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A solar power generation system with a seven-level inverter

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Abstract
This paper presents a new seven level inverter with a 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 boost converter and a transformer to convert the output voltage of the solar cell array into independent voltage sources with multiple relationships. The most commonly used solar cell model is introduced and the generalized PV model using Matlab simulation is developed. Taking the effect of solar intensity and cell temperature, the characteristics of PV model are simulated. This model can be used for analysis of PV characteristics and for simulation with Maximum power point tracking algorithms.
This new seven level inverter is configured using a capacitor selection circuit and a full bridge power converter. 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 converter further converts this three level dc voltage into seven level ac voltage. The proposed system generates a sinusoidal output current that is in phase with the utility voltage and is fed into the utility.

Keywords: grid-connected, multilevel inverter, pulse-width modulated (PWM) inverter

1. 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. 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 is difficult 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.

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.

2. Circuit Configuration

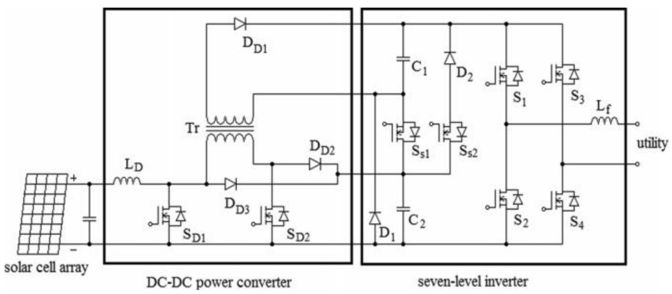

Fig 1: Configuration of the proposed solar power generation system.

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.

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. 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 $2V_{dc}/3$, 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.2.

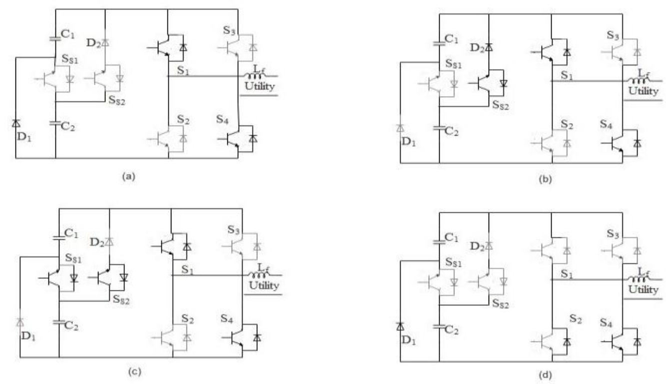

Fig 2: Operation of the seven level inverter in the positive half cycle (a) mode 1, (b) mode 2, (c) mode 3, and (d) mode 4.

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.

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.

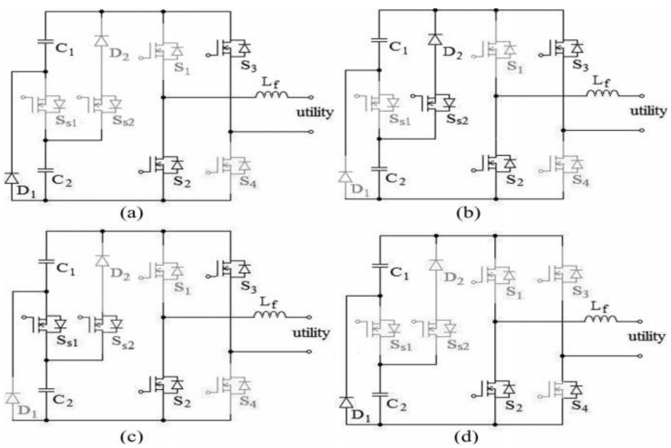

Fig 3: Operation of the seven-level inverter in the negative half cycle: (a) mode 5, (b) mode 6, (c) mode 7, and (d) mode 8.

