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Research Article

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A Control Scheme of a Multilevel Inverter for Integration of Solar Energy Systems in Coordination to the Utility Grid

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Abstract In this paper to improve the grid performance, a 3-Ø, 7-level inverter is used with solar energy system (SES) in coordination to the utility grid which undergoes to the power problems. In this paper the active and reactive power compensation will be done at the grid side. In the event of voltage sag condition, continuity of power supply has to be there to the grid. A DC/DC converter is used; this integrates a DC-DC boost converter and a transformer to convert the output voltage of the SES into two independent voltage sources. A new 7-level inverter is configured using a capacitor with a 3-Ø full-bridge power converter, connected in cascade. The inverter is controlled such that it provides 3-Ø balanced voltage condition in all phases by injecting reactive power. The simulation results presented to validate the performance of proposed converter using MATLAB/SIMULINK software.

Keywords Solar Energy System, Multi-level inverter, Active and Reactive power compensation

Introduction

The widespread use of fossil fuels has led to global greenhouse gas emissions. In addition, they will become more and more expensive as the future supply of fossil fuels is depleted. Hence, the solar energy is gaining importance with latest environment conditions and residential usage due to rise and decrease of fossil fuel energy cost and solar array cost respectively [1-2]. The energy conversion interface is important for solar power systems connected to the grid because it converts the direct current generated by the solar cells into alternating current and feeds it into the grid [3-8]. A power conversion interface is needed to convert dc power to ac power. Also as the solar output is low, a dc to dc converter is required to match the dc bus voltage of the inverter by increasing the output voltage of small capacity generating systems [6-8]. The energy conversion efficiency of the energy conversion interface is important to ensure that the energy generated by the solar cell system is not wasted. Active and passive components in the inverter can cause power loss.

Power losses due to active devices include conductivity losses and switching losses. The loss of conductivity is caused by the use of active devices, and the switching losses are proportional to the voltage and current variations of each switch and switching frequency. The filter inductor [8] is used to process the switching harmonics of the inverter, making the power loss proportional to the amount of switching harmonics. The voltage in each switching operation for the multilevel inverter is varied to increase the efficiency of the power conversion and the switching voltage of the active device. The number of switching harmonics is also attenuated, so the power loss caused by the filter inductor is also reduced. Therefore, multi-level inverter technology [9-15] has been widely used now-a-days. For single-phase seven-level inverters, twelve power electronic switches are required in a topology with diode terminations and a topology of flying capacitors [10]. Cascaded H-bridge multi-level inverters use asymmetric voltage technology to allow multiple stages of output voltage, so cascaded H-bridge multilevel inverters are suitable for applications with higher voltage levels. For photovoltaic systems, a single-phase inverter connected to the grid was developed. This seven-stage inverter with grid contains six power electronic switches. However, three DC capacitors are used to build three voltage levels, resulting in a more complex capacitor balance.

In this paper, a new solar energy system (SES) in coordination to the utility grid is presented. The proposed solar system includes a DC converter and a 7-level converter. The 7-level inverter comprises of a cascaded capacitor selection circuit with 6- power electronic switches and a full-bridge converter to make circuit simple. At any time of switching, one power electronic switch is ON to the high frequency to have a 7-level output voltage. Hence, the switching power loss is low and energy efficiency is high. Due to the seven output voltages, the inductance of the filter inductor is also reduced.

Presented Circuit Analysis

Figure-1 below shows the configuration of the proposed solar power system. The presented system have 7-level inverter comprises of a cascaded capacitor selection circuit with 6- power electronic switches and a full-bridge converter to make circuit simple. The solar array is interfaced to the DC-DC converter acting as a gain converter that includes a 2:1 ratio transformer. The DC-DC converter converts the output of the solar system into two independent multi-relational voltages to power the 7-level inverter, consisting of a capacitor selection circuit and a full-bridge converter connected in cascade.

