Power Quality Enhancement in Photovoltaic System Using Cascaded Sinusoidal PWM Multilevel Inverter

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Abstract - Over the past two decades, multilevel inverters have become popular among research and development groups for high and medium industrial applications. The multilevel inverters, in recent times attracted more interest due to their ability to produce high-quality waveforms at lower frequencies; the multilevel topology used in the dynamic voltage reduces the harmonic distortion of the output waveform without causing loss in the inverter output. A new multi-level inverter is additionally used with a two-way switch between the capacitor and the conventional H-bridge module. By connecting these two H-bridge modules in series, nine output voltage levels are possible including zero. This paper explores the most popular topologies that incorporate control techniques for multilevel inverters, making their deployment flexible in many industrial sectors and in several power applications. The aim of the proposed topology is to reduce the number of switches and provide good results with relatively less power loss compared to other conventional basic conventional inverters. In this paper, sinusoidal pulse width modulation technique is used to operate the switching devices of multi-level inverters. According to the results, we observe that the topology is proposed with reduced quantity switches gives lower electromagnetic interference, lower harmonic distortion.

Keywords- Harmonics, Multilevel Inverter, Power Quality, Voltage Regulation.

1. INTRODUCTION

In recent trends, photo-voltaic (PV) is mostly build upon competitive technological development of power quality (PQ) issues As global energy demand continues to increase, alternatives are being sought to develop renewable, sustainable, efficient and inexpensive energy sources, such as solar power. One way to convert solar energy into electrical energy is to use photovoltaic cells. Photovoltaic system is a major source of power generation. Its production is affected by varying shading conditions due to climate change and other environmental factors. Modular multilevel converters(MMLCs)are a promising option for achieving high power. However, to gain greater voltage levels, traditional MMLCs need more cells, which influence complexity and losses. In this paper, a cascaded H-bridge MLI is proposed, which has few range of IGBT switches for the identical range of output levels, which subsequently reduces losses and improves output voltage. Power quality issues such as voltage, current, and capacity are also satisfactorily resolved by the converter. Due to changes in the input radiation and temperature, the output parameters such as voltage, current, and power show disturbances. Therefore, minimizing this imbalance in grid-connected converters is important to stabilize the control and quality of energy delivered to the grid.

One of the most advantageous converters is the multilevel inverters (MLIs).MLIs are nothing but the converters which have the high magnitude of the output voltage levels when compared with the common inverters. The main benefit of these MLIs is the superior output voltage levels Hence these MLIs will have a lower THD. The various types of MLIs are cascaded H-bridge (CHB), flying capacitor (capacitor clamped), and diode clamped (neutral clamped).The most common type of MLIs is the CHB because of its modular structure

Among these three, cascaded MLI (CMLI) has a modular structure and it has advantages of having less number of components when compared with the other two topologies, and moreover, it has many applications in the electrical field. There are several modulation and control strategies being, including the following: multilevel selective harmonic elimination, multilevel sinusoidal pulse width modulation, and space vector modulation (SVM).

The main difficulty of the SVM is that the mathematical modelling and the selection of switching states are complicated. To overwhelm these drawbacks, multicarrier PWM is used as the control strategy. Some literatures were gone through to identify some of the existing approaches to improve power output and quality of a solar PV system, some noteworthy points are mentioned below: Irradiance fluctuation between PV modules might cause the MPPT algorithms to operate inefficiently and result in an inaccurate control. [8] The PV system can be made more efficient by combining it with ANN and bio inspired forecasting methods to deal with upcoming uncertainties and in turn making better decisions which will help in improving power production. [5] Medium Voltage converters for grid integrated circuits are mostly proposed for NPC multilevel converters [9] and CHB multilevel converters [10–13]. CHB is one of the promising approach towards the high power photovoltaic system integration with the grid. In this topology, the resonant controller is incorporated which controls the imbalances produced due to the switching schemes of converter modules [14].Modular multilevel converter receives a lot of attention in industrial practices and research which leads to other studies related to its control, topological, and modulation schemes for attaining more advantages [15].The goal of this study is to examine the use of a various based controller to eliminate harmonics in order to improve quality of power as well as to increase the overall efficiency of a cascaded Multi Level inverter (MLI) based PV system.

2. METHODOLOGY:

Solar energy has attracted significant attention as an eco-friendly and sustainable means of generating electrical power. The use of cascaded multilevel inverters has seen a emergent popularity in the conversion of solar energy into compatible electricity, primarily due to their capability to supplyoutstanding voltage waveforms and counteract harmonic disturbances. Nevertheless, accomplishing an best possible power quality level remains a persistent challenge, particularly in the features of fluctuating solar irradiance and varying load conditions.

