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A Prototype Hardware Model of Solar Power Generation System with a Seven-Level Inverter

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ABSTRACT

This paper proposes a new solar power generation system, which is composed of a dc/dc power converter and a new seven-level inverter. The dc/dc power converter integrates a dc–dc boost converter and a transformer to convert the output voltage of the solar cell array into two independent voltage sources with multiple relationships. This new seven-level inverter is configured using a capacitor selection circuit and a full-bridge power converter, connected in cascade. The capacitor selection circuit converts the two output voltage sources of dc–dc power converter into a three-level dc voltage, and the full-bridge power converter further converts this three-level dc voltage into a seven-level ac voltage. In this way, the proposed solar power generation system generates a sinusoidal output current that is in phase with the utility voltage and is fed into the utility. The salient features of the proposed seven-level inverter are that only six power electronic switches are used, and only one power electronic switch is switched at high frequency at any time. A prototype is developed and tested to verify the performance of this proposed solar power generation system.

Keywords—Grid-connected, multilevel inverter, pulse-width modulated (PWM) inverter.

I.INTRODUCTION

The extensive use of fossil fuels has resulted in the global problem of greenhouse emissions. Moreover, as the supplies of fossil fuels are depleted in the future, they will become increasingly expensive. Thus, solar energy is becoming more important since it produces less pollution and the cost of fossil fuel energy is rising, while the cost of solar arrays is decreasing. In particular, small-capacity distributed power generation systems using solar energy may be widely used in residential applications in the near future [1], [2]. The power conversion interface is important to grid connected solar power generation systems because it converts the dc power generated by a solar cell array into ac power and feeds this ac power into the utility grid. An inverter is necessary in the power conversion interface to convert the dc power to ac power [2], [3]. Since the output voltage of a solar cell array is low, a dc–dc power converter is used in a small-capacity solar power generation system to boost the output voltage, so it can match the dc bus voltage of the inverter. The power conversion efficiency of the power conversion interface is important to insure that there is no waste of the energy generated by the solar cell array. The active devices and passive devices in the inverter produce a power loss. The power losses due to active devices include both conduction losses and switching losses [4]. Conduction loss results from the use of active devices, while the switching loss is proportional to the voltage and the current changes for each switching and switching frequency. A filter inductor is used to process the switching harmonics of an inverter, so the power loss is proportional to the amount of switching harmonics.

This paper proposes a new solar power generation system. The proposed solar power generation system is composed of a dc/dc power converter and a seven-level inverter.The seven level inverter is configured using a capacitor selection circuit and a full-bridge power converter, connected in cascade. The seven-level inverter contains only six power electronic switches, which simplifies the circuit configuration. Since only one power electronic switch is switched at high frequency at any time to generate the seven-level output voltage, the switching power loss is reduced, and the power efficiency is improved. The inductance of the filter inductor is also reduced because there is a seven level output voltage. In this study, a prototype is developed and tested to verify the performance of the proposed solar power generation system.

II.CIRCUIT CONFIGURATION

Fig. 1 shows the configuration of the proposed solar power generation system. The proposed solar power generation system is composed of a solar cell array, a dc–dc power converter, and a new seven-level inverter. The solar cell array is connected to the dc–dc power converter, and the dc–dc power converter is a boost converter that incorporates a transformer with a turn ratio of 2:1. The dc–dc power converter converts the output power of the solar cell array into two independent voltage sources with multiple relationships, which are supplied to the seven-level inverter. This new seven-level inverter is composed of a capacitor selection circuit and a full-bridge power converter, connected in a cascade. The power electronic switches of capacitor selection circuit determine the discharge of the two capacitors while the two capacitors are being discharged individually or in series. Because of the multiple relationships between the voltages of the dc capacitors, the capacitor selection circuit outputs a three-level dc voltage. The full-bridge power converter further converts this three-level dc voltage to a seven-level ac voltage that is synchronized with the utility voltage. In this way, the proposed solar power generation system generates a sinusoidal output current that is in phase with the utility voltage and is fed into the utility, which produces a unity power factor. As can be seen, this new seven-level inverter contains only six power electronic switches, so the power circuit is simplified.