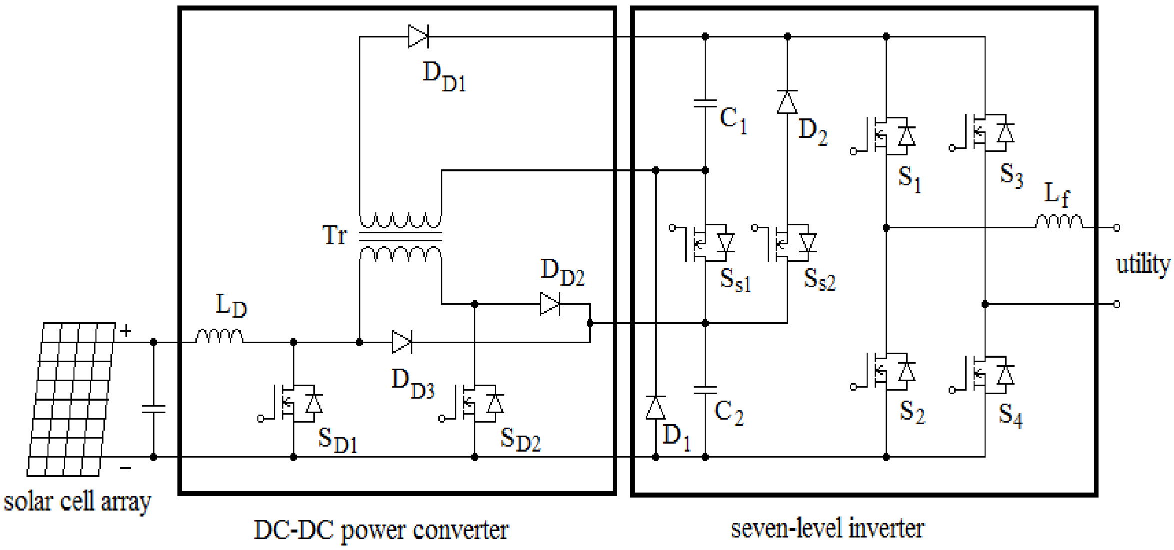

Figure 1: Line diagram of the proposed solar power generation system

The power electronic capacitor switch circuit determines discharge of the both capacitors individually or in series. Due to the various relationships between the DC capacitor voltages, the capacitor selection circuit output is 3-level DC voltage. The full bridge converter again converts the three stage DC voltage to a 7-level AC voltage in coordination with the utility common voltages. In this manner, the proposed solar energy system produces a sinusoidal output current that is inphase with the utility common voltages and is fed into the utility that produces a power factor with uniform power. It can be seen that this new 7-level inverter contains only six power electronic switches, thus simplifying the power supply circuit.

Operation of DC-DC Power Converter:

As shown in Figure-1, the DC-DC converter includes a gain converter and a forward power converter. The gain converter consists of an inductor, L_D, power electronic switch, S_{D1} and diode D_{D3}. The power converter charges the capacitor C_2 of the 7-level inverter. The current supplied power converter consists of an inductor, L_D, power electronic switch, S_{D1} and S_{D2}, a transformer and diodes D_{D1} and D_{D2}. The current supplied power converter charges the C_1 of the 7-level inverter. In addition, the inductor of the current supply power converter, L_D and the power electronic switch S_{D1} are also used in the gain converter. Below Figure 2(a) shows the operating circuit of the DC voltage converter when S_{D1} is turned On. The solar array is powered by the inductor L_D. When S_{D1} is turned OFF and S_{D2} is turned ON, its operation circuit is as shown in Figure 2(b) below.

