MODELING AND SIMULATION OF SOLAR PHOTOVOLTAIC APPLICATION BASED MULTILEVEL INVERTER WITH REDUCED COUNT TOPOLOGY FOR STAND-ALONE SYSTEM

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ABSTRACT

As the solar market is blooming and forecasted to continue this trend in the coming years. The efficiency and reliability of PV based system has always been a contention among researchers. Therefore, multilevel inverters are gaining more assiduity as it has multitude of benefits. It offers high power capability along with low output harmonics. The main disadvantage of MLI is its complexity and requirement of large number of power devices and passive components. This paper presents a topology that achieves 37.5% reduction in number of passive components and power devices for five-level inverter. This topology is basically based on H-bridge with bi-directional auxiliary switch. This paper includes a stand-alone PV system in which designing and simulation of Boost converter connected with multilevel inverter for ac load is presented. Perturb and observe MPPT algorithm has been implemented to extract maximum power. The premier objective is to obtain Voltage with less harmonic distortion economically. Multicarrier Sinusoidal PWM techniques have been implemented and analysed for modulation scheme. The Proposed system is simulated in MATLAB/Simulink platform.

KEYWORDS

MLI; P&O MPPT algorithm; MC-SPWM; Boost converter.

1. INTRODUCTION

Increasing energy demands due to population growth and technology advancement, there is tremendous stress on our environment. Majority of electrical production are provided by fossil fuels like coal, natural gas and oil which contribute highly to the increasing CO₂ production. Photovoltaic power generation is a technology that directly transforms unlimited, unpolluted and free solar energy into electric energy. Renewable energy resources include solar, wind, biomass, geothermal and tidal. These energy resources are not only clean, sustainable but also available in a large amount. However, there are some disadvantages with these sources like unreliability in supply, resource location and cost which prevents them from entering in mainstream energy sources. Solar Energy is becoming quite significant among sustainable energy system since it offers many advantages such as no fuel cost, no pollution, requirement of little maintenance and no noise. But solar PV system is accused of having relatively low conversion efficiency in order of (12%-15%), high installation cost, and energy fluctuation and location dependency. The output power of PV array is dependent on temperature as well as solar radiation or insolation [1]. So with the variation in environmental temperature or insolation, PV power and maximum power point also varies. The non-linear characteristics of PV panel and underutilization (because of shading or low insolation) do affect the efficiency of a PV array. For tracking of a maximum operating point under a different environmental condition, we use controlled converter with maximum power point tracking algorithm. To make it use as standalone it must be converted from dc to ac with high efficiency and less total harmonic distortion. Therefore, multilevel inverter can be a good option for this.

High power applications are in demand now-a-days. Many industrial applications require medium voltage and high power level [2]. Therefore, multilevel inverter can be a good alternative for applications like PV panel, wind and fuel cell. Conventionally, there are three topologies for MLI. But now-a-days researchers are working on reduced count topology because conventional topologies require a lot of power electronic switches and capacitors. The rating of these power electronics switches depend on the dc voltage source to which it is connected. Multilevel inverter has lots of advantages over conventional inverter. The voltage generated by MLI contains very less harmonics. Common mode voltage produced by MLI is very less which reduces stress on motor bearings. Input current of MLI contains less distortion. In addition to these MLI also works on low switching frequency which causes less switching loss and high efficiency.

2. PROPOSED SYSTEM

This system consists of two stage stand-alone PV system in which voltage is stepped up by boost converter and then is converted to AC with the help of MLI. The P&O MPPT algorithm is implemented to control the duty cycle of boost converter. The output voltage obtained by MLI consists of five levels with multicarrier sinusoidal pulse width modulation scheme. The block diagram of the stand-alone solar PV system is shown in figure 1.

Figure1. Block diagram of system configuration

3. SOLAR PV ARRAY

3.1 OVERVIEW

The proportional single diode model of a viable PV cell is shown in figure....It is also termed as five parameter model(n , R_{sh} , R_s , I_o , I_{ph}). R_s is acquainted as with consider the voltage drops and inward misfortunes in because of stream of current. R_{sh} takes into record the spillage current to the ground when diode is backward one-sided.

Figure2. Practical single diode model of PV cell

Where,

n is ideality factor of diode

R_S is series resistance

R_{sh} is parallel resistance

I_{ph} is photon current which is directly proportional to solar insolation

I_D is diode current

3.2 SPECIFICATION OF SOLAR PV ARRAY

UE Solar ZHM175 is the Solar Module that has been taken for Analysis and its data sheet is shown in Table 1 [3]-[4].