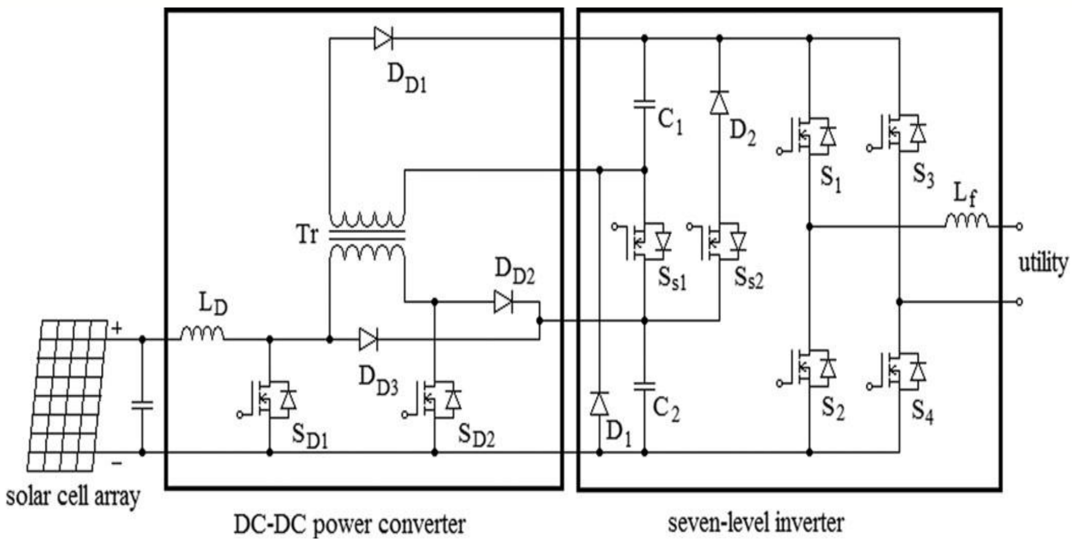

Fig. 1: Configuration of the proposed solar power generation system

III.SEVEN-LEVEL INVERTER

As seen in Fig. 1, the seven-level inverter is composed of a capacitor selection circuit and a full-bridge power converter, which are connected in cascade. The operation of the seven level inverter can be divided into the positive half cycle and the negative half cycle of the utility. The voltages of both capacitors *C*1 and *C*2 in the capacitor selection circuit are constant and equal to Vdc/3 and 2Vdc/3, respectively. Since the output current of the solar power generation system will be controlled to be sinusoidal and in phase with the utility voltage, the output current of the seven-level inverter is also positive in the positive half cycle of the utility. The operation of the seven-level inverter in the positive half cycle of the utility can be further divided into four modes, as shown in Fig. 2.

Mode 1*:* The operation of mode 1 is shown in Fig. 2(a). Both *SS*1 and *SS*2 of the capacitor selection circuit are OFF, so *C*1 is discharged through *D*1 and the output voltage of the capacitor selection circuit is *V*dc/3. *S*1 and *S*4 of the full-bridge power converter are ON. At this point, the output voltage of the seven-level inverter is directly equal to the output voltage of the capacitor selection circuit, which means the output voltage of the seven-level inverter is *V*dc/3.

Mode 2*:* The operation of mode 2 is shown in Fig. 2(b). In the capacitor selection circuit, *SS*1 is OFF and *SS*2 is ON, so *C*2 is discharged through *SS*2 and *D*2 and the output voltage of the capacitor selection circuit is 2*V*dc/3. *S*1 and *S*4 of the full-bridge power converter are ON. At this point, the output voltage of the seven-level inverter is 2*V*dc/3.

Mode 3*:* The operation of mode 3 is shown in Fig. 2(c). In the capacitor selection circuit, *SS*1 is ON. Since *D*2 has a reverse bias when *SS*1 is ON, the state of *SS*2 cannot affect the current flow. Therefore, *SS*2 may be ON or OFF, to avoiding switching of *SS*2. Both *C*1 and *C*2 are discharged in series and the output voltage of the capacitor selection circuit is *V*dc. *S*1 and *S*4 of the full-bridge power converter are ON. At this point, the output voltage of the seven-level inverter is *V*dc.

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Mode 4: The operation of mode 4 is shown in Fig. 2(d). Both *SS*1 and *SS*2 of the capacitor selection circuit are OFF. The output voltage of the capacitor selection circuit is *V*dc/3. Only *S*4 of the full-bridge power converter is ON. Since the output current of the seven-level inverter is positive and passes through the filter inductor, it forces the anti parallel diode of *S*2 to be switched ON for continuous conduction of the filter inductor current. At this point, the output voltage of the seven level inverter is zero. Therefore, in the positive half cycle, the output voltage of the seven-level inverter has four levels: *V*dc, 2*V*dc/3, *V*dc/3, and 0. In the negative half cycle, the output current of the seven-level inverter is negative.