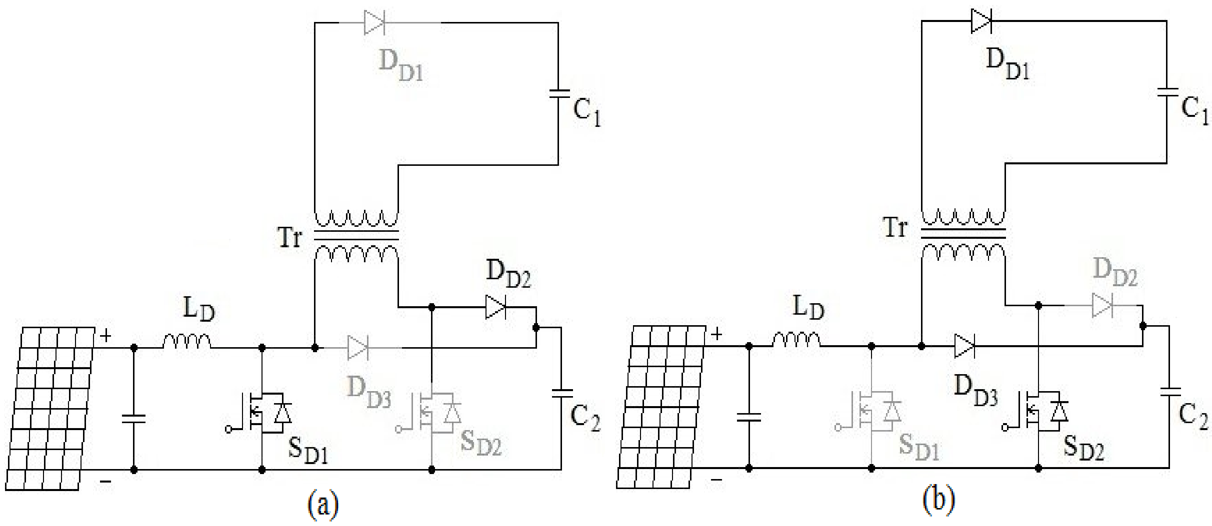

Figure 2: Operation of DC-DC power converter (a) S_{D1} is ON (b) S_{D1} is OFF

Therefore, the capacitor C_1 is connected in parallel to the capacitor C_2 via the transformer such that the energy of the inductor L_D and the charging capacitor C_2 by the solar array through DD_3, and charge capacitor C_1 through the transformer and D_{D1} during the off state S_{D1}. Since the capacitors C_1 and C_2 are charged in parallel using a transformer, the voltage ratios of the capacitors C_1 and C_2 are the same as the transformer ratio (2:1). Therefore, the voltages of C_1 and C_2 have various relationships. The power inverter operates in continuous conduction (CCM) mode. The voltages of capacitors C_1 and C_2 can be represented as:

$$Vc1 = \frac{1}{2(1-D)} * Vs \quad (1)$$

$$Vc2 = \frac{1}{1-D} * Vs \quad (2)$$

Where V_S is the output voltage of solar array and D is the duty ratio of S_{D1}.

In the presented DC-DC power converter, when SD2 is OFF, the energy stored in the magnetic induction is connected to the C2 capacitor via DD2 and SD1. Since the energy stored in the magnetic induction passes to the output condenser C2 instead of the direct current source, the energy efficiency is improved. In addition, since the charging circuits of capacitors C1 and C2 are compact, the power circuit is simplified. Capacitors C1 and C2 are charged in parallel with the transmitter so that their voltages automatically have multiple bonds, hence the circuit is simplified.

The 7-Level Inverter

The seven-stage inveter consists of a condenser selection circuit and a full bridge power adapter that are connected in sequence. The operation of the seven-stage reflector can be divided into semi-positive and semi-cyclic instruments.

For ease of analysis, the electronic switch and the electronic diode are assumed to be ideal, and the capacitors C_1 and C_2 in the constant capacity selection circuit are ideal and equal to V_{dc} / 3 and $2V_{dc}$ / 3, respectively. Since the output of the solar system will be sinusoidal and phase controlled using utility voltage, the inverter's 7-layer output current is also positive during the positive half cycle of the utility. The operation of seven-layer inverter can be divided into a four modes during positive cycle and negative cycle as shown in the figure 3 and figure 4 below.

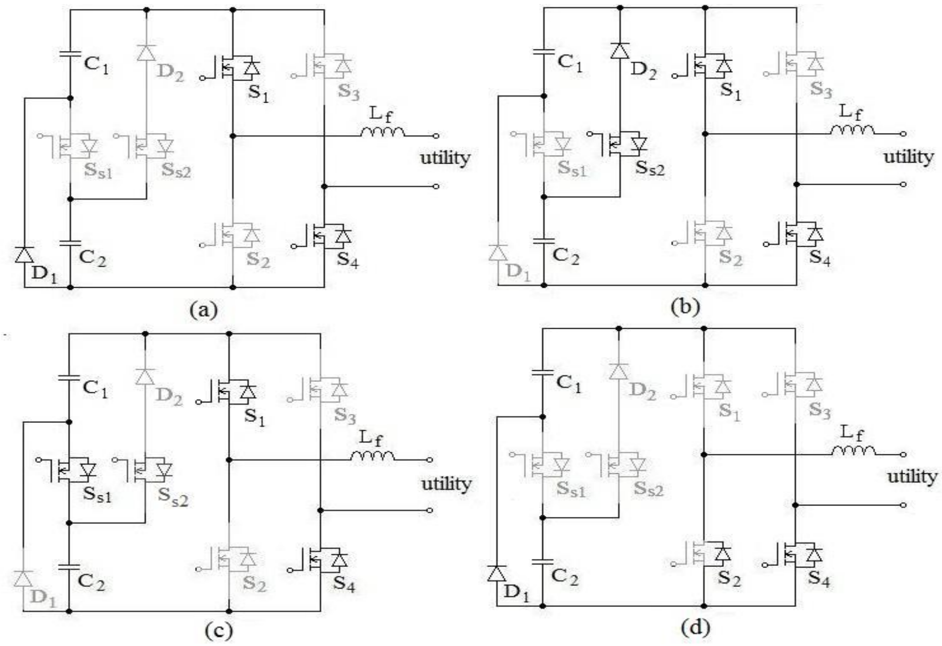

Figure 3 Operation of 7-level inverter in the positive half cycle (a) Mode 1 (b) Mode 2 (c) Mode 3 (d) Mode 4