The smallest building block of a solar module comprises a P-N junction which is useful for converting the light energy into electrical energy and it is called the solar cell. The equivalent circuit of the solar cell is shown. It is a form of a tool for which the electrical parameters, such as current, voltage, or resistance, varies when exposed to sunlight. The solar panels can be used as a light sensitive cell (photo detector), which is helpful for detecting the solar light (infrared detectors),near the visible range

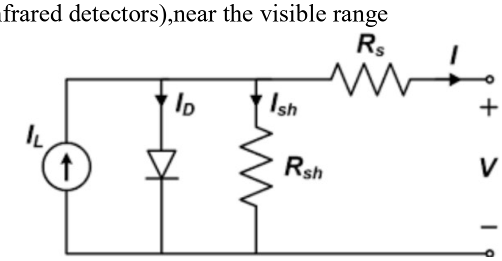


Figure.1 Equivalent circuit of solar cell

When a photovoltaic (PV) module is linked to a load, the consequent output voltage (V), current (I), and power (P) depend on the running state of the PV module. Different types of loads display unique I-V and P-V characteristic curves, with each PV module having its own distinctive I-V and P-V characteristic curve.

2.1 I-V and P-V characteristics.

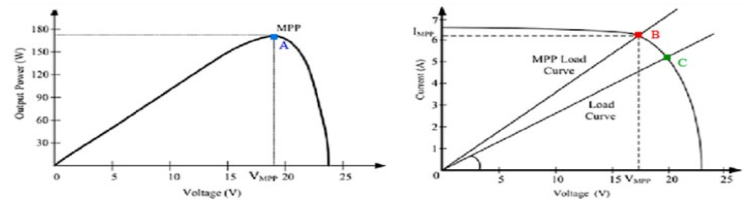
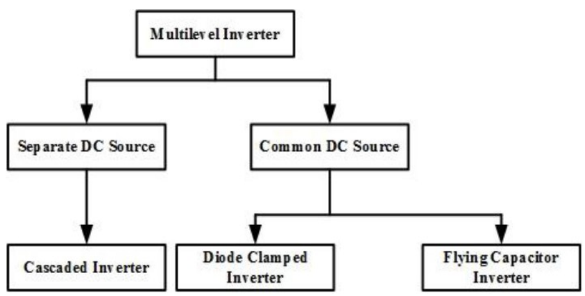


Figure.2 Generalized P-V And I-V Characteristic Curve of PV Module

Figure 2 indicatesillustrates a generalized P-V and I-V characteristic curve for a PV module A curve drawnbetween current and voltage. The area of this curve gives us theinformation about the maximum power that a panel could generate at the maximum current and the maximum voltage conditions. The region of this curve declines while increasing the solar cell voltage due to its incline in temperature. Because of the variations in environment conditions, the maximum power point will also change which indicates the change in temperature and irradiance levels.

3. INVERTER TOPOLOGIES

The inverter is an electronic control device that changes dc power at the appropriate frequency and output voltage into accurate power. The basic inverter deals for high switching losses, high frequency switching, and high voltage applications. This kind of reverse engine is faced with many issues, such as EMI, harmonic distortion and high switch tension. With the aid of a high voltage level in the converter, a high power rating is possible. This reduces the converter switch rate. This type of converter generates a smooth sine waveform from different levels of dc voltage. For different high power applications, it can simply be synchronised with renewable energy sources. The voltage of the DC link comes from renewable sources of electricity, from the rectifier.

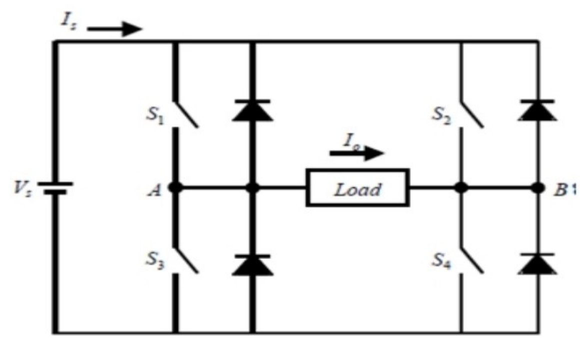


The main disadvantage of conventional CMLI is more number of DC sources and as the level increases, the number of devices also inclines. So as to achieve this, an improved topology has been introduced. The merits of this novel topology are the number of switches and the numbers of sources that are required are reduced.