In the negative half cycle, the output current of the seven-level inverter is negative. The operation of the seven-level inverter can also be divided into four modes, as shown in Fig. 4. The difference is that *S*2 and *S*3 of the full-bridge power converter are ON during modes 5, 6, and 7, and *S*2 is also ON during mode 8 of the negative half cycle. Accordingly, the output voltage of the capacitor selection circuit is inverted by the full-bridge power converter, so the output voltage of seven level inverter also has four levels: Vdc, 2Vdc/3, Vdc/3, 0, −Vdc/3, −2Vdc/3, and −Vdc.

3. Simulation

The Simulink model of the proposed Multi Level Inverter is simulated in MATLAB. The Simulink block diagrams of the proposed topology are shown in Fig.4.

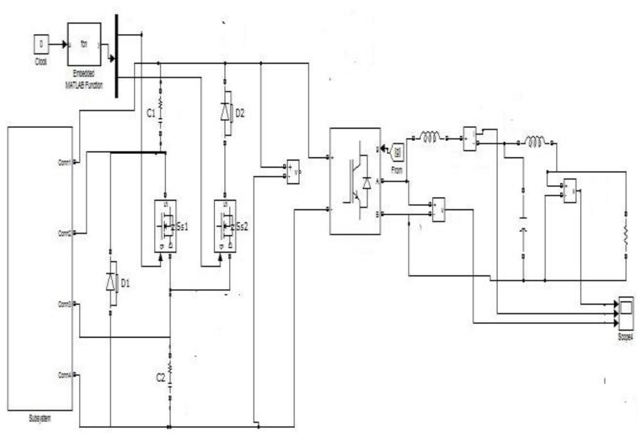

Fig 4: Simulation diagram of seven level inverter

For generating the dc source to the inverter photovoltaic array is used replacement for the dc source by renewable energy source. According to study and mathematical modeling of PV Module in MATLAB simulation has been implemented. Various parameters like T_C, S_C are taken from the reference paper, whereas some parameters like V_C, I_{ph}, etc. are been calculated from formula. The Simulink block diagrams of PV module is shown in Fig. 5 below.

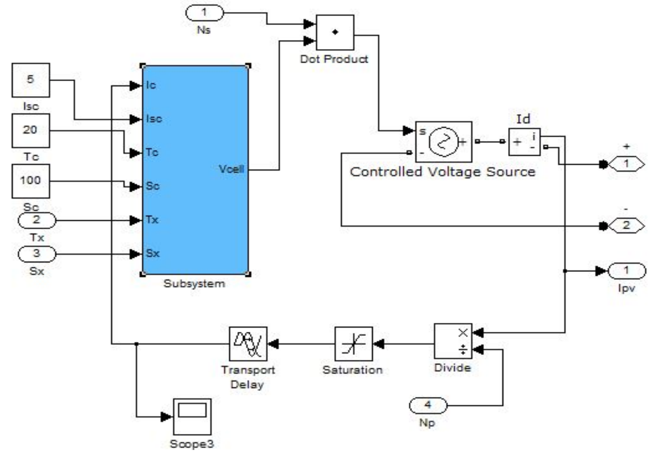

Fig 5: Matlab simulation model of PV.

MPPT algorithms are necessary because PV arrays have a nonlinear voltage current characteristic with a unique point where the power produced is maximum. This point depends on the temperature of the panels and on the irradiance conditions. Both conditions change during the day and are also different depending on the season of the year. Furthermore, irradiation can change rapidly due to changing atmospheric conditions such as clouds. It is very important to track the MPP accurately under all possible conditions so that the maximum available power is always obtained. The MPPT provides the output in the form of duty cycle, this duty cycle is then provided to DC-DC Boost converter. Boost converter is used to convert the input voltage in compatible magnitude, so that it can be used as source for Multi-Level Inverter. The Simulink Block Diagrams of DC-DC Boost converter with MPPT and PV module is shown in below:

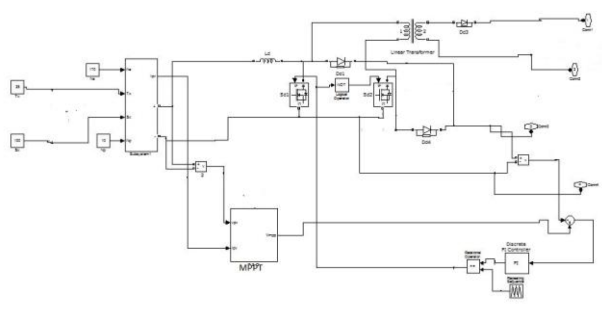

Fig 6: Matlab simulation of dc-dc converter with PV module and MPPT.