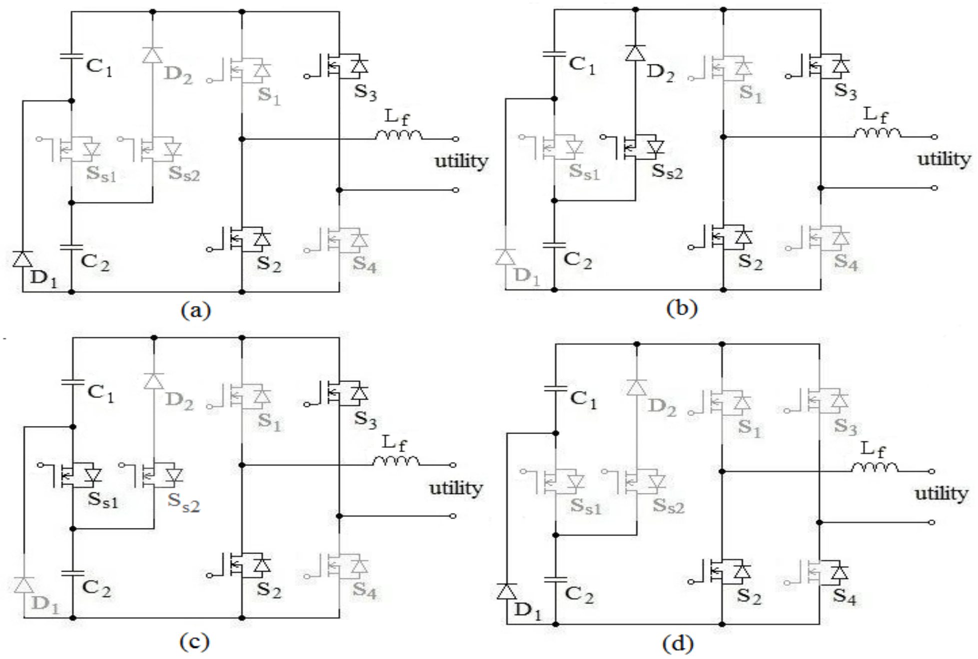

Figure 4: Operation of 7-level inverter in the positive half cycle (a) Mode 5 (b) Mode 6 (c) Mode 7 (d) Mode 8

The capacitor selection circuit is operated in a negative half cycle as same as positive half cycle. The difference is that the S_2 and S_3 of the full bridge power converter are in playback mode during modes 5, 6 and 7 and S_2 is also triggered during mode 8 of negative cycle. Accordingly, the output voltage of the capacitor selection circuit is inverted by the full-bridge power converter, so the output voltage of the seven-level inverter also has four levels: $-V_{dc}$, $-2V_{dc}/3$, $-V_{dc}/3$ and 0. Therefore, the output voltage of the seven-level inverter has the voltage levels: V_{dc}, $2V_{dc}/3$, $V_{dc}/3$, 0, $-V_{dc}/3$, $-2V_{dc}/3$ and $-V_{dc}$. The 7-level inverter is controlled by the current mode control and generates power converter control signals via PWM. Depending on the utility voltage, the output voltage of the 7-level inverter should be divided into two levels. The primary output voltage is higher than the utility voltage to increase the induction current of the filter and the second output voltage is less than the utility voltage to reduce the filter's inductive current. In this way, the output current of the can be controlled from seven levels for reference current monitoring. Therefore, the output voltage of the inverter must be changed from seven levels according to the utility voltage. The states of the power electronic switches of the 7-level inverter are detailed in Table 1 below.

