International Journal for Modern Trends in Science and Technology
Volume: 03, Issue No: 05, May 2017
ISSN: 2455-3778
http://www.ijmtst.com

Design and Analysis of 3 Phase Modular Cascaded HBM Inverter with Individual MPPT for Grid - Connected PV Systems.

S.Anurekha[1] | M.Nandhini[2]

[1] PG Scholar, Department of EEE, Vivekanandha College of Engineering for Women, Tiruchengode, India.
[2] PG Scholar, Department of EEE, Vivekanandha College of Engineering for Women, Tiruchengode, India.

To Cite this Article
S.Anurekha and M.Nandhini, "Design and Analysis of 3 Phase Modular Cascaded HBM Inverter with Individual MPPT for Grid - Connected PV Systems", International Journal for Modern Trends in Science and Technology, Vol. 03, Issue 05, May 2017, pp. 317-323.

ABSTRACT

A three-phase modular cascaded HBM (H-bridge multilevel inverter) for a grid-connected photovoltaic (PV) system is presented in this paper. To maximize the solar energy extraction from the PV panel, an individual maximum power point tracking (MPPT) control scheme is applied, which allows the independent control of each dc-link voltage. PV mismatches may introduce unbalanced power supplied to the three-phase system. To solve this problem, a control scheme with modulation compensation is proposed. The three-phase modular cascaded multilevel inverter prototype has been built. Each H-bridge is connected to a 185 W solar panel. Simulation and experimental results are presented to validate the proposed ideas.

I. INTRODUCTION

Due to shortage of fossil fuels and environmental problems caused by conventional power generation, renewable energy, especially solar energy, has become very popular and demanding. Photovoltaic (PV) systems offer the advantages of being pollution free, emitting no noise and little maintenance, and they are ideally distributed generation units. Solar-electric-energy demand has grown consistently by 20%-25% per annum over the past 20 years [1], and the growth is mostly in grid-connected applications. Utilities are adapting to solar as their fastest growing electricity source. In 2011, utilities in the U.S. interconnected over 62,500 PV systems, and conservative forecasts indicate that this number will grow to more than 150,000 interconnections in 2015 [2].

To convert DC power from the solar panels into AC power to be fed into the grid, an inverter is a necessary and important element in the grid-connected PV system. Many different types of PV inverters have been proposed and studied [3-6]. The cascaded H-bridge multilevel inverter requires an isolated DC source for each H-bridge; thus, the high power and/or high voltage from the combination of the multiple modules would favor this topology in medium and large grid-connected PV systems [7-10]. In addition, the separate DC links in the multilevel inverter make independent voltage control possible. As a result, individual maximum power point tracking (MPPT) control in each string can be achieved, and the energy harvested from PV panels can be maximized. Meanwhile, the modularity and low cost of multilevel converters would position them as a prime candidate for the next generation of efficient, robust, and reliable grid-connected solar power electronics.

A three-phase cascaded H-bridge multilevel inverter topology for a grid-connected PV system is presented in this paper. The panel mismatch issues are addressed to show the necessity of individual MPPT control, and a control scheme with independent MPPT control in each string is then proposed.

If each string is operated at its own maximum power point, PV mismatches would introduce unbalanced power supplied to the three-phase grid-connected H-bridge multilevel inverter. To balance the three-phase grid current, modulation compensation is also added to the control system.

A three-phase modular cascaded multilevel inverter prototype has been built. Each H-bridge is connected to a 185W solar panel. The modular design will increase the flexibility of the system, and reduce the cost as well. Simulation and experimental results are provided to demonstrate the developed control scheme.

II. SYSTEM DESCRIPTION

The three-phase modular cascaded H-bridge multilevel inverter for grid-connected PV system is shown in Fig. 1. Each phase consists of *n*H-bridge converters connected in series, and the DC link of each H-bridge is fed by a short string of PV panels. The cascaded multilevel inverter is connected to the grid through *L* filters, which are used to reduce the switching harmonics in the current.

