COMPARATIVE STUDY OF MULTILEVEL INVERTER TOPOLOGIES APPLICATION WITH PHOTOVOLTAIC CELL

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Abstract – This paper proposes the solar power generation with dc-dc converter and seven level inverter. Here in paper comparison between the diode clamped inverter which is traditional method and new proposed topology of inverter is made. Photovoltaic cell is used as dc voltage source which is fed to dc-dc converter and then to dc- ac inverter. The new proposed topology has less number of power electronic switches as compared to any traditional inverter topology. Here in this paper we have discuss in what aspect new proposed topology is advantageous to the traditional one.

Keywords - DC-DC converter, DC-AC inverter, Photovoltaic cell.

I. INTRODUCTION

The use of fossil fuel has increased from past few decades so, it has been resulted into the global problem of greenhouse emission. Moreover, as the quantity of fossil fuel is decreasing day by day the prices of fossil fuel will increase simultaneously and it will become more expensive. Thus, solar power is becoming more important as it is free of cost, produces less pollution and the amount of solar array is reducing day by day. 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 interfacing of power conversion is important in grid connected solar power generation system as it converts dc power by PV cell to ac power that is fed to utility grid. An inverter is necessary in the power conversion interface to convert the dc power to ac power [2-5]. As we now that the output voltage of PV cell is very low hence, dc-dc power converter is needed in between the PV cell and inverter to boost the voltage level so, it can come to level of inverter dc bus voltage. The efficiency of power conversion of power conversion interface is important to insure that there should be as low as possible losses from solar cell array.

Non-conventional energy sources are option to non-renewable sources as fossil fuel. The conventional energy sources are limited and can be exhausted. Thus, the use of renewable energy sources such as solar, wind, biomass, hydro, geothermal and ocean power are increased. The use of wind and solar are less than the hydropower plant. The sufficient amount of power can be generated with the help of wind and solar energy. But the generation of wind is not constant as the wind is highly unpredictable as it can be here one moment and gone in another moment. But in case of solar the sun will present whole day. Solar energy is more important since it produced less pollution and the cost of fossil fuel energy is rising, while the cost of solar array is decreasing.

The power losses occurs due to active devices is combination of conduction losses and switching losses [6]. Conduction losses occurs due to use of active devices whereas switching losses is proportional to the voltage and the current changes for each switching and switching frequency.

Traditional multilevel inverters topologies are of three types (i) diode-clamped multilevel inverter, (ii) flying capacitors multilevel inverter and (iii) cascaded H-bridge multilevel inverter. In case of diode-clamped and flying capacitors multilevel inverter capacitors are used to achieve several levels from inverter. But the regulation of voltage of these capacitors are difficult. 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. In diode-clamped and flying capacitors multilevel inverter topologies for seven level twelve power electronics switches are needed in one leg of inverter. But in cascaded H-bridge asymmetrical voltage technology is used to achieve several level [7] so, it is suitable for application for more numbers of voltage levels.

In this paper there is comparison between diode-clamped multilevel inverter and new proposed topology consist of full-bridge power converter, connected in cascade. The seven-level inverter contains only six power electronic switches, which simplifies the circuit configuration.

II. CIRCUIT DISCRPTION

This paper consists of solar power generation system with seven level inverter as shown in fig. 1. Here there proposed solar power generation system includes solar panel array, dc-dc converter and seven level inverter. In dc-dc converter consist of dc-dc boost converter and a transformer with turn’s ratio 2:1 to achieve two independent voltage levels this is fed to seven level inverter. There are two types of inverter connected to dc-dc converter simultaneously in which one is new proposed technology and another one is conventional diode clamped multilevel inverter. Both inverter has seven level voltage level. In proposed technology capacitor \( C_1 \) and \( C_2 \) is used as input to inverter. New proposed technology consist of capacitor selection circuit and full bridge power converter connected in cascade. Due to multiple relationships between the voltages of the dc capacitors, the capacitor selection circuit outputs a three-level dc voltage. And this three level voltage is converted into seven level by inverter.

III. DC-DC POWER CONVERTER

As seen in fig. 2 DC-DC converter consist of a boost converter and current-fed forward conductor. Boost converter includes inductor \( L_D \), power electronic switch \( S_{D1} \), and diode \( D_{D3} \) from this boost converter charging of capacitor \( C_2 \) is done. Similarly current-fed forward converter includes inductor \( L_D \), power electronic switch \( S_{D1} \) and \( S_{D2} \), transformer and diode \( D_{D1} \) and \( D_{D2} \). It charges the capacitor \( C_1 \).

Fig. 3 shows the operation modes of DC-DC converter that are of two types. When switch \( S_{D1} \) is turned ON. Solar cell supply energy to inductor \( L_D \). When \( S_{D1} \) is OFF and \( S_{D2} \) is turned ON it will work as shown in fig. 3(b). The solar cell array and inductor

![Figure 1: Block diagram of proposed work](image-url)
Figure 2: Configuration of the proposed solar power generation system
L₂ charge capacitor C₂ through D₂,3, and capacitor C₁ through transformer and diode D₁ during OFF state of S₁. The voltage ratio of capacitor C₁ and C₂ are same as transformers turns ratio (2:1). Therefore, the voltages of C₁ and C₂ have multiple relationship.