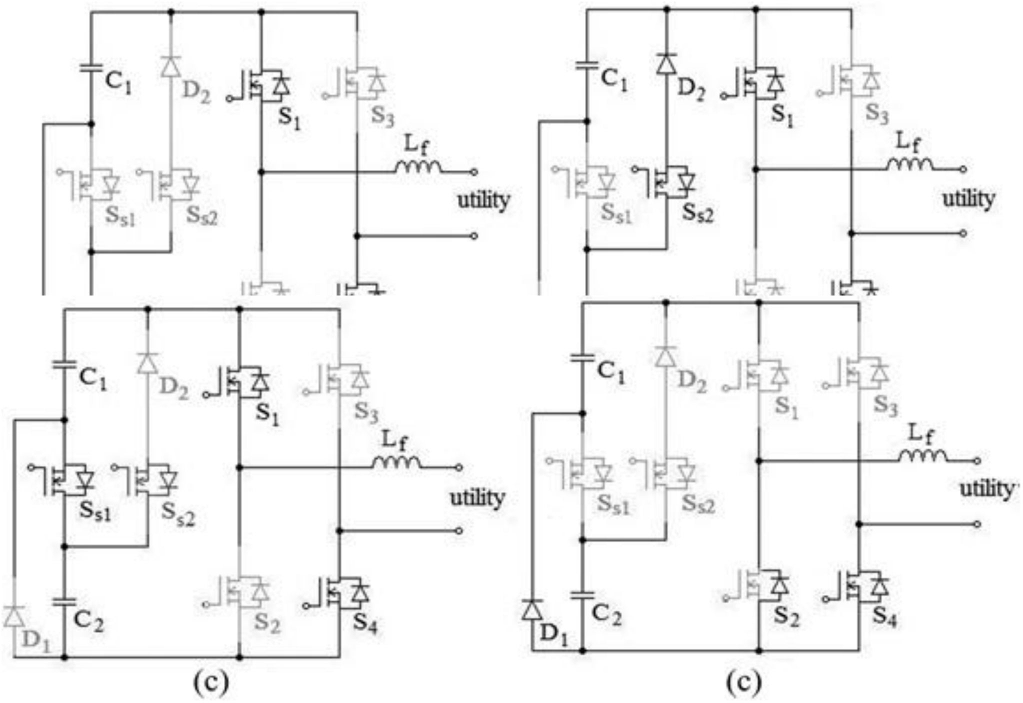

Fig. 2: Operation of the seven-level inverter in the positive half cycle, (a) mode 1, (b) mode 2, (c) mode 3, and (d) mode 4.

IV.HARDWARE MODEL

- Fig. 3 shows the control block diagram for the seven-level inverter. The control object of the seven-level inverter is its output current, which should be sinusoidal and in phase with the utility voltage.
- The utility voltage is detected by a voltage detector, and then sent to a phase-lock loop (PLL) circuit in order to generate a sinusoidal signal with unity amplitude.
- The voltage of capacitor C_2 is detected and then compared with a setting voltage.

