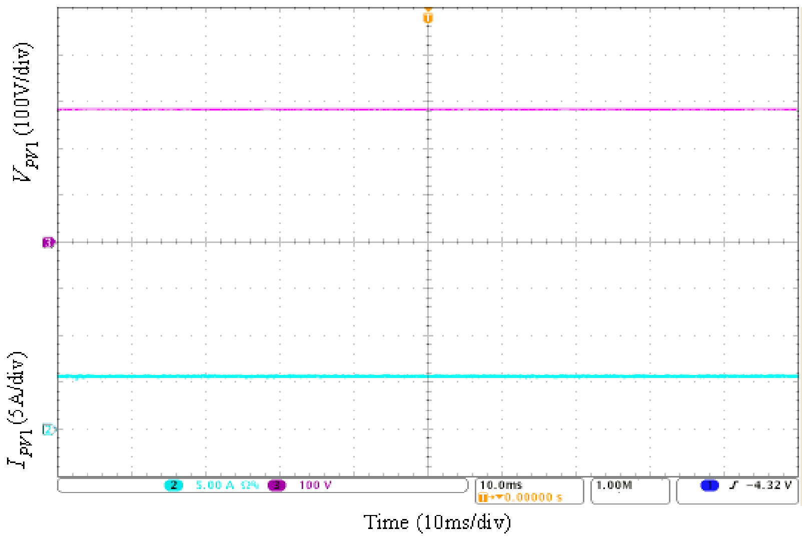
Fig. 4. The control scheme for two string input in grid-connected PV systems.

4.1 Steady-state experiment

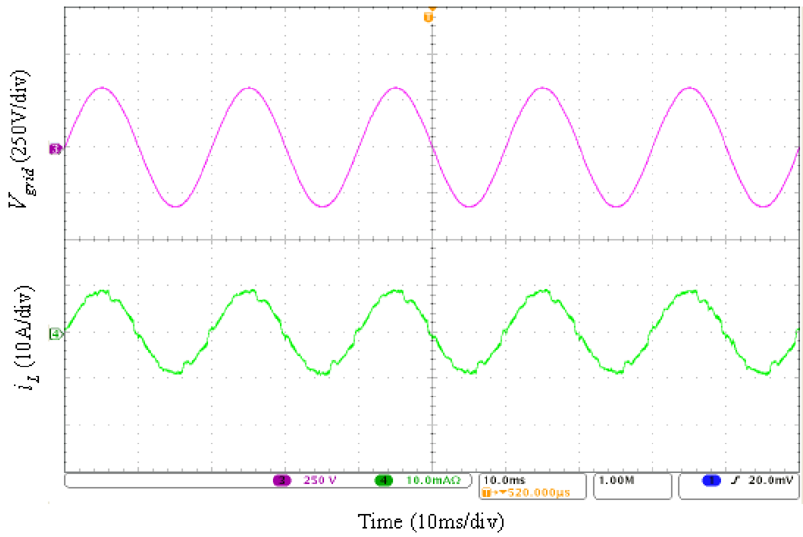
In the first study, the steady-state performance is investigated when the PV string 1 is on and the PV string 2 is off. The output power is about 1500W, the PV string 1 output voltage and output current are displayed in Fig.6(a) and the grid voltage and the output current are shown in Fig. 6(b). The grid voltage and the output current are shown in Fig.6 (c) when the PV string 1 and the PV string 2 are on at the same time, and the PV string 2 output voltage and output current are the same with Fig.6(a). From the Fig.6(a), it can be found that the output voltage is about 280V and the output current is about 5.5A, which realizes MPPT. From the Fig.6 (b) and the Fig.6 (c) show that the output current is well sinusoidal and the output current is phase with the grid voltagge, which achieves an almost unity power factor. From the steady-state experimental results, it shows that the steady-state performance of the systems is excellent.

