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ANALYSIS OF A SOLAR POWER GENERATION SYSTEM

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Abstract –

This paper proposes 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 Mat lab/simulink 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 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.

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. 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 gridconnected 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]–[4]. 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 [5]. 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 [6] 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).

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VOLUME-2 ISSUE-1
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fossil fuel energy is rising, while the cost of solar arrays is decreasing. The growing energy demand coupled with the possibility of reduced supply of conventional fuels, along with growing concerns about environmental preservation, has driven research and development of alternative energy sources that are cleaner, renewable and that produce little environmental impact. Among the alternative sources the electrical energy from PV is currently regarded as the natural energy source more useful, since it is free, abundant, and clean, distributed over the earth and participates as a primary factor of all other processes of energy production on earth.

The power conversion interface is more 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 utility. An inverter is necessary in the power conversion interface to convert the dc power into ac power. Since the output voltage of solar cell array is low, dc/dc power converter is used in small capacity solar power generation system to boost the output voltage so it can match the dc bus voltage of the inverter. 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 control circuit not only provides PWM signals to switches of two power stages, but also traces maximum PV module energy as well as real time grid detection and protection. The efficiency of conventional boost converter is restricted by duty ratio for higher output voltage. Theoretically, when duty ratio is closed to unity the voltage gain will be infinity.

The 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. In both the diode clamped and flying capacitor topologies 12 power electronic switches are used for seven level inverters. The new seven level grid connected inverter contains only six power electronic switches.

This paper proposes the design and implementation of a PV module inverter. The dc-dc converter with maximum power point tracking control raises the input voltage level into a high voltage level. There is only one MPP (MPP-Maximum Power Point) and this varies according to climatic and irradiation conditions. The photovoltaic power characteristics vary with the level of solar irradiation and temperature which make the extraction of maximum power a complex task. To overcome this problem several methods for extracting maximum power have been proposed. In this paper the maximum power point tracking algorithm uses Perturb and Observe (P & O) method; the method senses the output voltage and current of solar panel to determine the duty cycle of the DC-DC converter to be increased or decreased. The P & O algorithms are widely used in control of MPPT which has simple structure, reduced number of necessary measured parameters and high tracking speed.

2. CIRCUIT CONFIGURATION

The proposed solar power generation system 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.

VOLUME-2 ISSUE-1
ISSN : 2799-18

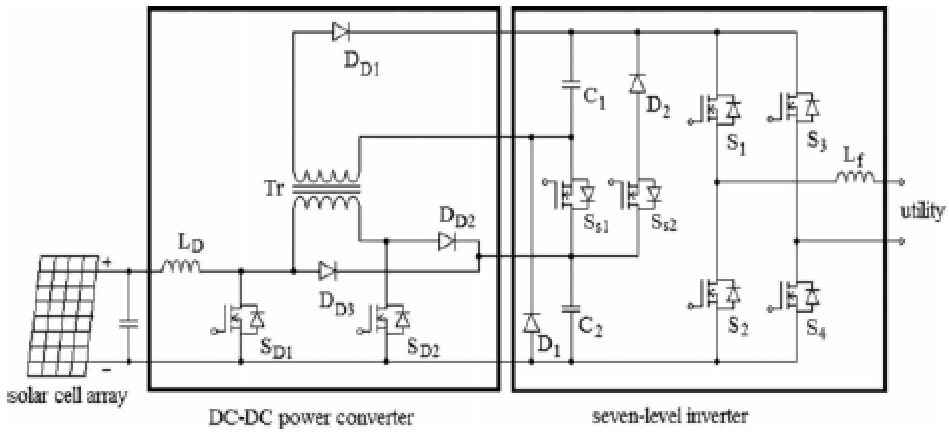

Fig-1 Proposed solar power generation system

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 then 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. This new seven-level inverter contains only six power electronic switches, so the power circuit is simplified.

2.1 DC-DC Power Converter

The DC–DC power converter incorporates a boost converter and a current-fed forward converter. The boost converter is composed of an inductor LD, a power electronic switch SD1, and a diode, DD3. The boost converter charges capacitor C2 of the seven-level inverter. The current-fed forward converter is composed of an inductor LD, power electronic switches SD1 and SD2, a transformer, and diodes DD1 and DD2. The current-fed forward converter charges capacitor C1 of the seven-level inverter. The inductor LD and the power electronic switch SD1 of the current-fed forward converter are also used in the boost converter. When SD1 is turned ON. The solar cell array supplies energy to the inductor LD. When SD1 is turned OFF and SD2 is turned ON. Accordingly, capacitor C1 is connected to capacitor C2 in parallel through the transformer, so the energy of inductor LD and the solar cell array charge capacitor C2 through DD3 and charge capacitor C1 through the transformer and DD1 during the off state of SD1. Since capacitors C1 and C2 are charged in parallel by using the transformer, the voltage ratio of capacitors C1 and C2 is the same as the turn ratio (2:1) of the transformer. Therefore, the voltages of C1 and C2 have multiple relationships. The boost converter is operated in the continuous conduction mode(CCM).

