Solar Power Generation with Capacitor Based Seven Level Inverter System

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Abstract - The proposed system is composed of a dc/dc power converter and a new seven- level inverter, produced seven level output voltage. The proposed inverter reduced the switching losses, complexity, size and cost. This new seven-level inverter is configured using a capacitor selection circuit and a full-bridge converter. The capacitor selection circuit converts the two output voltage sources of dc–dc converter into a three-level dc voltage, and the full-bridge converter further converts three-level dc voltage into a seven-level ac voltage. The PWM signals are generated by using fuzzy logic controllers.

Key Words: seven-level inverter, capacitor selection circuit, fuzzy logic, dc-dc converter.

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 system 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 system is low, a dc–dc power converter is used step-up the output voltage level, 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 system.

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.

Conventional multilevel inverter topologies include the diode clamped, the flying-capacitor, and the cascade H-bridge types, 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 and H-bridge inverter to allow more levels of output voltage in this eight power electronic switches are used more recently various topologies for seven level inverters has been proposed.

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 part, is proposed. There, only power electronic switches of the level generation part switch in high frequency, but ten power electronic switches and three dc capacitors are used. In a modular multilevel inverter with a new modulation method is applied to the photovoltaic grid-connected generator.

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.

II. BLOCK DIAGRAM

The proposed solar power generation system is composed of a solar system, 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 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 system 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.

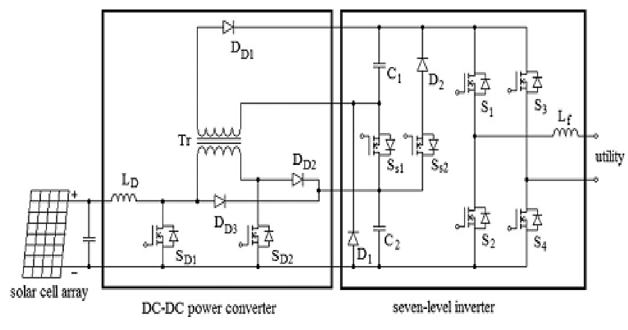
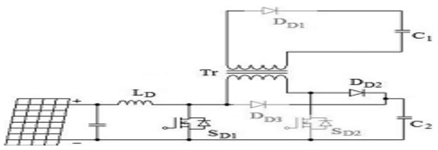


Fig.1 proposed block diagram

II.A. DC-DC CONVERTER

The boost converter is composed of an inductor L_D, a power electronic switch S_{D1}, and a diode, D_{D3}. The boost converter charges capacitor C_2 of the seven-level inverter. The current-fed forward converter is composed of an inductor L_D, power electronic switches S_{D1} and S_{D2}, a transformer, and diodes D_{D1} and D_{D2}. The current-fed forward converter charges capacitor C_1 of the seven-level inverter. The inductor L_D and the power electronic switch S_{D1} of the current-fed forward converter are also used in the boost converter.



(a)

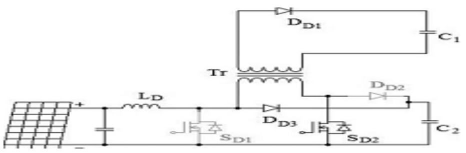


Fig.2 Operation of DC-DC Converter

Capacitor C_1 is connected to capacitor C_2 in parallel through the transformer, so the energy of inductor L_D and the solar cell array charge capacitor C_2 through D_{D3} and charge capacitor C_1 through the transformer and D_{D1} during the off state of S_{D1}. Since capacitors C_1 and C_2 are charged in parallel by using the transformer, the voltage ratio of capacitors C_1 and C_2 is the same as the turn ratio (2:1) of the transformer. The boost converter is operated in the continuous conduction mode (CCM). The voltage of C_2 can be represented as

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

Where V_S is the output voltage of solar cell array and D is the duty ratio of S_{D1}. The voltage of capacitor C_1 can be represented as

$$V_{c1} = \frac{1}{2(1-D)} V_s \quad (2)$$

In addition, the power circuit is simplified because the charging circuits for capacitors C_1 and C_2 are integrated. Capacitors C_1 and C_2 are charged in parallel by using the transformer, so their voltages automatically have multiple relationships.