Table 1: States of the power electronic switches of the 7-level inverter

positive half cycle						
	S_{S1}	S_{S2}	S_1	S_2	S_3	S_4
$\lvert v_u \rvert < V_{dc}/3$	off	off	PWM	off	off	on
$2V_{dc}/3 > \lvert v_u \rvert > V_{dc}/3$	off	PWM	on	off	off	on
$\lvert v_u \rvert > 2V_{dc}/3$	PWM	on	on	off	off	on
negative half cycle						
$\lvert v_u \rvert < V_{dc}/3$	off	off	off	on	PWM	off
$2V_{dc}/3 > \lvert v_u \rvert > V_{dc}/3$	off	PWM	off	on	on	off
$\lvert v_u \rvert > 2V_{dc}/3$	PWM	on	off	on	on	off

Since only six power electronic switches are used in the proposed 7-level inverter, the power circuit is significantly simplified compared with a conventional 7-level inverter. It can be seen that only one power electronic switch is switched in PWM within each voltage range and the change in the output voltage of the seven-level inverter for each switching operation is $V_{dc}/3$, so switching power loss is reduced. As shown in figure 3 and 4, only three semiconductor devices are conducting in series in modes 1, 3, 4, 5, 7 and 8 and four semiconductor devices are conducting in series in modes 2 and 6. This is superior to the conventional multi-level inverter topologies, in which at least four semiconductor devices are conducting in series. Therefore, the conduction loss of the proposed seven-level inverter is also reduced slightly.

Simulation Analysis

The performance of the presented system is validated in MATLAB/Simulink software. The figure 5 below shows the Simulink diagram of the solar power generating system connected to utility grid.

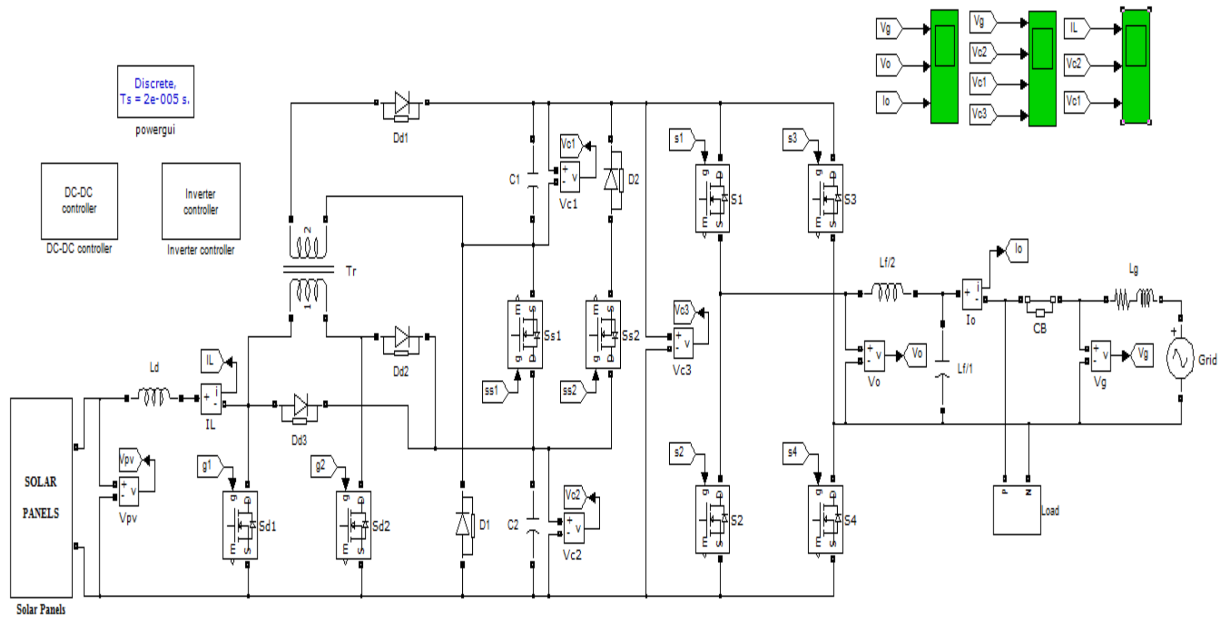

Figure 5: Simulink diagram of the solar power generating system connected to utility grid