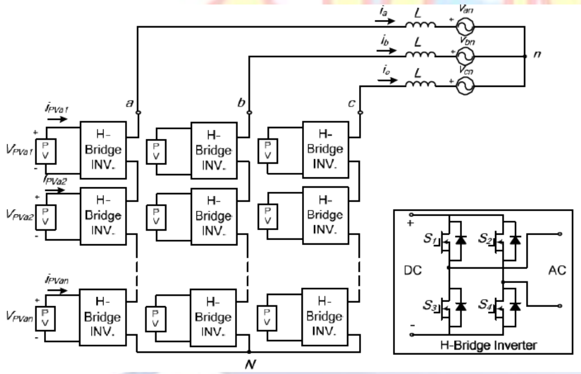

Fig. 1.Topology for the three-phase grid-connected system.

By different combinations of the four switches in each H- bridge module, three output voltage levels can be generated,

$-vdc$, 0, or $+vdc$. A cascaded multilevel inverter with n input

195 W and 114.6 W respectively when S = 1000 W/m2 and 600 W/m2, which means the total power harvested from the sources will provide *2n+1* levels to synthesize the AC output

Power (W) waveform. This *(2n+1)*-level voltage waveform enables the reduction of harmonics in the synthesized current, reducing the output filters. Multilevel inverters also have other advantages such as reduced voltage stresses on the semiconductor switches, as well as having higher efficiency when compared to other converter topologies [11].

III. PANEL MISMATCHES

PV mismatch is an important issue in the PV system. Due to the unequal received irradiance, different temperature and aging of the PV panels, the maximum power points (MPPs) of each PV string may be different. If each string is not controlled independently, the efficiency of the overall PV system will be decreased.

To show the necessity of individual MPPT control, a 5- level two H-bridges single-phase inverter is simulated in MATLAB/SIMULINK. Each H-bridge has its own 195 W PV panel connected as an isolated DC source. The PV panel is modeled according to the specification of the commercial PV panel from Sanyo, HIP-195BA19.

Consider an operating condition that each panel has a different irradiation from the sun; panel 1 has irradiance S =1000 W/m2, and panel 2 has S = 600 W/m2. If only panel 1is tracked and its MPPT controller determines the voltagereference for the two panels, the power extracted from panel 1 would be around 147 W, and the power from panel 2would be 60 W, as seen in Fig. 2. Without individual MPPT However, Fig. 3 shows the MPPs of the PV panels under the different irradiance. The maximum output power will be195 W and 114.6 W respectively when S = 1000 W/m2 and 600 W/m2,which means the total power harvested from the

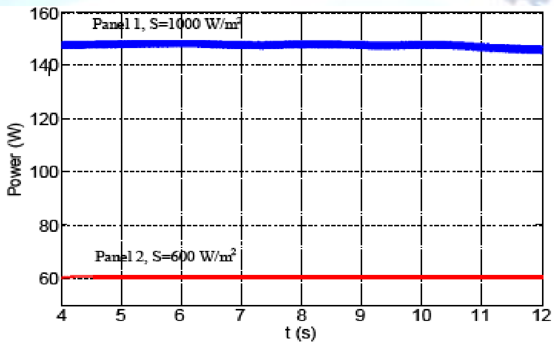

Fig. 2. Power extracted from two PV panels.

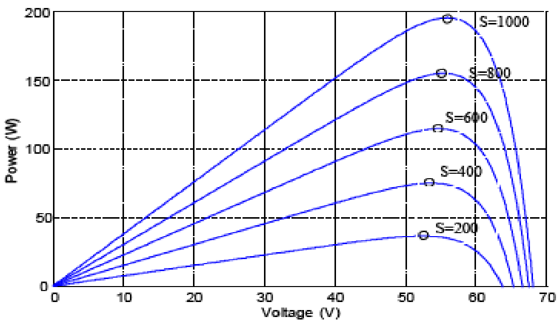

Fig. 3. *P-V* characteristic under the different irradiance.