II.B.SEVEN-LEVEL INVERTER

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 seven-level inverter is controlled by the current-mode control, and pulse-width modulation (PWM) is use to generate the control signals for the power electronic switches. The output voltage of the seven-level inverter must be switched in two levels, according to the utility voltage. One level of the output voltage is higher than the utility voltage in order to increase the filter inductor current, and the other level of the output voltage is lower than the utility voltage, in order to decrease the filter inductor current. In this way, the output current of the seven-level inverter can be controlled to trace a reference current. Accordingly, the output voltage of the seven-level inverter must be changed in accordance with the utility voltage. . In the positive half cycle, when the utility voltage is smaller than $V_{dc}/3$, the seven-level inverter must be switched between modes 1 and 4 to output a voltage of $V_{dc}/3$ or 0. Within this voltage range, S_1 is switched in PWM. the duty ratio d of S_1 can be represented as

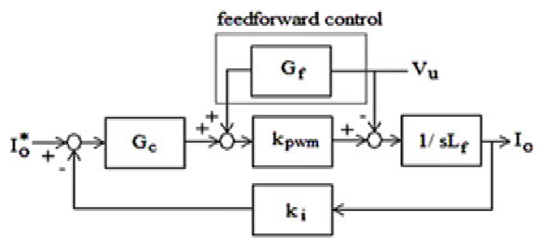
$$d = v_m / V_{tri} \qquad (3)$$

Where v_m and V_{tri} are the modulation signal and the amplitude of carrier signal in the PWM circuit, respectively. As The output voltage of the seven-level inverter.

$$V_o = d.V_{dc}/3 = k_{pwm} v_m \qquad (4)$$

Where k_{pwm} is the gain of inverter

$$k_{pwm} = V_{dc}/3V_{tri} \qquad (5)$$



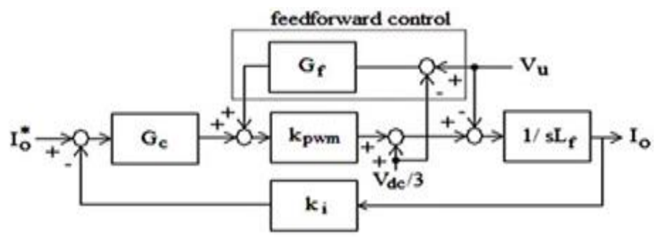
the simplified model for the seven-level inverter when the utility voltage is smaller than $V_{dc}/3$.The closed loop transfer function is

$$I_o = \frac{k_{pwm} G_c / L_f}{s + k_i k_{pwm} G_c / L_f} I_o^* - \frac{1/L_f}{s + k_i k_{pwm} G_c / L_f} V_u \qquad (6)$$

Where G_c is the current controller and k_i is the gain of the current detector. in case of seven level inverter mode 1& 2 in order the output voltage range is ($V_{dc}/3$, $2V_{dc}/3$).

The output voltage of seven level inverter is

$$v_o = d.V_{dc}/3 + V_{dc}/3 = k_{pwm} v_m + V_{dc}/3 \qquad (7)$$

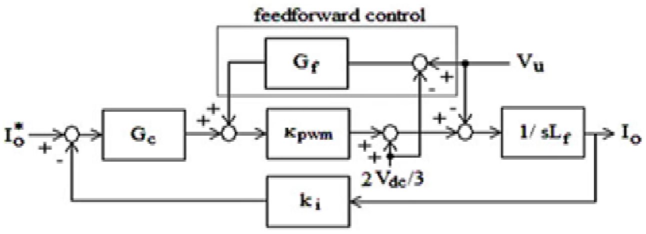


The closed loop transfer function for utility voltage is within the range

$$I_o = \frac{k_{pwm} G_c / L_f}{s + k_i k_{pwm} G_c / L_f} I_o^* - \frac{1/L_f}{s + k_i k_{pwm} G_c / L_f} (V_c - V_{dc}/3) \qquad (8)$$

The seven level inverter switched between mode 2&3 when the utility output voltage range is ($2V_{dc}/3$,V_{dc}).

$$v_o = d.V_{dc}/3 + 2V_{dc}/3 = k_{pwm}v_m + 2V_{dc}/3. \quad (9)$$



$$I_o = \frac{k_{pwm}G_c/L_f}{s + k_i k_{pwm}G_c/L_f} I_o^* - \frac{1/L_f}{s + k_i k_{pwm}G_c/L_f}(V_u - 2V_{dc}/3).$$