In proposed seven level inverter the control of bridge converter and capacitor selection circuit. Bridge converter is controlled by controlled circuited which gives the pulses to all four switches of bridge converter whereas, the capacitor selection switches pulses are given embedded MATLAB function.

3.1 PV Module

The PV array replaced the dc source as input to the dc-dc converter the. The waveform of output voltage and current of

PV cell is shown in Fig. 7 and Fig. 8 respectively. The voltage waveform of PV cell is constant whereas the current waveform is fluctuating.

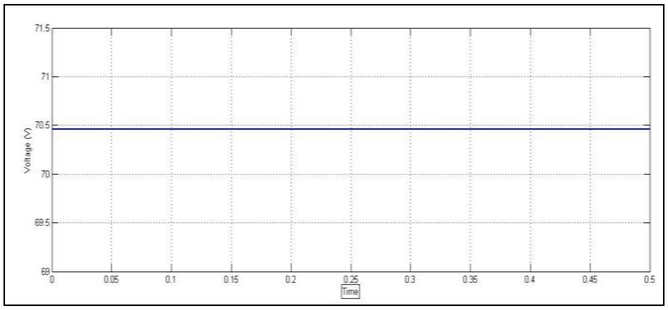

Fig 7: Output voltage of PV module.

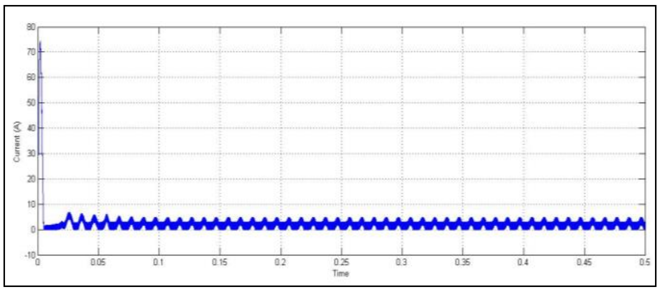

Fig 8: Output current of PV module.

3.2 DC to DC Converter

The input to the DC-DC converter is directly come from the PV module and the output voltage of DC-DC converter is fed to the capacitors which is shown Fig.9 below.

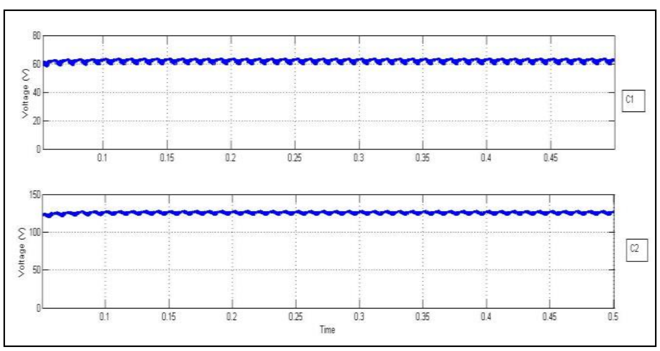

Fig 9: Voltage across the Capacitors $C_1$and C_2.

3.3 Proposed Topology Inverter

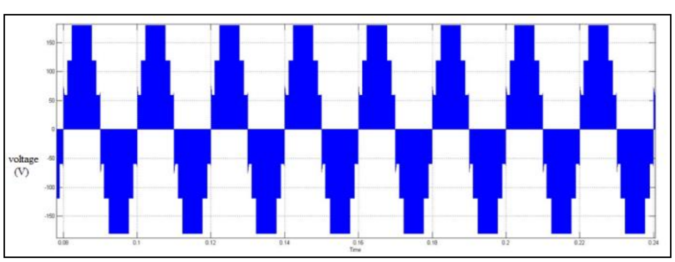

Fig 10: Seven level output voltage of proposed topology inverter.