In a three-phase grid-connected PV system, PV mismatch may cause more problems. Besides decreasing the overall efficiency, this could even introduce unbalanced power supplied to the three-phase grid-connected system. If there are PV mismatches between phases, the input power of each phase would be different. Since the grid voltage is balanced, the different input power will cause imbalanced current to the grid, which is harmful to the grid and not allowed by power quality standards, like IEEE 1547 in the U.S. and IEC 61727 in Europe.

To solve the PV mismatch issue, a control scheme with individual MPPT control and modulation compensation is proposed, as shown in Fig. 4. The details of the control scheme will be discussed in the next section.

IV. CONTROL SCHEME

A. Individual MPPT Control

In order to eliminate the adverse effect of the mismatches and increase the efficiency of the PV system, the PV strings need to operate at different voltages to maximize the energy harvested from each string.

The separate DC links in the cascaded H-bridge multilevel inverter make independent voltage control possible. To realize individual MPPT control in each string, the control scheme proposed in [12, 13] is updated for this application.

The individual MPPT control of the cascaded H-bridge inverter in phase *a* is shown in Fig. 4. In each H-bridge string, an MPPT controller is added to generate the dc-link voltage reference. Each dc-link voltage is compared to the corresponding voltage reference, and the sum of all the

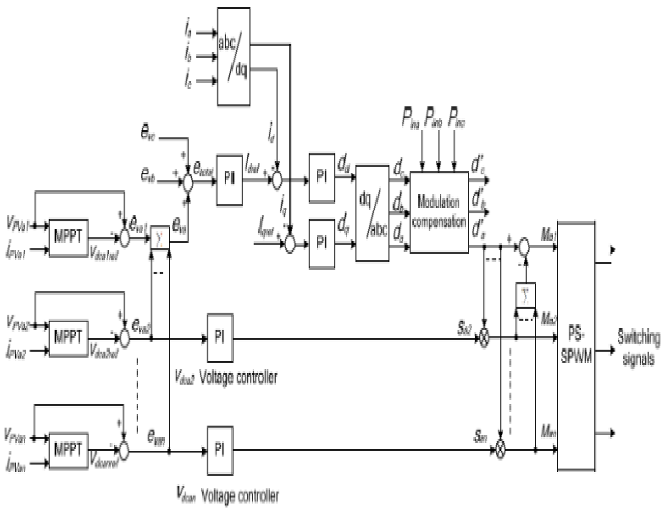

Fig. 4. Control scheme for three-phase modular cascaded H-bridge multilevel PV inverter.

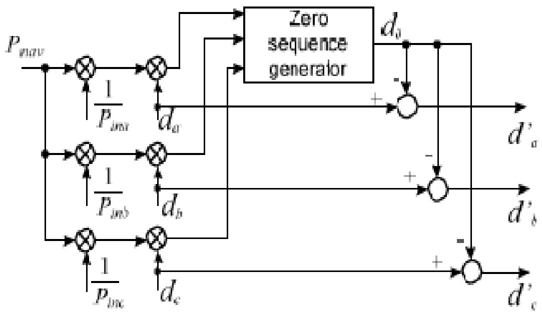

Fig. 5.Modulation compensation scheme.

Therefore, a modulation compensation scheme is applied, as shown in Fig. 5. First, the unbalanced power is weighted by ratio *ri*, which is calculated as

Results

Simulation and experimental tests are carried out to validate the proposed ideas. A modular cascaded multilevel inverter prototype has been built in the laboratory, as shown in Fig. 7. The modular design will increase the flexibility of the system, and reduce the cost as well. The MOSFET IRFSL4127 is selected as inverter switches operating at 1.5 kHz. The control signals to the H-bridge inverters are sent by a dSPACE ds1103 controller. A three-phase 7-level cascaded H-bridge inverter is

$$P\,r = inav (1)$$

simulated and tested. Each H-bridge has its own 185 W PV *Pini* where*Pini*is the input power of phase *i*(*i*=*a, b, c*), and *Pinav*is the average input power. The injected zero sequence modulation index can be generated as d0=1/2[min(ra.da, rb.db ,rc.dc)+max(ra.da, rb.db ,rc.dc)] (2) panel (Astronergy CHSM-5612M) connected as an independent source. The inverter is connected to the grid through a transformer, and the phase voltage of the secondary side is 60 VRMS. The system parameters are shown in Table I.