(10)

the negative half cycle, the seven-level inverter is switched between modes 5 and 8, in order to output a voltage of $-V_{dc}/3$ or 0, when the absolute value of the utility voltage is smaller than $V_{dc}/3$. Accordingly, S3 is switched in PWM. The seven level inverter is switched in modes 6 and 5 to output a voltage of $-2V_{dc}/3$ or $-V_{dc}/3$ when the utility voltage is in the range ($-V_{dc}/3$, $-2V_{dc}/3$).Within this voltage range, S_{S2} is switched in PWM. The seven-level inverter is switched in modes 7 and 6 to output a voltage of $-V_{dc}$ or $-2V_{dc}/3$, when the utility voltage is in the range ($-2V_{dc}/3$, $-V_{dc}$). At this voltage range, SS1 is switched in PWM and S_{S2} remains in the ON state to avoid switching of S_{S2}. The simplified model for the seven-level inverter in the negative half cycle is the similar to that for the positive half cycle.

Only six power electronic switches are used in the proposed new seven-level inverter, 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 and the conduction loss of the proposed seven-level inverter is also reduced slightly.

II.C.CONTROL BLOCK

The dc–dc power converter supplies two independent voltage sources with multiple relationships and performs MPPT and collect the maximum output power from the solar system. The absolute value of the utility voltage and the outputs of the compared circuit are sent to a feed-forward controller to generate the feed-forward signal. Then, the output of the current controller and the feed-forward signal are summed and sent to a PWM circuit to produce the PWM signal and the PWM signal, the square signal, and the outputs of the compared circuit are sent to the switching signal processing circuit to generate the control signals for the seven-level inverter.

Table -1: States for seven level inverter

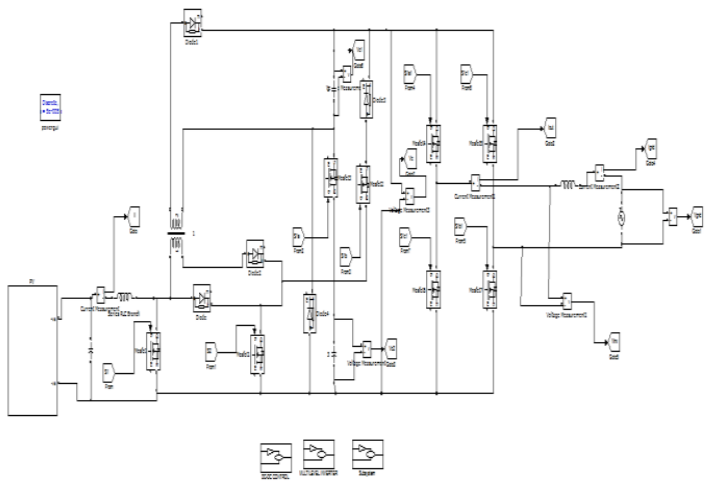
Positive half cycle						
	S_{a1}	S_{a2}	S_1	S_2	S_3	S_4
$\lvert V_U \rvert < V_{dc}/3$	off	off	pwm	off	off	on
$2V_{dc}/3 > \lvert V_U \rvert > V_{dc}/3$	off	pwm	on	off	off	on
$\lvert V_U \rvert > 2V_{dc}/3$	pwm	on	on	off	off	on
Negative half cycle						
$\lvert V_U \rvert < V_{dc}/3$	off	off	off	on	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

Fuzzy logic controller could control the switches in the boost and full bridge inverter, Membership function values are assigned to the linguistic variables, using seven fuzzy subsets: NB (negative big), NS(negative small), ZE(zero), PS(positive small), and PB (positive big). The set of rules designed in fuzzy logic controller are shown in Table 1. Based on the rules framed in the table, the fuzzy logic controller controls the switches present in the dc/dc boost converter and single H-bridge inverter.