Figure 3: Operation of dc–dc power converter: (a) S₁ is on and (b) S₁ is off

IV. SEVEN LEVEL INVERTER

Here we are used two types of seen level inverter one is traditional multilevel inverter that is diode clamped multilevel inverter and another one is proposed topology. The working of inverter are discuss below.

A. Proposed Seven Level Inverter

As shown in fig. 2 proposed technology consist of capacitor selection circuit and full bridge power converter connected in cascade. The operation of proposed seven level inverter divided into two parts positive half cycle and negative half cycle. The voltage across both capacitors C₁ and C₂ are constant and are equal to \( V_{dc}/3 \) and \( 2V_{dc}/3 \). From this two voltages we can obtained seven level output from inverter. The output current of seven level inverter is also positive in positive half cycle. Further operation of proposed seven level inverter in positive half cycle divided into four modes as shown in fig.4

Figure 4: 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 mode 1 operation is shown in fig. 4(a). Here both switches $S_1$ and $S_2$ of capacitor selection circuit are OFF. So, only capacitor $C_1$ will be connected to the circuit and discharge through diode $D_1$. Output voltage will be $\frac{V_{dc}}{3}$. $S_1$ and $S_4$ of bridge converter are ON and the output voltage will be equal to $V_{dc}/3$.

Mode 2: The mode 2 operation is shown in fig. 4(b). Now switch $S_{21}$ is OFF and $S_2$ is ON. So, the capacitor $C_2$ will connect across the circuit and it will discharge through $D_2$. The output voltage across the circuit is $2V_{dc}/3$. The switches $S_1$ and $S_4$ of bridge converter are ON. The output voltage of seven-level inverter will be $2V_{dc}/3$.

Mode 3: The mode 3 operation is shown in fig. 4(c). In this switch $S_{s1}$ is ON. So, diode $D_2$ will be reverse biased and capacitors $C_1$ and $C_2$ are now connected in series. Hence, the voltage across the circuit will be $V_{dc}$. $S_1$ and $S_2$ of bridge converter are ON. The output voltage of seven-level inverter is $V_{dc}$.

Mode 4: The mode 4 operation is shown in fig. 4(d). Here both switches $S_{s1}$ and $S_{s2}$ of capacitor selection circuit are OFF. Now only $S_4$ of bridge converter is ON. Since the output current of the seven-level inverter is positive and passes through the filter inductor, it forces the antiparallel 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.

Likewise we get the three different voltage levels in positive half cycle that are $V_{dc}/3$, $2V_{dc}/3$, $V_{dc}$ and 0. Similarly are turning ON switch $S_2$ and $S_3$ and turning OFF switches $S_1$ and $S_4$ operation of $n=mode$ 5, 6 and 7 can be achieve and $S_2$ is also ON during mode 8.

Figure 5: Operation of the seven-level inverter in the negative half cycle, (a) mode 5, (b) mode 6, (c) mode 7, and (d) 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 the seven-level inverter also has four levels: $-V_{dc}/3$, $-2V_{dc}/3$, $-V_{dc}/3$, and 0.

In summary, the output voltage of the seven-level inverter has the voltage levels: $V_{dc}/3$, $2V_{dc}/3$, $V_{dc}$, 0, $-V_{dc}$, $-2V_{dc}/3$, and $-V_{dc}/3$. 

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### Table no.1: States of power electronic switches for a proposed seven level inverter

|        | \( V_{dc}/3 \) | \( 2V_{dc}/3 \) | \( V_{dc}/3 \) | \( 2V_{dc}/3 \) |
|--------|----------------|----------------|---------------|----------------|
| Positive half cycle | S\(_{S1}\) | S\(_{S2}\) | S\(_{1}\) | S\(_{2}\) | S\(_{3}\) | S\(_{4}\) |
| \( |V|<V_{dc}/3 \) | off | off | pwm | off | off | on |
| \( 2V_{dc}/3>|V|>V_{dc}/3 \) | off | pwm | on | off | off | on |
| \( |V|>2V_{dc}/3 \) | pwm | on | on | off | off | on |
|        | S\(_{S1}\) | S\(_{S2}\) | S\(_{1}\) | S\(_{2}\) | S\(_{3}\) | S\(_{4}\) |
| Negative half cycle | S\(_{S1}\) | S\(_{S2}\) | S\(_{1}\) | S\(_{2}\) | S\(_{3}\) | S\(_{4}\) |
| \( |V|<V_{dc}/3 \) | off | off | off | on | pwm | off |
| \( 2V_{dc}/3>|V|>V_{dc}/3 \) | off | pwm | off | on | on | off |
| \( |V|>2V_{dc}/3 \) | pwm | on | off | on | on | off |

#### B. Diode-Clamped Multilevel Inverter

One phase of a seven level diode clamped inverter is shown in Fig. 6. As it is shown in the circuit, in this type of multilevel we have only one DC-source and the DC-bus is split into N level by \( m-1 \) capacitors. Here \( m = 7 \) and we have six capacitors.

