



REDUCTION OF HARMONICS IN SOLAR POWER GENERATION SYSTEM BY USING FIVE LEVEL INVERTER

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Abstract: A five-level inverter implemented in this paper for injecting of the real power of the solar power into the grid to eliminate the switching losses, harmonic distortion, and electromagnetic interference caused by the switching operation. Five level inverter can be designed with combination of two dc capacitors which are connected to the dual-buck converter and single phase H-bridge converter. The output voltage of the dual-buck converter supplies to the full-bridge inverter. The switches of the full-bridge inverter are triggered in low frequency synchronous with the utility voltage to convert the output voltage of the dual-buck converter to a five-level ac voltage. The output current of the five-level inverter is controlled by producing a sinusoidal current in phase with the utility voltage to inject into the grid this system can be designed by matlab/simulink software.

Key Words: Harmonic distortion, inverters, electromagnetic interference dual-buck converter and power electronics.

1. INTRODUCTION

The conventional single-phase inverter topologies for grid connection include half-bridge and full bridge. The half-bridge inverter is configured by one capacitor arm and one power electronic arm. The dc bus voltage of the half-bridge inverter must be higher than double of the peak voltage of the output ac voltage. The output ac voltage of the half-bridge inverter is two levels. The voltage jump of each switching is the dc bus voltage of the inverter. The full-bridge inverter is configured by two power electronic arms. The popular modulation strategies for the full-bridge inverter are bipolar modulation and uni polar modulation. The dc bus voltage of the full-bridge inverter must be higher than the peak voltage of the output ac voltage. The output ac voltage of the full-bridge inverter is two levels if the bipolar modulation is used and three levels if the uni polar modulation is used. Multilevel inverter can effectively reduce the voltage jump of each switching operation to reduce the switching loss and increase power efficiency. The number of power electronic switches used in the multilevel inverter is larger than that used in the conventional half-bridge and full-bridge inverters. Moreover, its control circuit is more complicated. Thus, both the performance and complexity should be considered in designing the multilevel inverter. However, interest in the multilevel inverter has been aroused due to its advantages of better power efficiency, lower switching harmonics, and a smaller filter inductor compared with the conventional half-bridge and full-bridge inverters. In this paper, a five-level inverter is developed and applied for injecting the real power of the renewable power into the grid. This five-level inverter is configured by two dc capacitors, a dual-buck converter, a full-bridge inverter, and a filter. The five-level inverter generates an output voltage with five levels and applies in the output stage of the renewable power generation system to generate a sinusoidal current in phase with the utility voltage to inject into the grid. The power electronic switches of the dual-buck converter

are switched in high frequency to generate a three-level voltage and balance the two input dc voltages. The power electronic switches of the full-bridge inverter are switched in low frequency synchronous with the utility to convert the output voltage of the dual-buck converter to a five-level ac voltage. Therefore, the switching power loss, harmonic distortion, and electromagnetic interference caused by the switching operation of power electronic devices can be reduced, and the control circuit is simplified. Besides, the capacity of output filter can be reduced. A hardware prototype is developed to verify the performance of the developed renewable power generation system.

1.1 circuit description

Five-level inverter applied to a photovoltaic power generation system. As can be seen, it is configured by a solar cell array, a dc–dc converter, a five-level inverter, two switches, and a digital signal processor (DSP)-based controller. Switches *SW1* and *SW2* are placed between the five-level inverter and the utility, and they are used to disconnect the photovoltaic power generation system from the utility when islanding operation occurs. The load is placed between switches *SW1* and *SW2* . The output of the solar cell array is connected to the input port of the dc–dc converter. The output port of the dc–dc converter is connected to the five-level inverter. The dc–dc converter is a boost converter, and it performs the functions of maximum power point tracking (MPPT) and boosting the output voltage of the solar cell array.

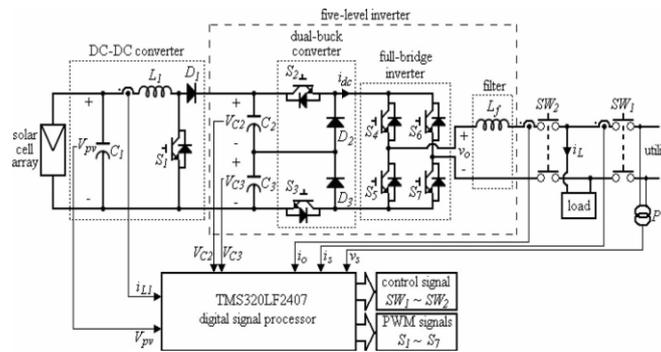


Fig.1. Circuit topology of the developed solar power generation system.