It should be noted that the current of the magnetizing inductance of the transformer increases when SD2 is in the ON state. Conventionally, the forward converter needs a third demagnetizing winding in order to release the energy stored in the magnetizing inductance back to the power source. However, in the proposed dc–dc power converter, the energy stored in the magnetizing inductance is delivered to capacitor C2 through DD2 and SD1 when SD2 is turned OFF. Since the energy stored in the magnetizing inductance is transferred forward to the output capacitor C2 and not back to the dc source, the power efficiency is improved. In addition, the power circuit is

VOLUME-2 ISSUE-1
ISSN : 2799-18

simplified because the charging circuits for capacitors C1 and C2 are integrated. Capacitors C1 and C2 are charged in parallel by using the transformer, so their voltages automatically have multiple relationships. The control circuit is also simplified. Thus complexity of the circuit is reduced.

2.2 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. 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 C1 and C2 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.

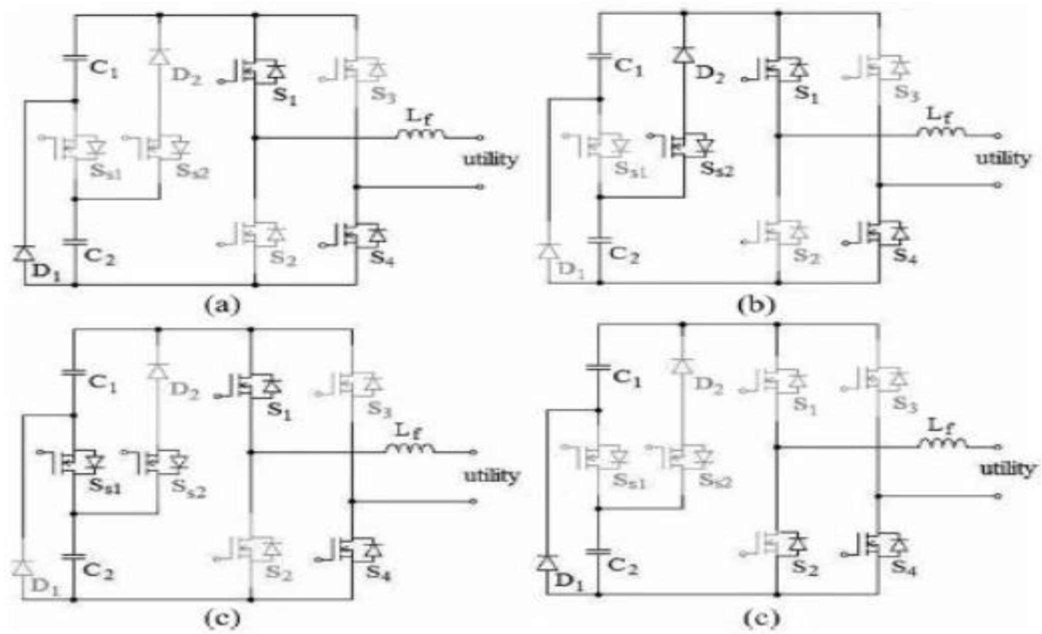

Fig-2. Operation in the positive half cycle (a) mode 1 (b) mode 2 (c) mode 3 (d) mode 4

3. DC–DC POWER CONVERTER

As seen in Fig. 1, the DC–DC power converter incorporates a boost converter and a current-fed forward converter. The boost converter is composed of an inductor LD , a power electronic switch SD1 , and a diode, DD3 . The boost converter charges capacitor C2 of the seven-level inverter. The current-fed forward converter is composed of an inductor LD , power electronic switches SD1 and SD2 , a transformer, and diodes DD1 and DD2 . The current-fed forward converter charges capacitor C1 of the seven-level inverter. The inductor LD and the power electronic switch SD1 of the current-fed forward converter are also used in the boost converter. Fig. 2(a) shows the operating circuit of the dc–dc power converter when SD1 is turned ON. The solar cell array supplies energy to the inductor LD . When SD1 is turned OFF and SD2 is turned ON, its operating circuit is shown in Fig. 2(b). Accordingly, capacitor C1 is connected to capacitor C2 in parallel through the transformer, so the energy of inductor LD and the solar cell array charge capacitor C2 through DD3 and charge capacitor C1 through the transformer and

VOLUME-2 ISSUE-1
ISSN : 2799-18

DD1 during the offstate of SD1 . Since capacitors C1 and C2 are charged in parallel by using the transformer, the voltage ratio of capacitors C1 and C2 is the same as the turn ratio (2:1) of the transformer. Therefore, the voltages of C1 and C2 have multiple relationships. The boost converter is operated in the continuous conduction mode (CCM). The voltage of C2 can be represented as

$$V_{c2} = \frac{1}{1-D} V_s$$

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 sevenlevel 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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