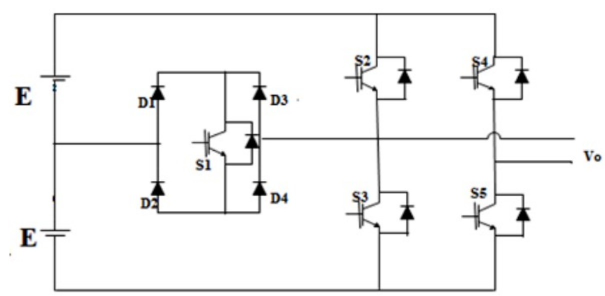
3.1 Proposed Cascaded H-Bridge Multilevel Inverter

A cascaded H-bridge multilevel inverter represents a multilevel inverter design that involves the connection of numerous H-bridge modules in a series configuration resulting in the generation of a superior quality output voltage waveform, as depicted in Figure 4. Within this cascaded arrangement, each H-bridge module typically consists of four power switches, as visually demonstrated in Figure 3 The operation of a cascaded H-bridge multilevel inverter involves the precise control of the switching states within the H-bridge modules to synthesize a stepped output voltage waveform. The quantity of voltage levels or steps within the output waveform corresponds directly to the number of H-bridge modules integrated into the cascaded configuration. Each H-bridge module contributes its unique voltage level, and the total number of levels depends on the quantity of modules used. By manipulating the distinct voltage levels offered by each H-bridge module, a multilevel output voltage can be generated. This output exhibits reduced harmonic content and an improved waveform quality when compared to conventional two-level inverters. Cascaded H-bridge multilevel inverters find widespread application in scenarios demanding high-power conversion and superior power quality, including renewable energy systems, motor drives, grid-connected systems, and high-voltage applications.

3.1.1 Cascaded H-bridge (CHB) 5- Level Multilevel Inverter



Basic building block of cascaded H-bridge multilevel inverter



5 - Level Cascaded H-bridge (CHB) Multilevel Inverter

The H-bridge circuit is equipped with eight semiconductor switches and 5 inverter levels. The DC input is connected to the H-bridge and provides 5 voltage output levels. These outputs differ with the control of 4 switches from -2 Edc to +2 Edc. This H-bridge series is related to multilevel inverter output and synchronises. The voltage steps are calculated by n=2s+1 in an H-bridge inverter. s- The number of DC sources and n- the output level of the inverter.

The switch combination has been shown in Table 1.

Switching sequence*(switch ON = 1, switch OFF = 0)					Output voltage (*Vo*)
S1	S2	S3	S4	S5	
0	1	0	0	0	2E
1	0	0	0	1	E
0	0 or1	1 or 0	0 or1	1 or 0	0
1	0	0	1	0	-E
0	0	1	1	0	-2E

3.1.2 Cascaded H-bridge (CHB) 7- Level Multilevel Inverter

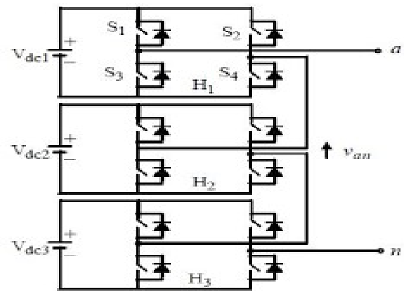
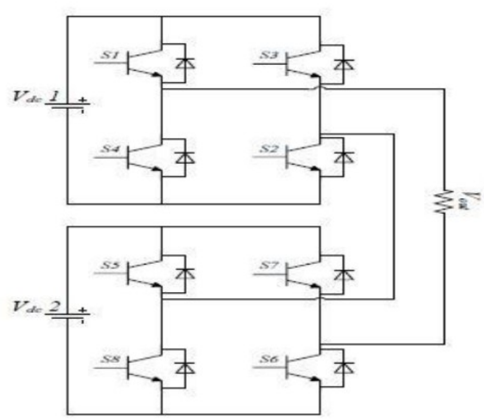


Figure:7- Level Cascaded H-bridge (CHB) Multilevel Inverter

In five-level each module in the inverter produces $2E$, E, 0, $-E$, $-2E$. In five-level each module in the inverter produces$2E$, E, 0, $-E$, $-2E$ Hence the proposed nine-level multilevel inverter can be formed by cascading operation of two five-level inverters. This produces the nine output voltages as $4E$, $3E$, $2E$, E, 0, $-E$, $-2E$, $-3E$, $-4E$. Since each of the terminal in the output of the inverter is connected in series; the output voltage will be obtained by adding the terminal voltages of every inverter