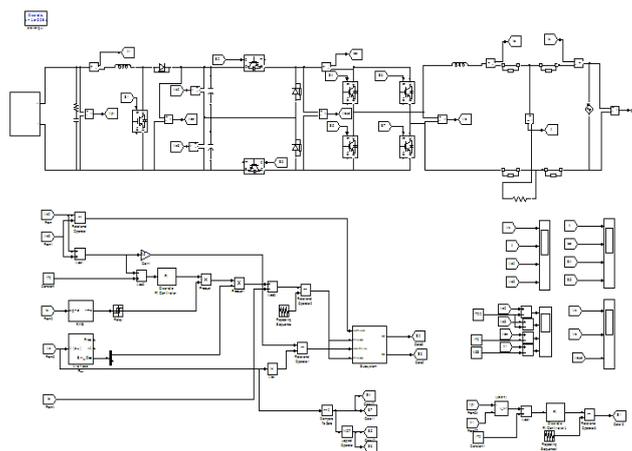


Fig 2.simulation circuit diagram

1.2 principle and modes of operation of five level inverter.

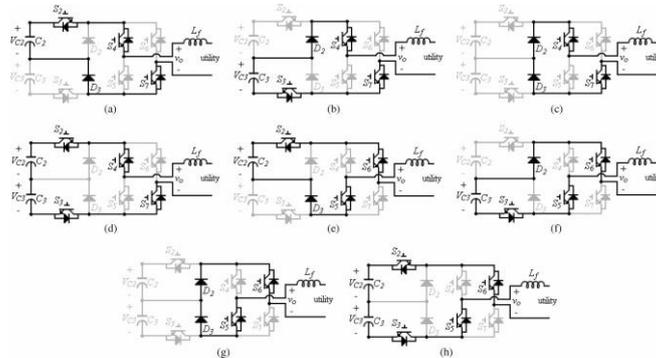


Fig. 3. Operation modes of the five-level inverter. (a) Mode 1. (b) Mode 2. (c) Mode 3. (d) Mode 4. (e) Mode 5. (f) Mode 6. (g) Mode 7. (h) Mode 8.

The operation of this five-level inverter can be divided into eight modes. Modes 1–4 are for the positive half-cycle, and modes 5–8 are for the negative half-cycle. Fig. 3 shows the operation modes of five-level inverter. As can be seen, the power electronic switches of the full-bridge inverter are switched in low frequency and synchronously with the utility voltage to convert the dc power into ac power for commutating. As seen in Fig. 3(a)–(d), the power electronic switches $S4$ and $S7$ are in the ON state, and the power electronic switches $S5$ and $S6$ are in the OFF state during the positive half-cycle. On the contrary, the power electronic switches $S4$ and $S7$ are in the OFF state, and the power electronic switches $S5$ and $S6$ are in the ON state during the negative half-cycle. Since the dc capacitor voltages $VC2$ and $VC3$ are balanced by controlling the five-level inverter, the dc capacitor voltages $VC2$ and $VC3$ can be represented as follows: $VC2 = VC3 = 1/2V_{dc}$. The operation modes of this five-level inverter are stated as follows.

Mode 1: Fig. 2(a) shows the operation circuit of mode 1.

The power electronic switch of the dual-buck converter $S2$ is turned ON and $S3$ is turned OFF. DC capacitor $C2$ is discharged through $S2$, $S4$, the filter inductor, the utility, $S7$, and $D3$ to form a loop. Both output voltages of the dual-buck converter and five-level inverter are $V_{dc}/2$. **Mode 2:** Fig. 2(b) shows the operation circuit of mode 2. The power electronic switch of the dual-buck converter $S2$ is turned OFF and $S3$ is turned ON. DC capacitor $C3$ is discharged through $D2$, $S4$, the filter inductor, the utility, $S7$, and $S3$ to form a loop. Both output voltages of the dual-buck converter and five-level inverter are $V_{dc}/2$. **Mode 3:** Fig. 2(c) shows the operation circuit of mode 3. Both power electronic switches $S2$ and $S3$ of the dual-buck converter are turned OFF. The current of the filter inductor flows through the utility, $S7$, $D3$, $D2$, and $S4$. Both output voltages of the dual buck converter and five-level inverter are 0. **Mode 4:** Fig. 3(d) shows the operation circuit of mode 4. Both power electronic switches $S2$ and $S3$ of the dual-buck converter are turned ON. DC capacitors $C2$ and $C3$ are discharged together through $S2$, $S4$, the filter inductor, the utility, $S7$, and $S3$ to form a loop. Both output voltages of the dual-buck converter and five-level inverter are V_{dc} . Modes 5–8 are the operation modes for the negative half cycle. The operations of the dual-buck converter under modes 5–8 are similar to that under modes 1–4, and the dual-buck converter can also generate three voltage levels $V_{dc}/2$, $V_{dc}/2$, 0, and V_{dc} , respectively. However, the operation of the full-bridge inverter is the opposite. The power electronic switches $S4$ and $S7$ are in the OFF state, and the power electronic switches $S5$ and $S6$ are in the ON state during the negative half-cycle. Therefore, the output voltage of the five-level inverter for modes 5–8 will be $-V_{dc}/2$, $-V_{dc}/2$, 0, and $-V_{dc}$, respectively.