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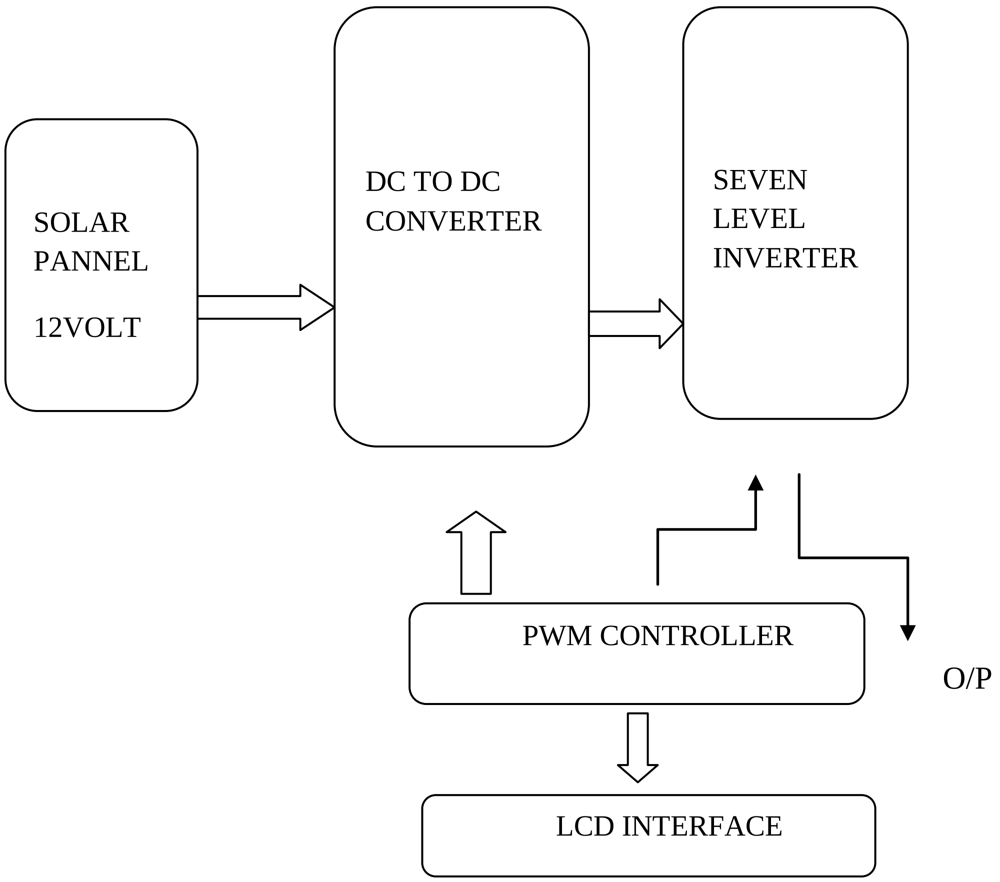

Fig.3 Hardware Block Diagram

- The compared result is sent to a PI controller. Then, the outputs of the PLL circuit and the PI controller are sent to a multiplier to produce the reference signal, while the output current of the seven-level inverter is detected by a current detector.
- The reference signal and the detected output current are sent to absolute circuits and then sent to a sub tractor, and the output of the sub tractor is sent to a current controller. The detected utility voltage is also sent to an absolute circuit and power electronic switches of the seven-level inverter, according to Table I.. The current controller controls the output current of the seven level inverter, which is a sinusoidal signal of 60 Hz..
- The control block diagram for the dc–dc power converter. The input for the DC-DC power converter is the output of the solar cell array. Therefore, the ripple voltages in $C1$ and $C2$ must be blocked by the dc–dc power converter to provide improved MPPT.
- Accordingly, dual control loops, an outer voltage control loop and an inner current control loop, are used to control the dc–dc power converter. Since the output voltages of the DC-DC power converter comprises the voltages of $C1$ and $C2$, which are controlled by the seven-level inverter, the outer voltage control loop is used to regulate the output voltage of the solar cell array.

- The output voltage of the solar cell array and the inductor current are detected and sent to a MPPT controller to determine the desired output voltage for the solar cell array.Then the detected output voltage and the desired output voltage of the solar cell array are sent to a sub tractor and the difference is sent to a PI control.

V.EXPERIMENTAL RESULTS

To verify the performance of the proposed solar power generation system, a prototype was developed with a controller based on the DSP chip TMS320F28035. The power rating of the prototype is 500 W, and the prototype was used for a single-phase utility with 110Vand 60 Hz. Table II shows the main parameters of the prototype. Figs. 4 show the experimental results for the seven level inverter when the output power of solar power generation system is 500 W.