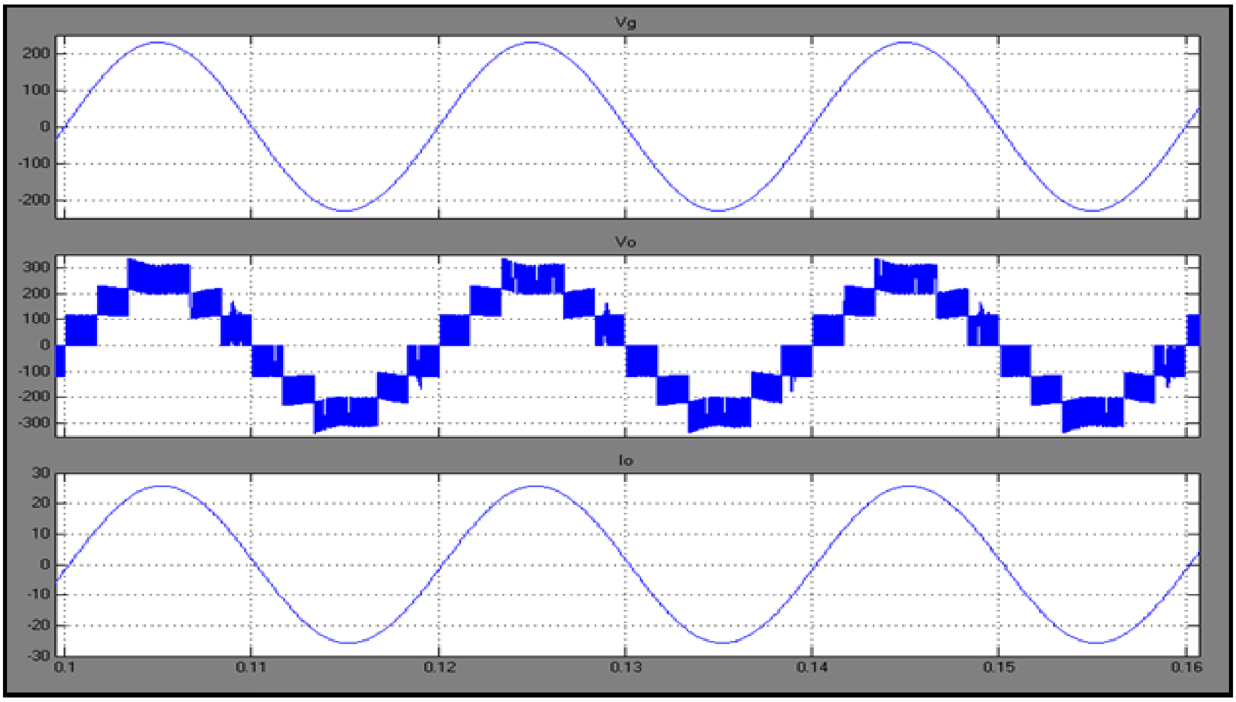

Figure 6: Simulation results for the ac side of the 7-level inverter: (a) utility voltage, (b) output voltage of 7 -level inverter and (c) output current of the 7-level inverter.

Figure-6 above shows the Simulation results for the AC side of the seven-level inverter. Figure 6(b) shows that the output voltage of the 7-level inverter has seven voltage levels. The output current of the 7-level inverter, shown in Figure 6(c), is sinusoidal and in phase with the utility voltage, which means that the grid-connected power conversion interface feeds a pure real power to the utility. The total harmonic distortion (THD) of the output current of the 7-level inverter is 4.6%.

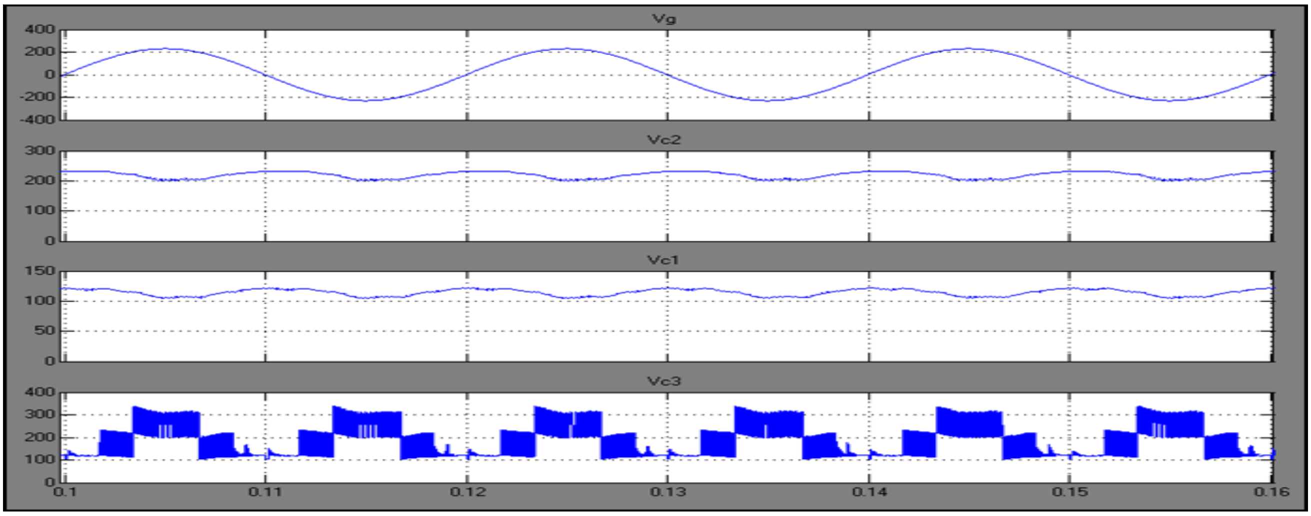

Figure 7: Simulation results for the dc side of the seven-level inverter: (a) utility voltage, (b) voltage of capacitor C2, (c) voltage of capacitor C1 and (d) output voltage of the capacitor selection circuit.