It is a conventional multilevel converter. In this converter capacitor is used to supply voltage across dc bus as shown in fig. two diodes are connected in circuit and it is clamped at neutral point so, it is also called as neutral point clamped multilevel converter. For \( m \) level of converter we need \((m-1)\) number of capacitor on dc bus. The number of diodes required for each phase will be \((m-1) \times (m-2)\). When the levels of output that is \( m \) is high then the number of diodes and power electronic switches are sufficiently more.

There are ten diodes. These diodes clamp the switching voltage to half level of the dc-bus voltage. The neutral point N is considered as the reference point. To produce a seven-level voltage, seven switch combinations must be used. Although each active switching device is only required to block a voltage level of \( V_{dc}/(m-1) \), the clamping diodes must have different voltage rating for reverse voltage blocking.

![Figure 6: Diode-clamped seven level inverter.](image)

#### V. CONTROL BLOCK

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.
A. DC–DC Power Converter

Fig. 7 shows the control block diagram for the dc–dc power converter. The input for the DC-DC power converter is the output of the solar cell array. A ripple voltage with a frequency that is double that of the utility appears in the voltages of C_1 and C_2, when the seven-level inverter feeds real power into the utility. The MPPT function is degraded if the output voltage of solar cell Array contains a ripple voltage. Therefore, the ripple voltages in C_1 and C_2 must be blocked by the dc–dc power converter to provide improved MPPT. Accordingly, dual control loops, an outer voltage control loop and an inner current control loop, are used to control the dc–dc power converter. Since the output voltages of the DC-DC power converter comprises the voltages of C_1 and C_2, which are controlled by the seven-level inverter, the outer voltage control loop is used to regulate the output voltage of the solar cell array. The inner current control loop controls the inductor current so that it approaches a constant current and blocks the ripple voltages in C_1 and C_2. The perturbation and observation method is used to provide MPPT. The output voltage of the solar cell array and the inductor current are detected and sent to a MPPT controller to determine the desired output voltage for the solar cell array. Then the detected output voltage and the desired output voltage of the solar cell array are sent to a subtractor and the difference is sent to a PI controller. The output of the PI controller is the reference signal of the inner current control loop. The reference signal and the detected inductor current are sent to a subtractor and the difference is sent to an amplifier to complete the inner current control loop. The output of the amplifier is sent to the PWM circuit. The PWM circuit generates a set of complementary signals that control the power electronic switches of the dc–dc power converter.

Figure 7: Control circuit of dc-dc converter

There are many types of MPPT and they are mainly classified into five types that are

• Hill Climbing Technique
• Fuzzy Logic
• Neural Network
• Fraction open circuit voltage
• Fraction short circuit current

The Hill climbing technique has sub classification as a) Perturb and Observe and b) Incremental conductance. The MPPT technique used is Perturb and Observe and its flowchart is shown in fig. 8. In this method, the sign of the last perturbation and the sign of the last increment in the power are used to decide what the next perturbation should be on the left of the MPP incrementing the voltage increases the power whereas on the right decrementing the voltage increases the power. If there is an increment in the power, the perturbation should be kept in the same direction and if the power decreases, then the next perturbation should be in the opposite direction. Based on these facts, the algorithm is implemented. The process is repeated until the MPP is reached. Then the operating point oscillates around the MPP.

A. Proposed Seven Level Inverter
In proposed seven level inverter the control of bridge converter and capacitor selection circuit. the 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 . The flowchart of program fed in embedded matlab function is shown in fig.9.

![Figure 9: Algorithm for capacitance selection circuit.](image)

In bridge converter control circuit the utility voltage is sensed by voltage sensor and it is given to phase-lock loop (PLL) circuit in order to generate a sinusoidal signal with utility amplitude. The utility current is sensed with the used of current sensor and the output of phase-lock loop and utility current is compared and fed to the PI controller. From PI controller it is sent to PWM circuit and its output is given as pulses to all four switches of bridge converter.

![Figure 10: Control circuit for bridge converter.](image)
VI. SIMULATION RESULTS

With the proper implementation of the proposed MLI topology and diode clamped seven level inverter we obtain seven level voltage waveform. Output voltage waveform of proposed topology with and without LC filter is shown in fig.11 and fig. 12 respectively, whereas fig. 13 shows the seven level voltage waveform of diode-clamped seven level inverter.

![Figure 11: Output Voltage Waveform of Proposed Seven Level Inverter.](image1)

![Figure 12: Output Voltage Waveform of Proposed Seven Level Inverter with LC filter.](image2)

![Figure 13: Output Voltage Waveform of Diode-Clamped Inverter.](image3)

VII. CONCLUSION

This paper presents comparison between new proposed topology of seven inverter and diode-clamped seven level inverter. Proposed topology of seven level inverter needs less number of bidirectional switches in comparison with diode-clamped. Hence, the losses occurring that are switching loss and conduction loss are reduced. The THD contained in proposed topology is 14.52% whereas, diode-clamped topology has 36.39%. The requirement of capacitors and clamping diodes are less in proposed topology.

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