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A Seven-Level Inverter For Photo Voltaic System

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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.**

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.

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. 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. 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.

The voltage change in each switching operation for a multilevel inverter is reduced in order to improve its power conversion efficiency and the switching stress of the active devices. The amount of switching harmonics is also attenuated, so the power loss caused by the filter inductor is also reduced. Therefore, multilevel inverter technology has been the subject of much research over the past few years. In theory, multilevel inverters should be designed with higher voltage levels in order to improve the conversion efficiency and to reduce harmonic content and electromagnetic interference (EMI).Conventional multilevel inverter topologies include the diode clamped the flying-capacitor, and the cascade H-bridge types. Diode-clamped and flying capacitor multilevel inverters use capacitors to develop several voltage levels. But it isdifficult to regulate the voltage of these capacitors. Since it is difficult to create an asymmetric voltage technology in both the diode-clamped and the flying capacitor topologies, the power circuit is complicated by the increase in the voltage levels that is necessary for a multilevel inverter. For a single-phase seven-level inverter, 12 power electronic switches are required in both the diode-clamped and the flying-capacitor topologies. Asymmetric voltage technology is used in the cascade H-bridge multilevel inverter to allow more levels of output voltage, so the cascade H-bridge multilevel inverter is suitable for applications with increased voltage levels. Two H-bridge inverters with a dc bus voltage of multiple relationships can be connected in cascade to produce a single phase seven-level inverter and eight power electronic switches are used. More recently, various novel topologies for seven level inverters have been proposed. For example, a single-phase seven-level grid-connected inverter has been developed for a photovoltaic system. This seven-level grid-connected inverter contains six power electronic switches. However, three dc capacitors are used to construct the three voltage levels, which results in that balancing the voltages of the capacitors is more complex. In a seven-level inverter topology, configured by a level generation part and a polarity generation.

II. THE PHOTOVOLTAIC ARRAY

A PV array consists of a number of PV modules, mounted in the same plane and electrically connected to give the required electrical output for the application. The PV array can be of any size from a few hundred watts to hundreds of kilowatts, although the larger systems are often divided into several electrically independent sub arrays each feeding into their own power conditioning system.

A PV system consists of a number of interconnected components designed to accomplish a desired task, which may be to feed electricity into the main distribution grid, to pump water from a well, to power a small calculator or one of many more possible uses of solar-generated electricity. The design of the system depends on the task it must perform and the location and other site conditions under which it must operate. This section will consider the components of a PV system, variations in design according to the purpose of the system, system sizing and aspects of system operation and maintenance.

III. SYSTEM DESIGN

There are two main system configurations – stand-alone and grid-connected. As its name implies, the stand-alone PV system operates independently of any other power supply and it usually supplies electricity to a dedicated load or loads. It may include a storage facility (e.g. battery bank) to allow electricity to be provided during the night or at times of poor sunlight levels. Stand-alone systems are also often referred to as autonomous systems since their operation is independent of other power sources. By contrast, the grid-connected PV system operates in parallel with the conventional electricity distribution system. It can be used to feed electricity into the grid distribution system or to power loads which can also be fed from the grid.

It is also possible to add one or more alternative power supplies (e.g. diesel generator, wind turbine) to the system to meet some of the load requirements. These systems are then known as 'hybrid' systems. Hybrid systems can be used in both stand-alone and grid-connected applications but are more common in the former because, provided the power supplies have been chosen to be complementary, they allow reduction of the loss of load probability. Figures below illustrate the schematic diagrams of the three main system types.

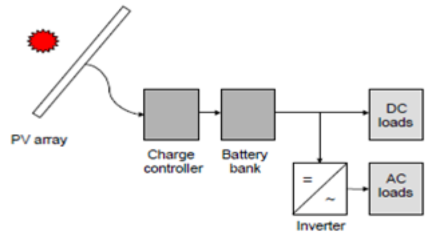

Fig. 2.5.Schematic diagram of a stand-alone photovoltaic system.