1.3. control block diagram

The developed photovoltaic power generation system consists of a dc–dc power converter and the five-level inverter. The five-level inverter performs the functions of converting the dc power into high-quality ac power

and injecting it into the utility, balancing two dc capacitor voltages V_{C2} and V_{C3} , and detecting the islanding operation. The dc-dc converter boosts the output voltage of the solar cell array and performs the MPPT to extract maximum output power of the solar cell array. The controllers of both the dc-dc converter and the five-level inverter are explained as follows.

Fig. 4 shows the control block diagram of five-level inverter. In the operation of the five-level inverter, the dc bus voltage must be regulated to be larger than the peak voltage of the utility, and the dc capacitor voltages of $C2$ and $C3$ must be controlled to be equal. Besides, the five-level inverter must generate a sinusoidal current in phase with the utility voltage to be injected into the utility. As seen in Fig. 6, the voltages of dc capacitors $C2$ and $C3$ are detected and then added to obtain a dc bus voltage V_{dc} . The added result is subtracted from a dc bus setting voltage V_{dc_set} . The dc bus setting voltage V_{dc_set} is larger than the peak voltage of the utility. The subtracted result is sent to a P-I controller. An islanding detection is also incorporated into the control of the five-level inverter. The concept of this islanding detection was proposed by authors. However, it will not be addressed in this paper. As seen in Fig. 4, the utility current is detected and sent to an RMS detection circuit. The output of the RMS detection circuit is sent to a hysteresis comparator that contains a low threshold value and a high threshold value. If the RMS value of the utility current is smaller than the low threshold value, the output of the hysteresis comparator is high, meaning the condition of islanding operation or power balance occurs. On the contrary, the output of the hysteresis comparator is low when the RMS value of the utility current is larger than the high threshold value, meaning the utility is normal. The output of the hysteresis comparator is sent to a signal generator. The output signal of the signal generator is an islanding control signal S_a with the detected utility voltage. The complementary square signals are the control signals of the power electronic switches of the full-bridge inverter. As mentioned earlier, only two power electronic switches $S2$ or $S3$ in the five-level inverter should be switched in high frequency, and only one of them is switched in high frequency at any time, and the voltage level of every switching is $V_{dc}/2$. Therefore, the five-level inverter can reduce the switching loss effectively.

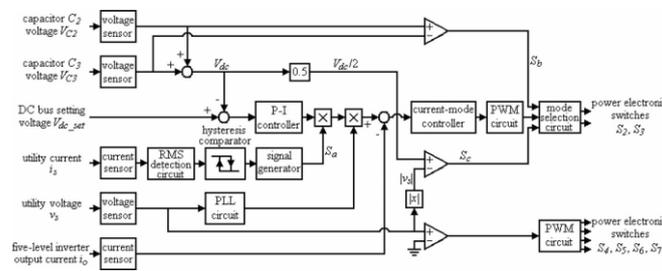


Fig.4. Control block diagram of five-level inverter.

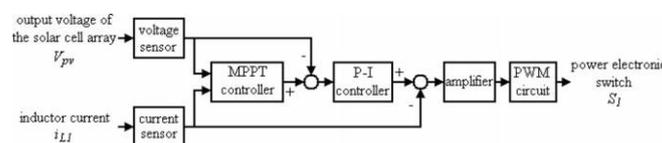


Fig. 5. Control block of the dc-dc converter.