Figure 7(b) and (c) show that the voltages of capacitors C2 and C1 of the capacitor selection circuit have multiple relationships and are maintained at 60 and 120 V, respectively. Figure 7(d) shows that the output voltage of the capacitor selection circuit has three voltage levels (60, 120, and 180 V).

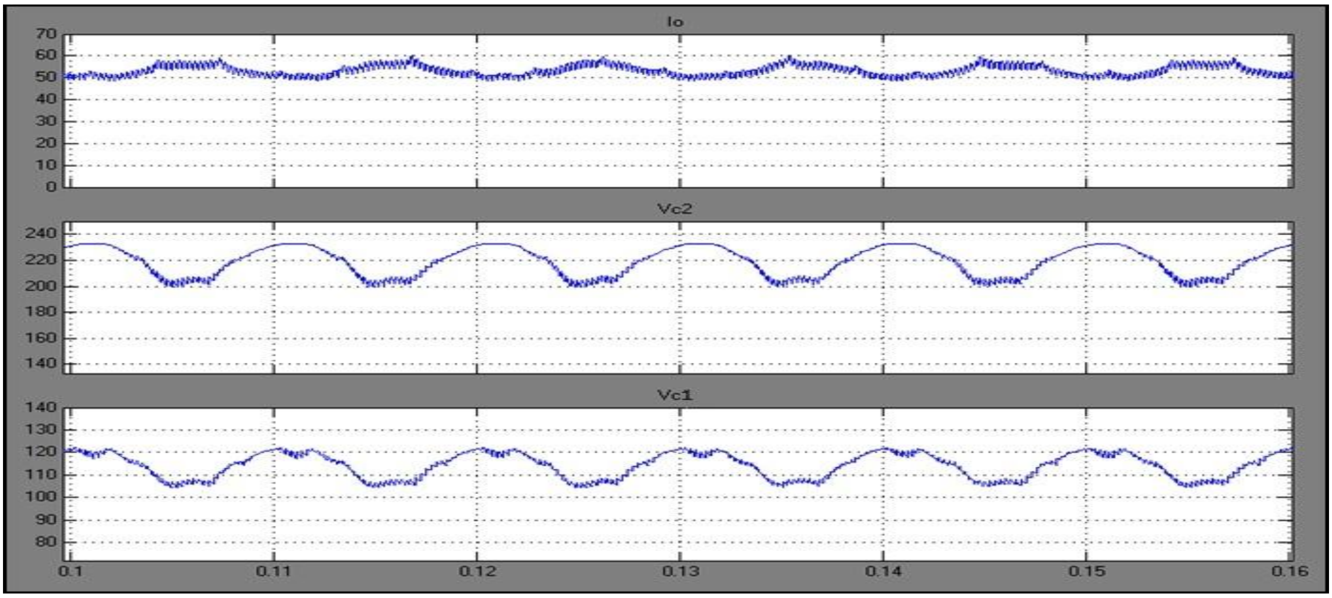

Figure 8: Simulation results of the dc–dc power converter: (a) ripple current of inductor, (b) ripple voltage of capacitor C2 and (c) ripple voltage of capacitor C1.

The above Figure 8(b) and (c) shows that the ripple voltages in capacitors C1and C2 of the capacitor selection circuit are evident. However, the ripple current in the inductor of the dc–dc power converter is less than 0.5 A when the average current of inductor is 8 A, as shown in Figure 8(a). Therefore, the ripple voltages in C1 and C2 are blocked by the dc–dc power converter.

Conclusion

This paper proposes a solar power generation system to convert the DC energy generated by a solar cell array into AC energy that is fed into the utility. The proposed solar power generation system is composed of a DC/DC power converter and a seven-level inverter. The seven-level inverter contains only six power electronic switches, which simplifies the circuit configuration. Furthermore, only one power electronic switch is switched at high frequency at any time to generate the seven-level output voltage. This reduces the switching power loss and improves the power efficiency. The voltages of the two DC capacitors in the proposed seven-level inverter are balanced automatically, so the control circuit is simplified. Experimental results show that the proposed solar power generation system generates a seven-level output voltage and outputs a sinusoidal current that is in phase with the utility voltage, yielding a power factor of unity. In addition, the proposed solar power generation system can effectively trace the maximum power of solar cell array.