To verify the proposed control scheme, the three-phase grid- connected PV inverter is operated in two different conditions. first all PV panels are operated under the same Irradiance S=1000 W/m2 and temperature T=25°C.At t=0.8s,the solar irradiance on the first and second panels of phase a decreases to W/m2 and that for the other panels stays the same. The dc-link voltage of phase a are shown fig.8, At the beginning, all PV panels are operated at the where*di*is the modulation index of phase *i*(*i*=*a, b, c*), and determined by the current loop controller.

Then, the modulation index of each phase is updated by

$d' = d - d$ (3)

A simple example is presented to show the modulation compensation scheme more clearly. Assume the input power of each phase is unequal,

$Pina = 0.8$,

$Pinb = 1$,

$Pinc = 1$ (4)

By injecting a zero sequence modulation index at t = 1 s, the balanced modulation index will be updated, as shown in Fig. 6. It can be seen that with the compensation, the updated modulation index is unbalanced proportional to the power, which means the output voltage (*viN*) of the three-phase inverter is unbalanced and finally results in a balanced grid current.

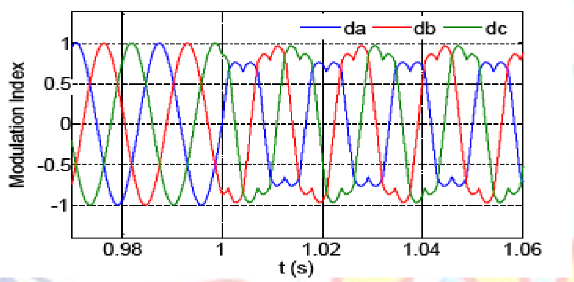

Fig. 6.Modulation index.

V. RESULTS

Simulation and experimental tests are carried out to validate the proposed ideas. A modular cascaded multilevel inverter prototype has been built in the laboratory, as shown in Fig. 7. The modular design will increase the flexibility of the system, and reduce the cost as well. The MOSFET IRFSL4127 is selected as inverter switches operating at 1.5 kHz. The control signals to the H-bridge inverters are sent by a dSPACE ds1103 controller.

To verify the proposed control scheme, the three-phase grid- connected PV inverter is operated in two different conditions. first all PV panels are operated under the same Irradiance S=1000 W/m2 and temperature T=25°C.At t=0.8s,the solar irradiance on the first and second panels of phase a decreases to W/m2 and that for the other panels stays the same. The dc-link voltage of phase a are shown fig.8, At the beginning, all PV panels are operated at the

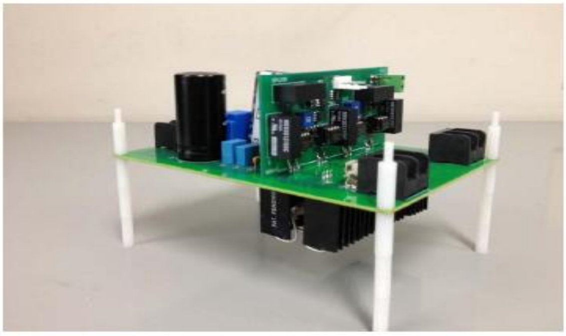

Fig. 7. H-bridge module prototype.