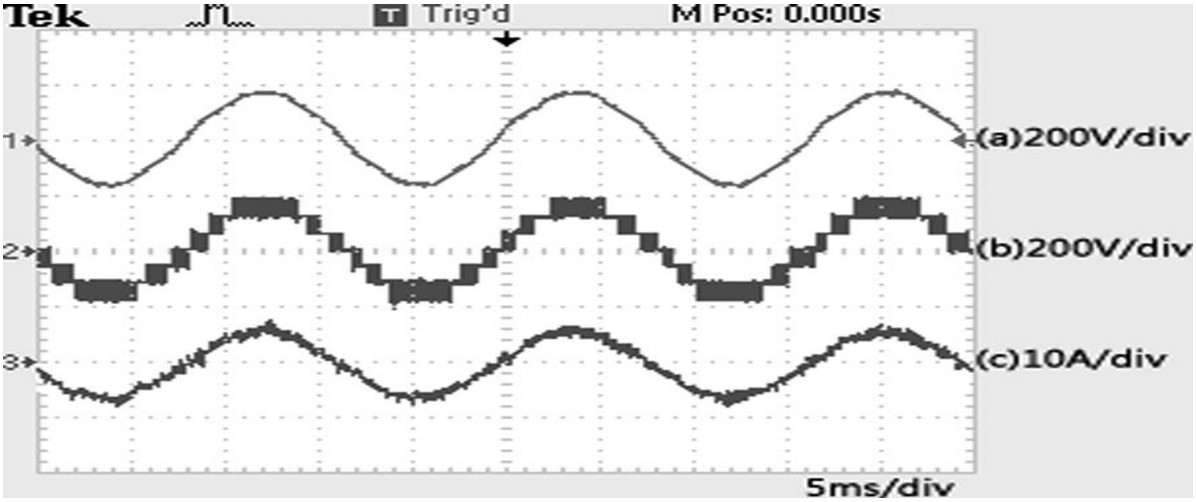

Fig. 4: Experimental results for the ac side of the seven-level inverter: (a) utility voltage, (b) output voltage of seven-level inverter, and (c) output current of the seven-level inverter

Fig. 4 shows the experimental results for the AC side of the seven-level inverter. Fig.4 (a) Shows utility voltage, Fig. 4(b) shows that the output voltage of the seven-level inverter has seven voltage levels. The output current of the seven-level inverter, shown in Fig. 4(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 seven-level inverter is 3.6%.

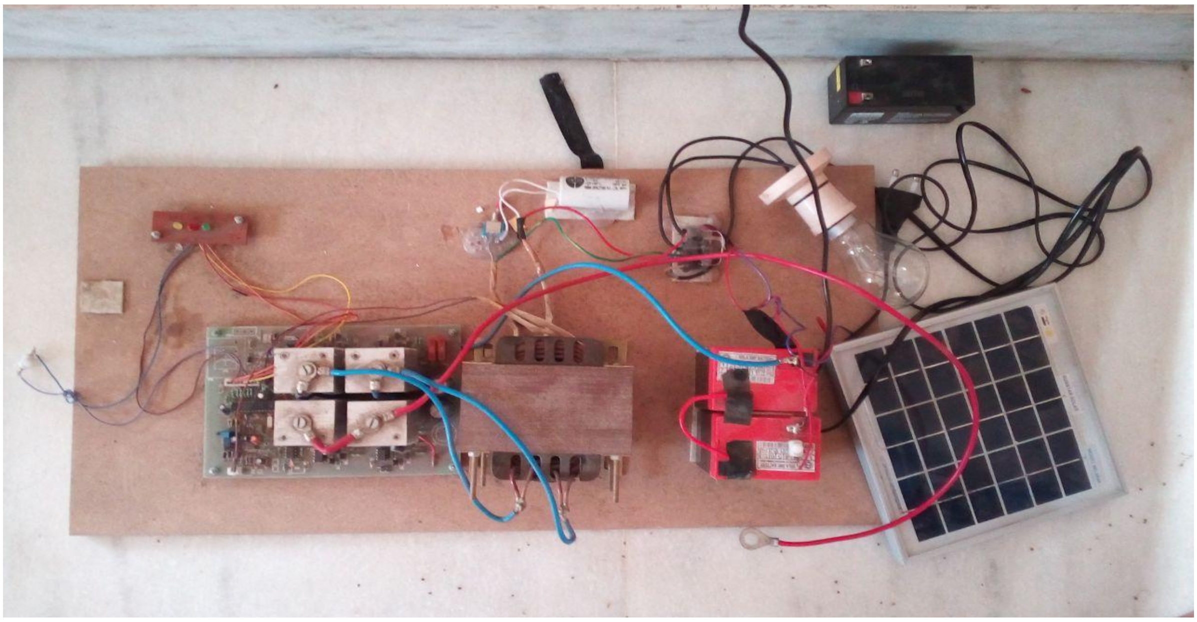

Photo 1: Prototype Hardware Model

Table 1: Parameters of Prototype

DC-DC POWER CONVERTER	
INPUT VOLTAGE	70V
INDUCTOR	1mH
PWM FREQUENCY	15360Hz
SEVEN LEVEL INVERTER	
CAPACITOR C1, C2	1000µF
FILTER INDUCTOR	1.9mH
PWM FREQUNCY	15360Hz

VII. 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.

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