4.2 Dynamic experiment

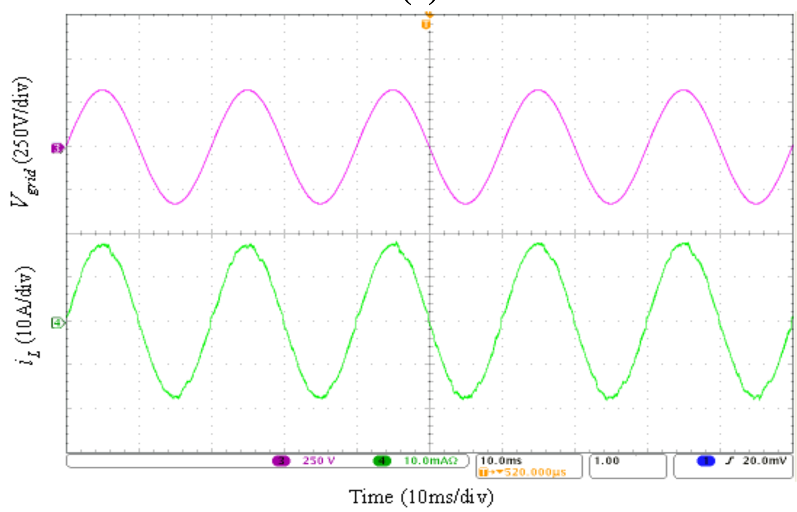
In another study, the transient performance for the grid-connected inverter is considered. Fig.7 (a) depicts the dynamic experimental waveforms of the grid voltage and the output current from the PV string 1 on to both of the PV strings on. Fig.7 (b) displays the dynamic experimental waveforms of the grid voltage and the output current from both of the PV strings on to the PV string 1 on. From the dynamic experimental results, it shows that the output current gets to the given current in less than 10 ms, while it undergoes very little variations during the transient.



(a)

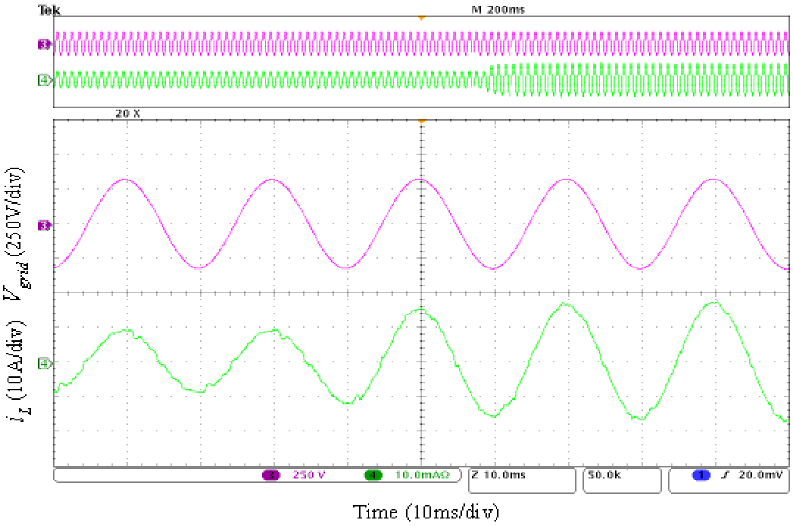


(b)

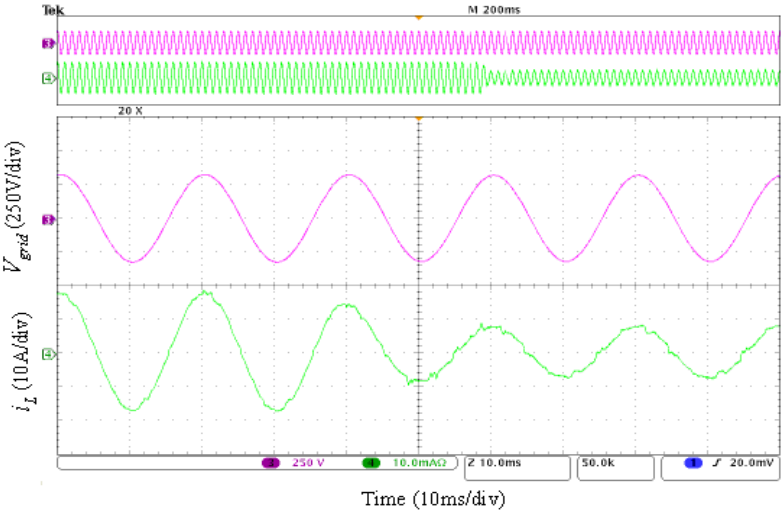


(c)