TABLE I SYSTEM PARAMETERS

Parameters	Value
DC-link capacitor	3600 µF
Connection inductor *L*	2 mH
Grid rated phase voltage	60 VRMS
Switching frequency	1.5 kHz

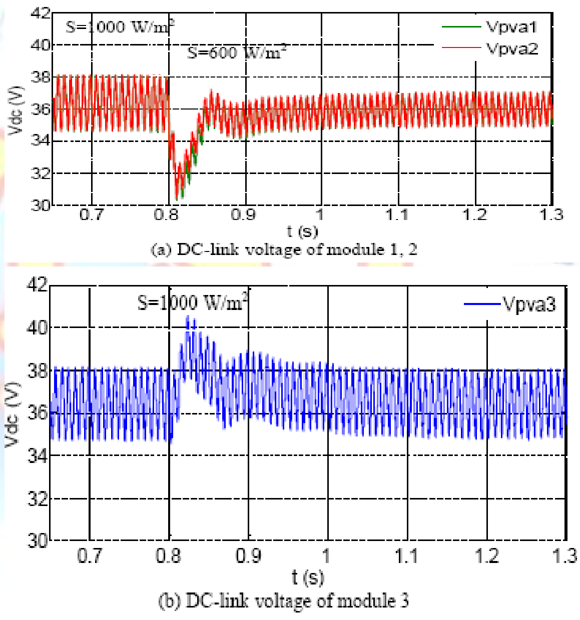

Fig. 8. DC-link voltages of phase *a* (T=25 °C).

MPP voltage 36.4 V. As the irradiance changes, the first and second dc-link voltages decrease and track the new MPP voltage 36 V, while the third panel is still operated at 36.4 V. The PV current waveforms of phase *a*are shown in Fig. 9. It can be seen that the lower irradiation affects the current in 555 W. After t = 0.8 s, the power harvested from phase *a* decreases to 400 W, and those from other phases stay the same. It can be seen clearly that the power supplied to the three-phase grid-connected inverter is unbalanced. However, with the modulation compensation, the three-phase current is balanced in less than two cycles, as shown in Fig. 12.

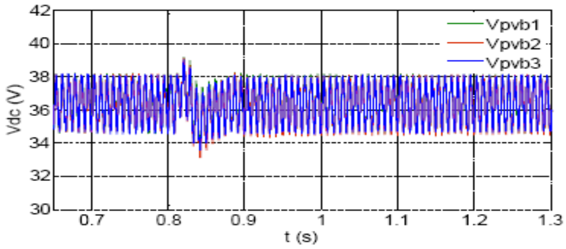

Fig. 10. DC-link voltages of phase *b* (T=25 °C).

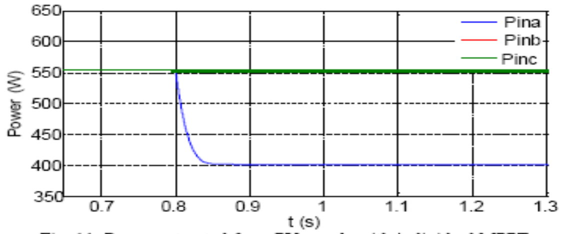

Fig. 11. Power extracted from PV panels with individual MPPT.

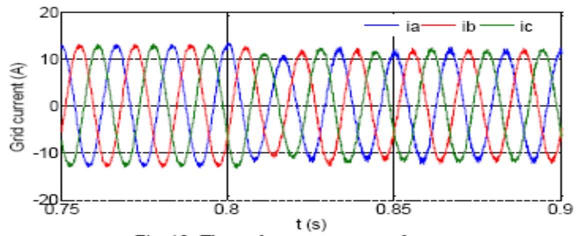

Fig. 12. There-phase current waveforms.

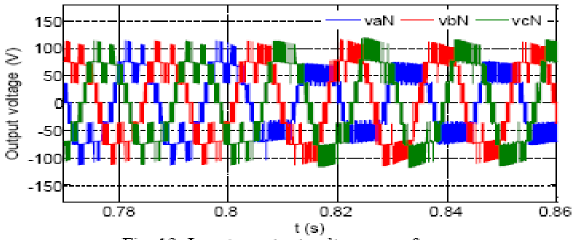

Fig. 13. Inverter output voltage waveforms.

the first and second PV panels, so the lower ripple of the dc-link voltage can be found in Fig. 8(a).