References:

[1]. IEA PVPS Annual Report 2010, [Online]. Available: www.iea-pvps.org/fileadmin/dam/public/report/annual/ar_2010.pdf

[2]. "How PV Inverters support electrical grid stability, integration of solar power into the electrical grid," SMA Solar Technology, 2010.

[3]. H. Hinz and P. Mutschler, "Voltage source inverters for grid connected photovoltaic systems," in Power Electronics and Motion Control Conference PEMC, Budapest, Hungary, 1996.

[4]. Standard for Interconnecting Distributed Resources with Electric Power Systems, IEEE 1547, 2003.

[5]. B. Sahan, A. N. Vergara, N. Henze, A. Engler and P. Zacharias, "A single-stage PV module Integrated converter based on a low -power current-source inverter," IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2602–2609, Jul. 2008.

[6]. W. Xiao, N. Ozog and W. G. Dunford, "Topology study of photovoltaic interface for maximum power point tracking," IEEE Trans. Ind. Electron., vol. 54, no. 3, pp. 1696–1704, Jun. 2007.

[7]. T. Kerekes, R. Teodorescu, M. Liserre, R. A. Mastromauro, and A. Dell'Aquila, "MPPT algorithm for voltage controlled PV inverters," in Proc. 11th Int. Conf. Opt. Electr. Electron. Equipment, OPTIM 2008, Brasov, Romania, May 22–24, 2008, pp. 427–432.
[8]. R. A. Mastromauro, M. Liserre and A. Dell Aquila, " Study of the effects of inductor nonlinear behavior on the performance of current controllers," IEEE Trans. Ind. Electron., vol. 55, no. 5, pp. 2043–2052, May 2008.
[9]. M. Chaves, E. Margato, J. F. Silva, S. F. Pinto, "New approach in back-to-back m-level diode clamped multilevel converter modelling and direct current bus voltages balancing," *IET Power Electron.*, Vol. 3, No. 4, pp. 578-589, 2010.
[10]. S. Choi, M. Saeedifard, "Capacitor Voltage Balancing of Flying Capacitor Multilevel Converters by Space Vector PWM," *IEEE Trans. Power Del.*, Vol.27, No.3, pp.1154-1161, 2012.
[11]. L. Maharjan, T. Yamagishi, H. Akagi, "Active-Power Control of Individual Converter Cells for a Battery Energy Storage System Based on a Multilevel Cascade PWM Converter," *IEEE Trans. Power Electron.*, Vol. 27, No.3, pp.1099-1107, 2012.
[12]. X. She, A. Q. Huang, T. Zhao; G. Wang, " Coupling Effect Reduction of a Voltage-Balancing Controller in Single-Phase Cascaded Multilevel Converters," *IEEE Trans. Power Electron.*, Vol. 27, No.8, pp.3530-3543, 2012.
[13]. J. Chavarria, D. Biel, F. Guinjoan, C. Meza, J. J. Negroni, "Energy -Balance Control of PV Cascaded Multilevel Grid –Connected Inverters Under Level-Shifted and Phase-Shifted PWMs," *IEEE Trans. Ind. Electron.*, Vol.60, No.1, pp.98-111, 2013.
[14]. J. Pereda, J. Dixon, " High - Frequency Link: A Solution for Using Only One DC Source in Asymmetric Cascaded Multilevel Inverters," *IEEE Trans. Ind. Electron.*, Vol. 58, No.9, pp.3884- 3892, 2011.
[15]. N. A. Rahim, K. Chaniago, J. Selvaraj, "Single-Phase Seven-Level Grid-Connected Inverter for Photovoltaic System," *IEEE Trans. Ind. Electron.*, Vol. 58, No.6, pp. 2 435-2443, 2011
[16]. R. A. Mastromauro, M. Liserre, T. Kerekes and A. Dell Aquila, "A single - phase voltage controlled grid - connected photovoltaic system with power quality conditioner functionality," IEEE Trans. Ind. Electron., vol. 56, no. 11, pp. 4436–4444, Nov. 2009
[17]. I. J. Gabe, V. F. Montagner and H. Pinheiro, "Design and implementation of a robust current controller for VSI connected to the grid through an LCL filter," IEEE Trans. Power Electron., vol. 24, no. 6, pp. 1444–1452, Jun. 2009