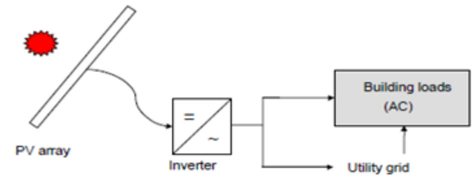

Fig 2.6Schematic diagram of grid-connected photovoltaic system.

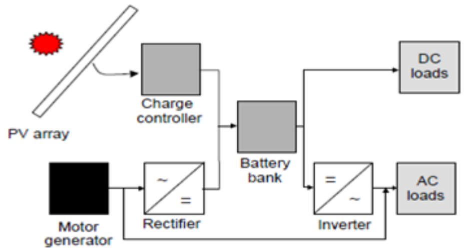

Fig2.7Schematic diagram of hybrid system incorporating a photovoltaic array and a motor generator (e.g. diesel or wind).

IV. PHOTOVOLTAIC INVERTER

The inverter is the heart of the PV system and is the focus of all utility-interconnection codes and standards. A Solar inverter or PV inverter is a type of electrical inverter that is made to change the direct current (DC) electricity from a photovoltaic array into alternating current (AC) for use with home appliances and possibly a utility grid. Since the PV array is a dc source, an inverter is required to convert the dc power to normal ac power that is used in our homes and offices.

To save energy they run only when the sun is up and should be located in cool locations away from direct sunlight. The PCU is a general term for all the equipment involved including the inverter and the interface with the PV (and battery system if used) and the utility grid. It is very important to point out that inverters are by design much safer than rotating generators. Of particular concern to utility engineers is how much current a generator can deliver during a fault on their system. Inverters generally produce less than 20% of the fault current as a synchronous generator of the same nameplate capacity. This is a very significant difference.

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V. DIODE-CLAMPED CONVERTER:

The simplest diode-clamped converter is commonly known as the neutral point clamped converter (NPC) which was introduced by Nabae. The NPC consists of two pairs of series switches (upper and lower) in parallel with two series capacitors where the anode of the upper diode is connected to the midpoint (neutral) of the capacitors and its cathode to the midpoint of the upper pair of switches; the cathode of the lower diode is connected to the midpoint of the capacitors and divides the main DC voltage into smaller voltages, which is shown in Figure 3.1. In this example, the main DC voltage is divided into two. If the point *O* is taken as the ground reference, the three possible phase voltage outputs are $-1/2V_{dc}$, 0, or $1/2V_{dc}$. The line-line voltages of two legs with the capacitors are: V_{dc} , $1/2V_{dc}$, 0, $-1/2V_{dc}$ or $-V_{dc}$. To generate a three-phase voltage, three phases are necessary.

The five-level output voltage can be generated by controlling the switches. Table 3.1 shows the proper switching states. The switches (S_{a1} and $S_{a'1}$) and (S_{a2} and $S_{a'2}$) are complementary pairs. When S_{a1} is on ($S_{a1} = 1$), $S_{a'1}$ is off ($S_{a'1} = 0$).

Some disadvantages of the diode-clamped multilevel converter may be observed. Using extra diodes in series becomes impractical when the number of levels *m* increases, requiring $(m-1)(m-2)$ diodes per phase if all the diodes have equal blocking voltages.

Note that the voltages for diodes in different positions are not balanced. For example, diode D_{a2} must block two capacitor voltages, $D_{a(m-2)}$ must block $(m-2)$ capacitor voltages. Also, the switch duty cycle is different for some of the switches requiring different current ratings.

In addition, the capacitors do not share the same discharge or charge current resulting in a voltage imbalance of the series capacitors. The capacitor voltage imbalance can be controlled by using a back-to-back topology, connecting resistors in parallel with capacitors, or using redundant voltage states.

The advantages for the diode-clamped converter are the following:

(1) A large number of levels yield a small harmonic distortion.

(2) All phases share the same DC bus.

(3) Reactive power flow can be controlled.

(4) Control is simple.