The dc-link voltages of phase *b* are shown in Fig. 10. All phase *b* panels track the MPP voltage 36.4 V, which shows that they are not influenced by other phases. With the individual MPPT control, the dc-link voltage of each H- bridge can be controlled independently. The efficiency of the overall PV system can be increased.

Fig. 11 shows the power extracted from each phase. At the beginning, all panels are operated under irradiance S = 1000 W/m2, and every phase is generating maximum power

Fig. 13 shows the output voltages (*viN*) of the three-phase inverter. Due to the injected zero sequence component, they are unbalanced after t= 0.8s, which help to balance the grid current.

A three-phase 7-level cascaded H-bridge inverter has been built by 9 H-bridge modules in the laboratory. Fig. 14 shows the experimental solar panels and the three-phase cascaded multilevel inverter. As mentioned above, the DC link of each H-bridge module is fed by one PV panel Astronergy CHSM-5612M.

The experimental results are presented in Figs. 15-18. Fig. 15 shows three dc-link voltages of phase *a*. It can be seen that each dc-link voltage is controlled independently, which means individual MPPT can be achieved. The inverter output voltage waveforms are presented in Fig. 16. With the modulation compensation, a zero sequence voltage is imposed upon the phase legs. The inverter output voltage (*viN*) is unbalanced proportional to the supplied power of each phase, which helps to balance the three-phase grid current. As shown in Fig. 17, even PV mismatch happens and the supplied PV power to the three-phase system is unbalanced, the three-phase grid current is still balanced.


(a) Solar panels Astronergy CHSM-5612M

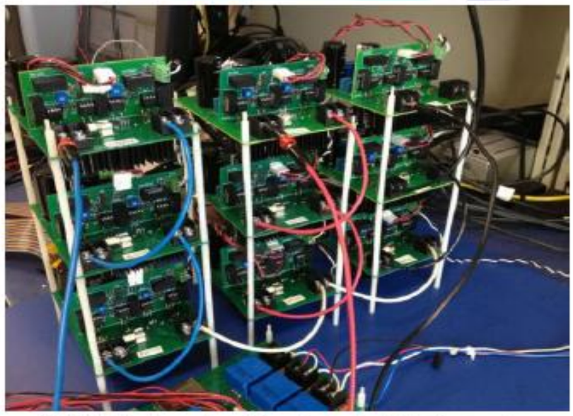
(b) Modular three-phase 7-level cascaded H-bridge inverter
Fig. 14. Experimental prototype.

Fig. 18 shows the grid voltage and current waveforms of phase *a*. It can be seen that the grid current has the same phase as the grid voltage and has unity displacement power factor. The THD of the grid current is 4.6%, as shown in Fig. 19, which is less than 5% and meets power quality standards, like IEEE 1547 in the U.S. and IEC 61727 in Europe.

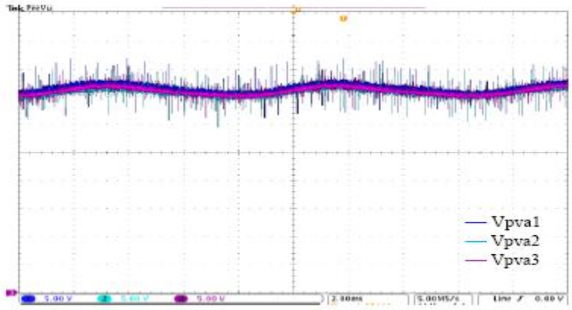

Fig. 15. DC-link voltages of phase *a*.

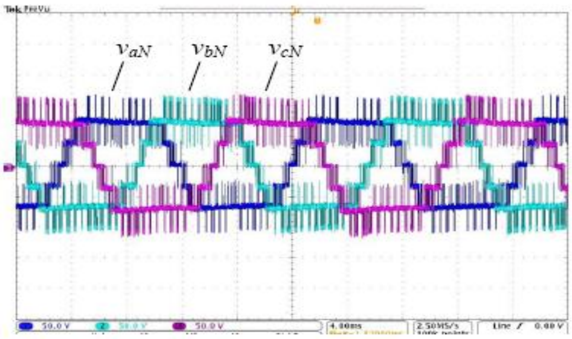

Fig. 16. Inverter output voltage waveforms with modulation compensation.