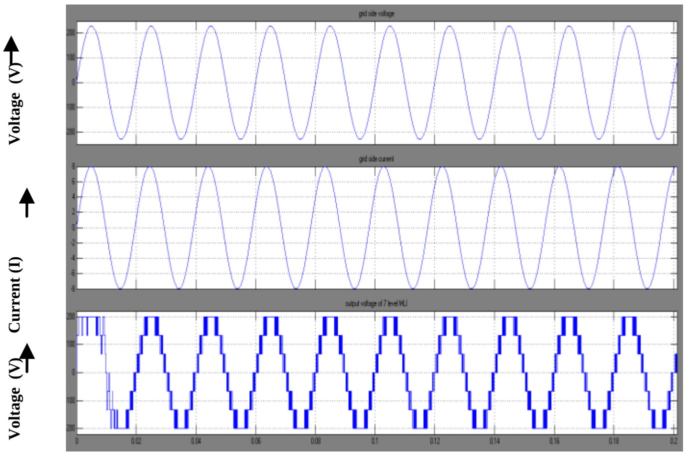
Table -2: Rule based logic controller

$E\downarrow \backslash CE \rightarrow$	NB	NS	ZE	PS	PB
NB	NB	NB	NS	NS	ZE
NS	NB	NS	NS	ZE	PS
ZE	NS	NS	ZE	PS	PS
PS	NS	ZE	PS	PS	PB
PB	ZE	PS	PS	PB	PB

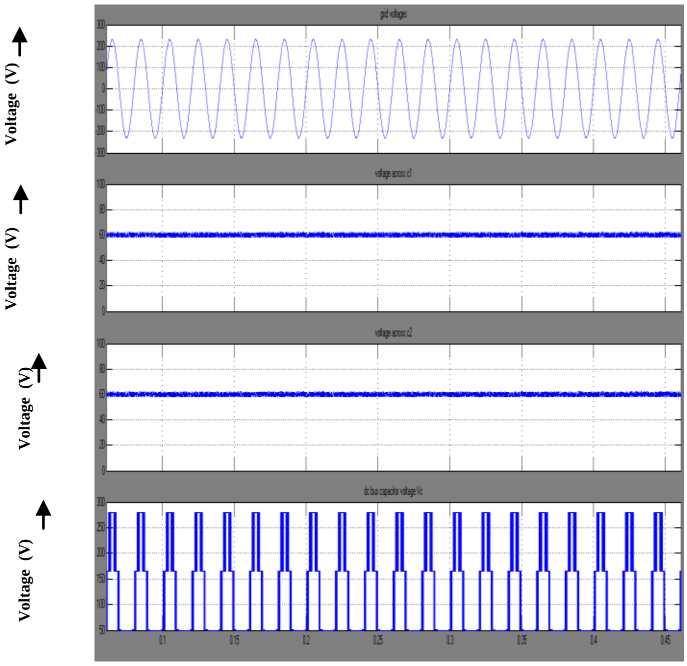
III.D.SIMULATION RESULT



It is the simlink model diagram for solar power generation system with capacitor based seven level inverter. It consisting of full bridge converter with dc-dc converter and transformer. The transformer converts the output voltage of solar system into two independent voltage sources with multiple relationships.

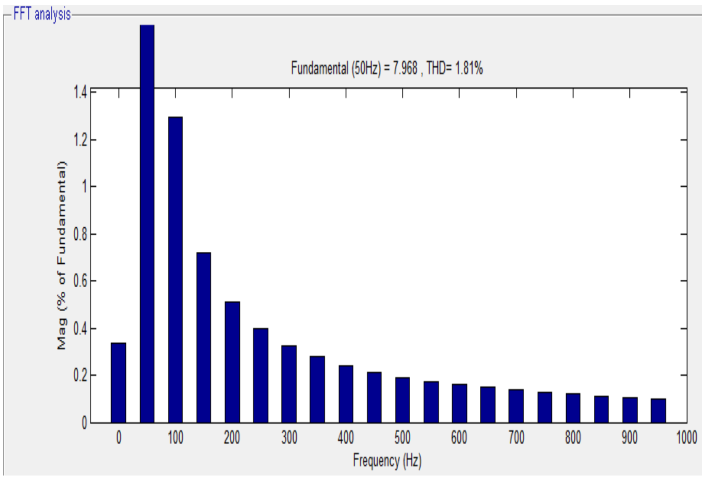


Simulation results for the ac side of the seven-level inverter: (a) grid voltage, (b) inverter current (c) output voltage of seven-level inverter



Simulation results for (a) grid voltage,(b) voltage of capacitor C1, (c) voltage of capacitor C2,and(d) output voltage of the capacitor selection circuit.

FFT analysis using Fuzzy controller



IV.CONCLUSION

The proposed technique has some features such as it reduces the cost of the overall system, compact size as well as an increased efficiency. With the help of lower number of switches, seven-level of output voltages are generated and thus it reduces the switching loss and conduction losses. The fuzzy logic controller could control the switches present in the boost converter and H-bridge inverter. For the seven level of output, only six power electronic switches are used and only one switch will operate at high frequency at any time.

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