Parameters	Values
Maximum Power (W)	174.93
Cells per module (N_{cell})	72
Open circuit voltage V_{oc} (V)	42.84
Short-circuit current I_{sc} (A)	5.39
Voltage at MPP, V_{mp} (V)	35.7
Current at MPP, I_{mp} (A)	4.9
Temperature coefficient of V_{oc} ($\%/^{\circ}\text{C}$)	-0.3803
Temperature coefficient of I_{sc} ($\%/^{\circ}\text{C}$)	0.053154

Table1.Parameters of solar module at insolation of 1000 W/m^2 and temperature of 25°C

The array is taken to get maximum power of 110kW approximately and is connected as:

Number of Parallel Strings = 70

Number of Series Connected modules per String = 9

I-V and P-V characteristics of the PV array taken are shown in Figure 3-6

Figure3. Solar PV characteristic with different insolation and constant temperature.(a) Solar I-V characteristic; (b)P-V characteristic

Figure4. Solar PV Characteristic With Different Temperature And Constant Insolation.(A) Solar I-V Characteristic; (B) Solar P-V Characteristic

4. BOOST CONVERTER

4.1. OVERVIEW

Boost converter is a class of switch-mode power supply which is used to step up DC voltage, having two semiconductor switches and two energy storing element as shown in figure7. When switch S is turned on, current flows through inductor and energy is stored. When Switch S is turned off, stored energy provides an induced voltage that is responsible for stepping up of voltage.

Figure5. Circuit diagram of boost converter

4.2. DESIGNING OF BOOST CONVERTER

While designing we have considered ideal boost converter. Selection of Inductor is done on the basis of estimated Inductor current ripple and can be calculated as [5]

$$L = \frac{V_i \times (V_o - V_i)}{\Delta I_L \times f_s \times V_o} \quad (1)$$

Where, ΔI_L is the estimated inductor current ripple and can be calculated as

$$\Delta I_L = 0.1 \times I_{L(max)} \quad (2)$$

Above calculated value of inductor must be more than the critical value of inductor (L_C) otherwise boost converter will not be able to operate in current continuous mode. Critical Inductance can be calculated as

$$L_C = \frac{D \times (1-D)^2 \times R_o}{2 \times f_s} \quad (3)$$

Selection of output capacitor is done on the basis of output voltage ripple and can be calculates as

$$C = \frac{D}{R_o \times f_s \times (\Delta V_o / V_o)} \quad (4)$$

Where, ΔV_o is the desired output voltage ripple and for voltage ripple of 1% of output voltage above equation can be rewritten as

$$C = \frac{D}{R_o \times f_s \times 0.01} \quad (5)$$

D is the duty cycle corresponding to MPP and can be calculated as

$$D = 1 - \sqrt{\frac{Z_{MPP}}{Z_o}} \quad (6)$$

Where, Z_{MPP} is the input impedance at Maximum Power Point and can be calculated as,

$$Z_{MPP} = \frac{V_{MPP}}{I_{MPP}} \quad (7)$$

Load impedance must be chosen as

$$Z_o \geq Z_{MPP}$$

Parameters	Values
V_{MPP}	320
I_{MPP}	343
D	0.9
Frequency	5KHz
V_o	3300
Inductor (L)	6mH
Output Capacitor (C_{out})	1mF
Input Capacitor(C_{in})	0.1mF

Table 2.Parameters of ideal boost converter

5. MPPT TECHNIQUE

Several MPPT techniques together with their implementation are explained in the literature [6]-[10]. Researchers always face problem while choosing an MPPT technique for a particular application. Unfortunately, only a few techniques were available in this field including Curve fitting, Fractional Short Circuit Current, Fractional Open Circuit Volta Among all the MPPT methods, Perturb & Observe (P&O) and Incremental Conductance (IC) are most generally used because of simple implementation and less tracking time to track the maximum power point. Under suddenly changing weather conditions Incremental Conductance method can be a good choice. However, instead of more efficiency the complexity of the algorithm is very high compared to the former one and hence the cost of execution increases. So we have to extenuate with a trade-off between ramification and efficiency. Therefore, keeping in view the complexity and easy implementation P&O method is used here to track maximum power.

5.1. PERTURB & OBSERVE ALGORITHM

Perturb and observe (P&O) method is mostly used out of other method as it is simple and less expensive [11]. This algorithm is based on the sign of slope of P-V curve of solar module. In this algorithm, voltage is perturbed and slope (dP / dV) is checked whether it is positive, negative or zero. If the slope is zero then that point is MPP and if slope is negative then voltage is perturbed in reverse direction else voltage perturbation is continued in same direction until we reach peak point. The algorithm for P&O is shown in Figure8.

Figure6. Flow chart of P&O MPPT algorithm

6. MLI TOPOLOGY

6.1. CIRCUIT CONFIGURATION

The proposed MLI consists of a basic cell which produces five level of output voltage. The circuit diagram is shown in the figure9.