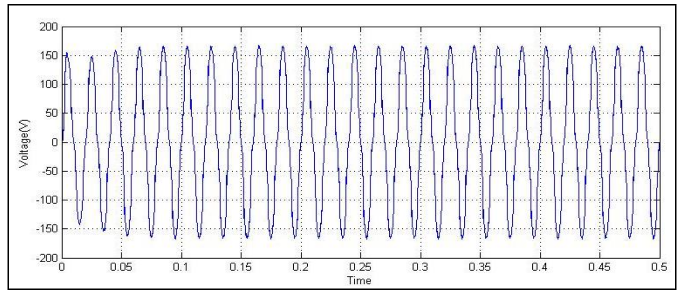

Fig 11: Output voltage of proposed topology inverter after connecting LC filter

Fig. 10 shows the seven level voltage of proposed topology inverter. Fig. 11 shows the utility voltage of proposed topology after connecting the LC filter at the output terminal.

4. Hardware Results

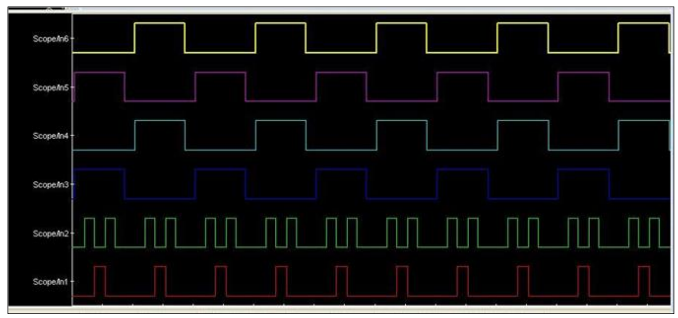

Fig 12: Pulses given to switches of hardware prototype

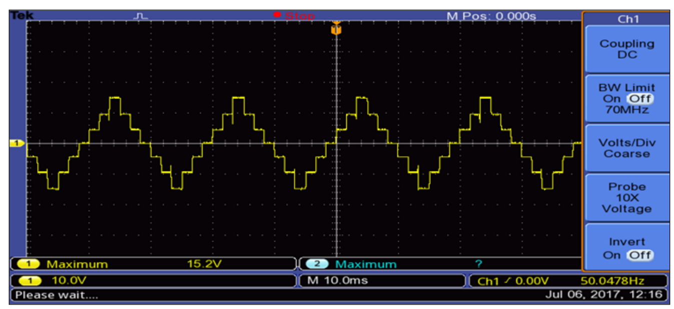

Fig 13: Seven level voltage of hardware prototype (digital storage oscilloscope).

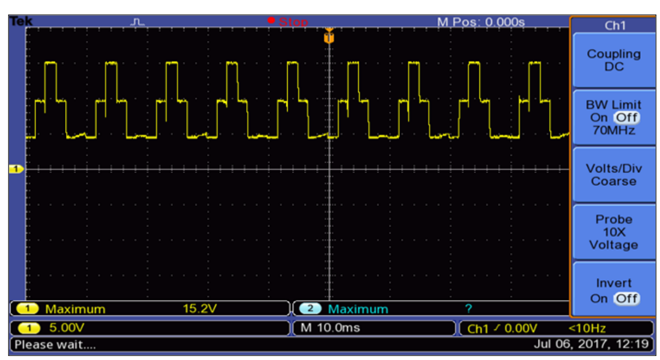

Fig 14: Voltage across voltage selection circuit.

Fig. 12 shows the pulses given to switches of hardware prototype. The result of hardware prototype of proposed topology on digital storage oscilloscope is shown in Fig. 13 and the voltage across the voltage selection circuit is shown in Fig. 14 which have three level of voltage.

5. Conclusion

This paper proposes a solar power generation system to convert the dc energy generated by a solar cell array into an 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.

6. References

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