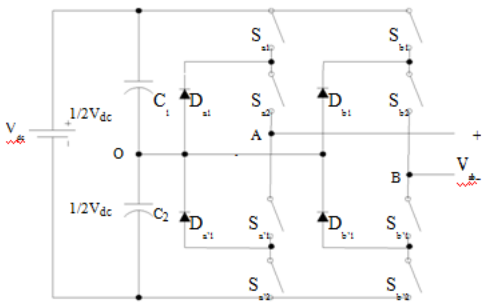

Fig 3.1 Neutral Point Diode Clamped Converter

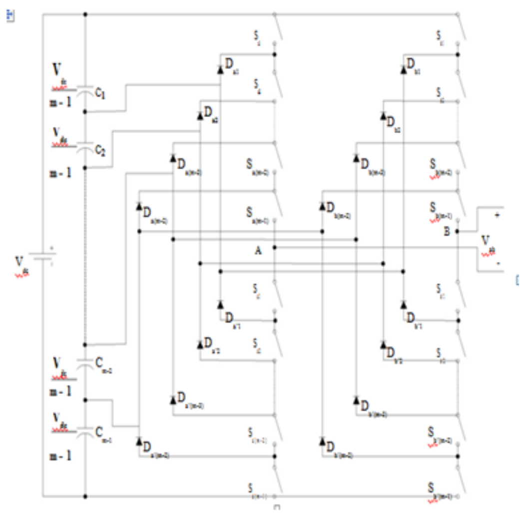

Fig 3.2 Two-Phase Diode Clamped Multi Level Converter

Sa1	*Sa2*	*Sa'1*	*Sa'2*	*Sb1*	*Sb2*	*Sb'1*	*Sb'2*	*Vao*	*Vbo*	*Vab*
0	0	1	1	1	1	0	0	$-1/2V_{dc}$	$1/2V_{dc}$	$-V_{dc}$
0	0	1	1	0	1	1	0	$-1/2V_{dc}$	0	$-1/2V_{dc}$
1	1	0	0	1	1	0	0	$1/2V_{dc}$	$1/2V_{dc}$	0
0	0	1	1	0	0	1	1	$-1/2V_{dc}$	$-1/2V_{dc}$	0
0	1	1	0	0	0	1	1	0	$-1/2V_{dc}$	$1/2V_{dc}$
1	1	0	0	0	0	1	1	$1/2V_{dc}$	$-1/2V_{dc}$	V_{dc}

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VI. SEVEN LEVEL INVERTER

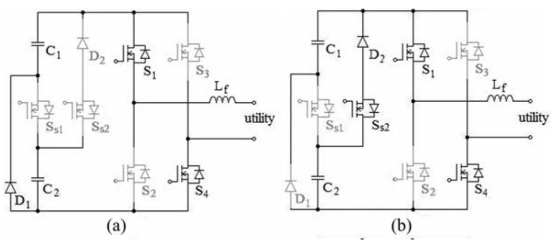
INTRODUCTION

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. For ease of analysis, the power electronic switches and diodes are assumed to be ideal, while the voltages of both capacitors *C*1 and *C*2 in the capacitor selection circuit are constant and equal to *V*dc/3 and 2*V*dc/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.4.1

Mode1: The operation of mode 1 is shown in Fig. 4.1(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. 4.1 (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. 4.1(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.



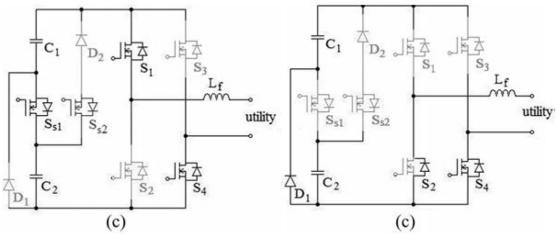


Fig.4.1. Operation of the seven-level inverter in the positive half cycle, (a) Mode 1, (b) Mode 2, (c) Mode 3, and (d) Mode 4.