Fig.6 Steady-state experimental waveforms



(a)



(b)

Fig.7 Dynamic experimental waveforms

5. CONCLUSIONS

This paper has presented a single-phase multistring based Cuk converter topology for grid-connected photovoltaic inverters. The circuit topology, control algorithm has been analyzed. The configuration is suitable for PV application as the PV strings can operate independently and later expansion can be possible. The experimental results obtained on a 3-kW prototype show high steady-state and dynamic performance of the proposed technique. All of algorithms and controllers are implemented on a TMS320F2808 microcontroller.

References

[1] F. Blaabjerg, R. Teodorescu, M. Liserre, and A. V. Timbus, Overview of control and grid synchronization for distributed power generation systems, IEEE Trans. Ind. Electron., vol. 53, no. 5, pp. 1398–1409, Oct 2006.

[2] J. R. Rodriguez, J. W .Dixon, J. R. Espinoza, and J. Pontt, P. Lezana, PWM regenerative rectifiers: state of the art, IEEE Trans. Industrial Electronics, vol. 52, No. 1, pp. 5-22, February 2005.

[3] J. Balaguer, L. Qin, Y. Shuitao, U. Supatti, and P. F. Zheng, Control for grid-connected and intentional islanding operations of distributed power generation, IEEE Trans. Ind. Electron., vol. 58, no. 1, pp. 147–157,Jan. 2011.

[4] J. T. Bialasiewicz, Renewable energy systems with photovoltaic power generators: Operation and modeling, IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2752–2758, Jul. 2008.

[5] H. Patel and V. Agarwal, Maximum power point tracking scheme for PV systems operating under partially shaded conditions, IEEE Trans. Ind. Electron., vol. 55, no. 4, pp. 1689–1698, Apr. 2008.

[6] J.M. Kwon, B.H. Kwon, and K.H. Nam, Three-phase photovoltaic system with three-level boosting MPPT control, IEEE Trans. Power Electron., vol. 23, no. 5, pp. 2319–2327, Sep. 2008.

[7] S. Jain andV.Agarwal, A new algorithm for rapid tracking of approximate maximum power point in photovoltaic systems, IEEE Power Electron Lett., vol. 2, no. 1, pp. 16–19, Mar. 2004.

[8] E. Koutroulis, K. Kalaitzakis, and N. C. Voulgaris, Development of a microcontroller-based, photovoltaic maximum power point tracking control system, IEEE Trans. Power Electron., vol. 16, no. 1, pp. 46–54, Jan.2001.

[9] N. Femia, G. Petrone, G. Spagnuolo, and M. Vitelli, Optimization of perturb and observe maximum power point tracking method, IEEE Trans. Power Electron., vol. 20, no. 4, pp. 963–973, Jul. 2005.

[10] M.G. Villalva, J. R. Gazoli, and E. R. Filho, Comprehensive approach to modeling and simulation of photovoltaic arrays, IEEE Trans. Power Electron., vol. 24, no. 5, pp. 1198–1208, Mar. 2009.

[11] P. Rodriguez, J. Pou, J. Bergas, J. I. Candela, R. P. Burgos, and D. Boroyevich, Decoupled double synchronous reference frame PLL for power converters control, IEEE Trans. Power Electron., vol. 22, no. 2, pp. 584–592, Mar. 2007.

[12] M. Ciobotaru, V. Agelidis, R. Teodorescu, and F. Blaabjerg, Accurateand less-disturbing active antiislanding method based on PLL for grid-connected converters, IEEE Trans. Power Electron., vol. 25, no. 6,pp. 1576–1584, Jun. 2010.