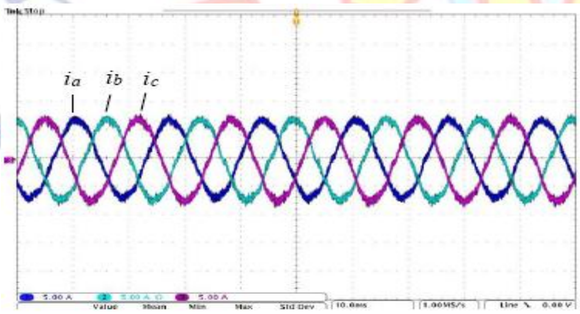

Fig. 17. Experimental grid currents with unbalanced PV power.

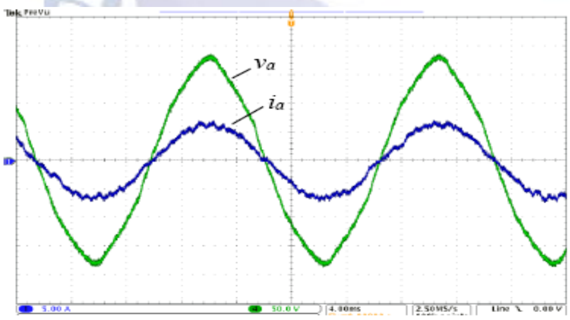

Fig. 18. Grid voltage and current waveforms of phase *a*.

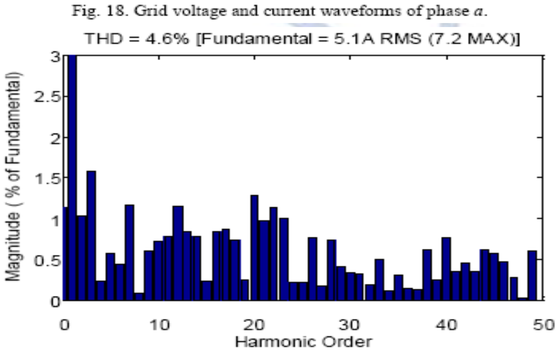

Fig. 19. THD of the grid current.

VI. CONCLUSIONS

In this paper, a control scheme of the three-phase modular cascaded H-bridge multilevel inverter for a grid- connected PV system has been presented. Individual MPPT control is realized to maximize the solar energy extraction of each PV string and improve the efficiency of the PV system. The imbalance issue introduced by PV mismatches is solved by the modulation compensation. Simulation and experimental results confirmed the proposed ideas.

REFERENCES

[1] J. M. Carrasco, L. G. Franquelo, J. T. Bialasiewicz, E. Galvan, R. C. PortilloGuisado, M. A. M. Prats, J. I. Leon, and N.Moreno-Alfonso, ―Power-electronic systems for the grid integration of renewable energy sources: A survey,‖ *IEEE Trans. Ind. Electron.*, vol. 53, no. 4, pp. 1002–1016, Aug. 2006.

[2] 2011 SEPA Utility Solar Rankings [Online]. Available: www.solarelectricpower.org

[3] S. B. Kjaer, J. K. Pedersen, and F. Blaabjerg, ―A review of single- phase grid connected inverters for photovoltaic modules,‖ *IEEE Trans. Ind. Appl.*, vol. 41, no. 5, pp. 1292–1306, Sep./Oct. 2005.

[4] J. M. A. Myrzik and M. Calais, ―String and module integrated inverters for single-phase grid connected photovoltaic systems—A review,‖ in *Proc. IEEE Bologna Power Tech Conf.*, 2003, vol. 2, p. 8.