VII. CONTROL MECHANISUM

The proposed solar power generation system consists of a dc– dc power converter and a seven-level inverter. The seven-level inverter converts the dc power into high quality ac power and feeds it into the utility and regulates the voltages of capacitors*C*1 and *C*2 . The dc–dc power converter supplies two independent voltage sources with multiple relationships and performs maximum power point tracking (MPPT) in order to extract the maximum output power from the solar cell array.

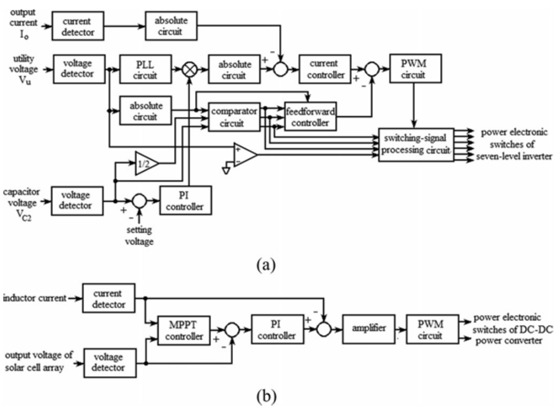


Fig.5.1. Control block: (a) seven-level inverter and (b) dc–dc power converter.

VIII. RESULTS

TEST 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 6.1 shows the main parameters of the prototype. Figs. 6.1 and 6.2 show the experimental results for the seven level inverter when the output power of solar power generation system is 500 W. Fig. 6.1 shows the experimental results for the AC side of the seven-level inverter. Fig. 6.1(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. 6.1 (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.

DC-DC power converter	
input voltage	70V
inductor	1mH
PWM frequency	15360Hz
seven-level inverter	
capacitor C_1, C_2	1000μF
filter inductor	1.9 mH
PWM frequency	15360Hz

Table 6.1 parameters of the prototype

IX. SIMULATION AND RESULTS

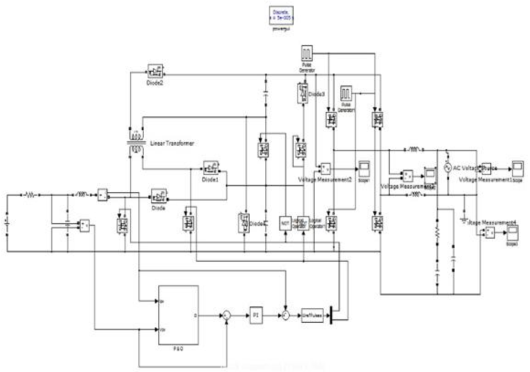


Fig.6.7 simulation diagram

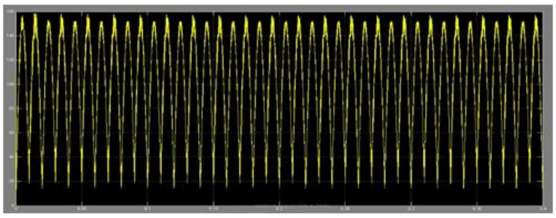


Fig 6.8: output waveform

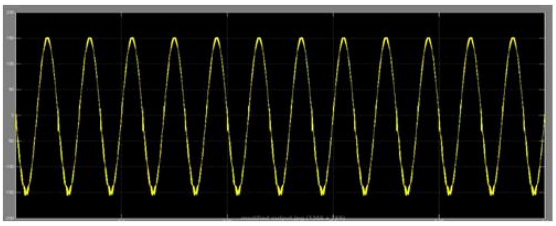


Fig 6.9: modified output waveform

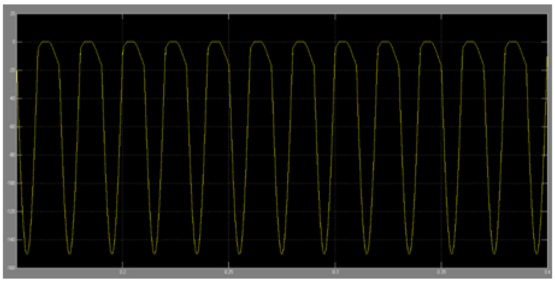


Fig 6.10: output after using filter

X. CONCLUSION

This project presents 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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