Figure7. Circuit diagram of diode clamped MLI

Proposed topology contains minimum number of switches for generating same number of output levels as compared to conventional MLI. This topology basically uses one voltage sources V_s (here voltage source represent stepped up DC-output voltage from PV arrays) and four power devices (Q1, Q2, Q3, Q4) and one auxiliary switch (S1) with four diodes.

<i>Multilevel Inverter Type</i>	<i>Diode clamped</i>	<i>Capacitor Clamped</i>	<i>H Bridge</i>	<i>Asymmetric Cascade</i>
<i>Main Controlled Switches</i>	8	8	4	8
<i>Auxiliary Controlled Switches</i>	0	0	1	0
<i>Diodes</i>	20	8	8	8
<i>Capacitors</i>	4	10	2	2

Table 3.Comparison of Number of components between different five levels MLI

6.2. WORKING

The table 4 below gives the switching states of basic cell of proposed MLI. Here logic '1' is considered as 'ON' state and logic '0' is considered as 'OFF' state of the switches.

<i>S1</i>	<i>Q1</i>	<i>Q2</i>	<i>Q3</i>	<i>Q4</i>	<i>Levels</i>
0	1	0	0	1	V_s
1	0	0	0	1	$V_s/2$

0	0	0	1	1	0
1	0	1	0	0	$-V_s/2$
0	0	1	1	0	$-V_s$

Table 4.Switching Pattern of 5-level MLI

Reactive load has been considered as load in this case. At the Output terminal of boost converter, two capacitors are connected in parallel so that no voltage swing is produced in normal operation.

7. MODULATION SCHEME

Appropriate Modulation Scheme is always required to generate and control high quality Output of MLI. Various techniques for modulation have been discussed in literature like Multi-carrier Pulse width Modulation and space Vector modulation [13]. Here, due to simplicity and easy implementation MCPWM scheme has been discussed.

To generate five levels output four carrier signals are required. Different way to generate multi-carrier signals based on level shift has been shown in figures 6.

Figure8.Classification of PWM modulation schemes

7.1. PHASE DISPOSITION (PD-PWM)

Figure9. PD scheme waveform

In this scheme all the carrier signals are in phase and level Shifted. The zero reference is placed at the middle of the carrier set.

7.2. PHASE OPPOSITION DISPOSITION (POD-PWM)

Figure10. POD Scheme waveform

In this scheme all the carrier signal above zero reference are in same phase and all the carrier signals below zero reference are shifted by 180 degree.

7.3. ALTERNATE PHASE OPPOSITION DISPOSITION (APOD-PWM)

Figure11.APOD Scheme waveform

In this technique all the carrier signals are alternately disposed in Phase by 180 degree. Reference signal is placed in the middle of carrier.

The comparison of different modulation schemes are shown in Table4. Here m_a and m_f are amplitude and frequency modulation index respectively.

$$m_a = \frac{A_m}{(m-1)A_c} \quad (8)$$

$$m_f = \frac{f_c}{f_m} \quad (9)$$

Where, A_m and A_c is amplitude of modulating and carrier signal respectively. f_m and f_c are frequency of modulating and carrier signal. Number of level is represented as m .

	PD $m_a = .85$ $m_f = 40$	POD $m_a = .85$ $m_f = 40$	APOD $m_a = .85$ $m_f = 40$
THD % in voltage waveform	23.37	22.23	22.67

Table4. Comparison of THD % with different modulation schemes

8. SIMULATION RESULTS

The following results are obtained with constant insolation of 1000 W/m^2 and Temperature of 25°C . The switching frequency of boost converter and inverter is taken 5 KHz and 2 KHz respectively. Resistance of 100 ohm is taken as load.

Figure12.PV voltage of solar panel

Figure13.PV Current of solar panel

Figure14.PV power of solar panel

Figure15.Output voltage of boost converter

Figure16.Output Current of boost converter

Figure17. Duty cycle of boost converter

Figure18. Output voltage of MLI

Figure20. Output Current of MLI

9. CONCLUSION

The paper presents a comprehensive analysis and simulation in MATLAB Simulink. The P-V and V-I curve is plotted for different temperature and insolation. The P&O MPPT algorithm is also implemented to extract maximum power with direct duty ratio control. Different curves of PV voltage, PV current, Boost converter outputs are obtained. Output voltage with five levels is obtained as expected with the bi-directional switch. The THD in output voltage of system is 22.23% without any filter. A significant reduction in number of switches is obtained. The aforementioned topology can also be used for asymmetric source configuration. Number of levels can also be increased by connecting this topology in cascade manner, as the number of levels increase it ameliorate the power quality and can moderate the need of filter.

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