[5] S. Daher, J. Schmid, and F. L.M. Antunes, ―Multilevel inverter topologies for stand-alone PV systems,‖ *IEEE Trans. Ind. Electron.*, vol. 55, no. 7, pp. 2703--2712, Jul. 2008.

[6] R. Mechouma, B. Azoui, and M. Chaabane, "Three-phase grid connected inverter for photovoltaic systems, a review," *Renewable Energies and Vehicular Technology (REVET), 2012 First International Conference*, Mar. 2012, pp. 37-42.

[7] L. M. Tolbert, F. Z. Peng, ―Multilevel converters as a utility interface for renewable energy systems,‖ *IEEE Power Engineering Society Summer Meeting*, Seattle, Washington, Jul. 2000, pp. 1271-1274.

[8] H. Ertl, J. Kolar, and F. Zach, ―A novel multicell DC-AC converter for applications in renewable energy systems,‖ *IEEE Trans. Ind. Electron.*, vol. 49, no. 5, pp. 1048-1057, Oct. 2002.

[9] F. Filho, Y. Cao, and L. M. Tolbert, ―11-level cascaded H-bridge grid-tied inverter interface with solar panels,‖ in *IEEE Proc. Applied Power Electronics Conference and Exposition (APEC)*, Feb. 2010, pp. 968-972.

[10] C. D. Townsend, T. J. Summers, and R. E. Betz, ―Control and modulation scheme for a cascaded H-bridge multi-level converter in large scale photovoltaic systems,‖ in *IEEE Proc. Energy Conversion* Fig. 19. THD of the grid current. *Congress and Exposition (ECCE)*, Sept. 2012, pp. 3707 – 3714.

[11] J. Rodriguez, J. S. Lai, and F. Z. Peng, ―Multilevel inverters: A survey of topologies, controls, and applications,‖ *IEEE Trans. Ind. Electron.*, vol. 49, no. 4, pp. 724-738, Aug. 2002.

[12] A. Dell'Aquila, M. Liserre, V. Monopoli, and P. Rotondo, ―Overview of pi-based solutions for the control of DC buses of a single-phase H- bridge multilevel active rectifier,‖ *IEEE Trans. Ind. Appl.*, vol. 44, no. 3, pp. 857-866, May/Jun. 2008.

[13] B. Xiao, K. Shen, J. Mei, F. Filho, and L. M. Tolbert, ―Control of cascaded H-bridge multilevel inverter with individual MPPT for grid- connected photovoltaic generators,‖ in *IEEE Proc. Energy Conversion Congress and Exposition (ECCE)*, Sept. 2012, pp. 3715 – 3721.

[14] Y. Xu, L. M. Tolbert, J. N. Chiasson, F. Z. Peng, and J. B. Campbell, ―Generalized instantaneous nonactive power theory for STATCOM,‖ *IET Electric Power Applications*, vol. 1, no. 6, Nov. 2007, pp. 853-861.

[15] T. Esram and P. L. Chapman, ―Comparison of photovoltaic array maximum power point tracking techniques,‖ *IEEE Trans. Energy Convers.*, vol. 22, no. 2, pp. 439-449, Jun. 2007.

[16] D. P. Hohm, and M. E. Ropp, ―Comparative study of maximum power point tracking algorithms,‖*Prog. Photovolt.: Res. Appl.*, vol. 11, no. 1, pp. 47-62, Jan. 2003.

[17] S. Rivera, S. Kouro, B. Wu, J. I. Leon, J. Rodriguez, and L. G. Franquelo, ―Cascaded H-bridge multilevel converter multistring topology for large scale photovoltaic systems,‖ in *IEEE International Symposium on Industrial Electronics (ISIE),* Jun. 2011, pp. 1837 – 1844.

[18] T. J. Summers, R. E. Betz, and G. Mirzaeva, ―Phase leg voltage balancing of a cascaded H-bridge converter based STATCOM using zero sequence injection,‖*European Conference on Power Electronics and Applications*, Sept. 2009, pp. 1-10