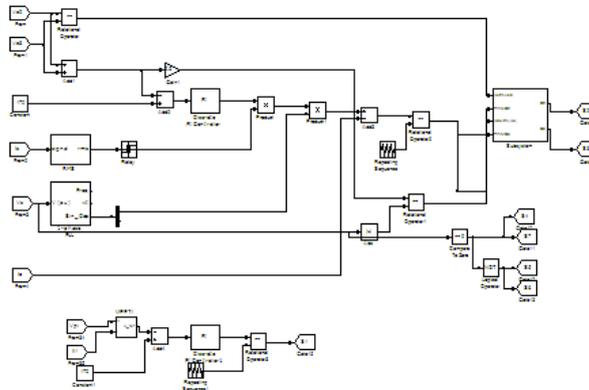


Fig 6 simulation diagram of control strategy

TABLE I
COMPARISON OF FIVE-LEVEL INVERTERS

	diode-clamped	flying capacitor	cascade H-bridge	developed inverter
power electronics	8	8	8	6
capacitors	2	4	2	2
balancing voltages of capacitors	hard	hard	hard	easier
high-frequency switching switches	8	8	8	2

2. Simulation Results

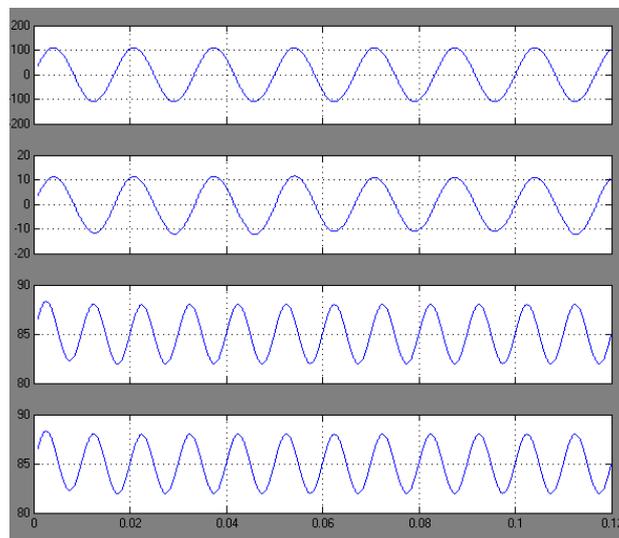


Fig 5. Simulation results of the five-level inverter. (a) Utility voltage. (b) Output current of the five-level inverter. (c) DC capacitor voltage VC 2. (d) DC capacitor voltage VC 3.

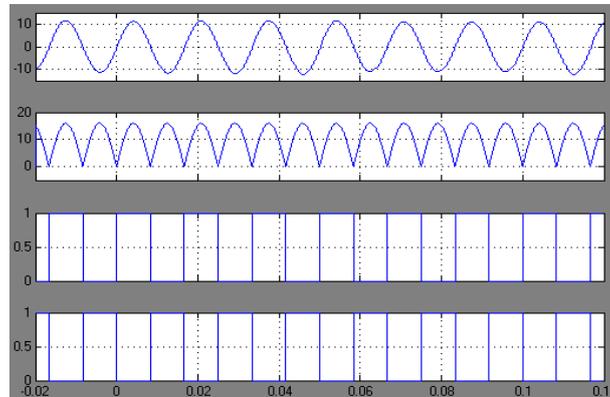


Fig 6. .Simulation results for full-bridge inverter of the five-level inverter.(a) Output current of the full-bridge inverter i_o . (b) Input current of the full bridge inverter i_{dc} . (c) Driver signal of S_4 . (d) Driver signal of S_5 .

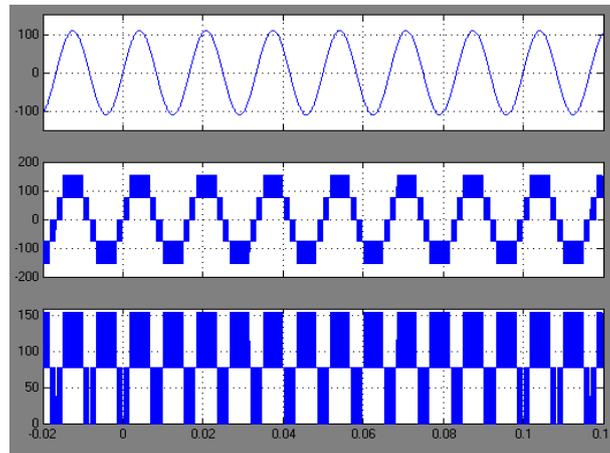


Fig.7. Simulation results of the five-level inverter. (a) Utility voltage.
(b) Output voltage of the full-bridge inverter. (c) Output voltage of the dual buck converter.

3. CONCLUSIONS

A photovoltaic power generation system with a five-level inverter is developed. The five-level inverter can perform the functions of regulating the dc bus voltage, converting solar power to ac power with sinusoidal current and in phase with the utility voltage, balancing the two dc capacitor voltages, and detecting is landing operation. From the grid single phase diode rectifier with R-L load developed using matlab/ simulink software.

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BIOGRAPHIES

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