Switching sequence*(switch ON = 1, switch OFF = 0)							Output voltage (Vo)
S1	S2	S3	S4	S5	S6	S7	
0	1	0	1	1	0	0	3E
0		1	1		1	0	2E
1	0	0	1	1	0	0	E
0	0	0	0	0	0	0	0
1	0	0	1	0	1	1	-E
0	1	1	0	0	1	1	-2E
0	1	0	1	0	1	0	-3E

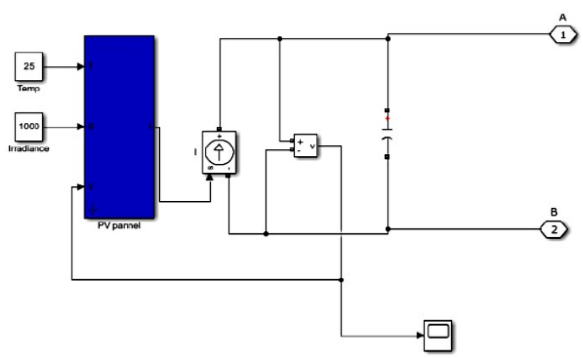


9- Level Cascaded H-bridge (CHB) Multilevel Inverter

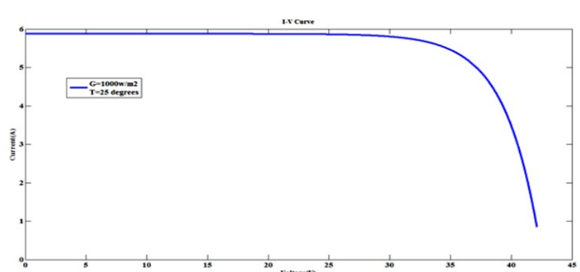
The switch combination has been shown in Table 2.

Switching sequence*(switch ON = 1, switch OFF = 0)										Output voltage (Vo)
S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	
0	1	0	0	1	0	1	0	0	1	4V
1	0	0	0	1	0	1	0	0	1	3V
0	0	0	0	0	0	1	0	0	1	2V
0	0	0	0	0	1	0	0	0	1	V
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	0	0	1	0	-V
0	0	0	0	0	0	0	1	1	0	-2V
1	0	0	1	0	0	0	1	1	0	-3V
0	0	1	1	0	0	0	1	1	0	-4V

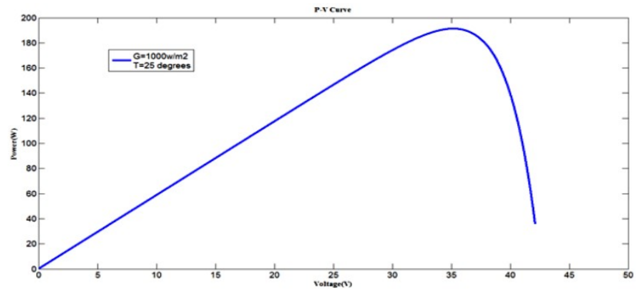
SIMULINK OUTPUT:
The design of the Multi-Level Inverter is simulated with different condition at the DC input. Firstly, the circuit is simulated with the same and equal values of DC input. The DC input assigned in this report is 12Volt. The relationship is analyzed from the results.
All this proposed work is verified in MATLAB. The technique of SPWM modulation is used for pulse generation. The solar panel is connected to the cascaded H-bridge MLI and the results are observed in Simulink. Figures 7, 8 show the PV and V-I characteristics of the solar collector. The output of this solar collector is taken at the temperature of 25 °C and at the radiance of 1000 W/m2.



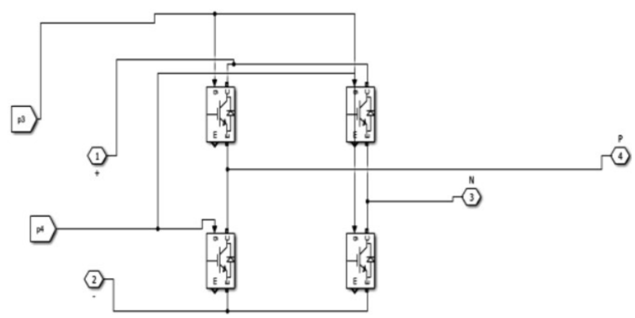
MATLAB/Simulink Implementation of PV Module



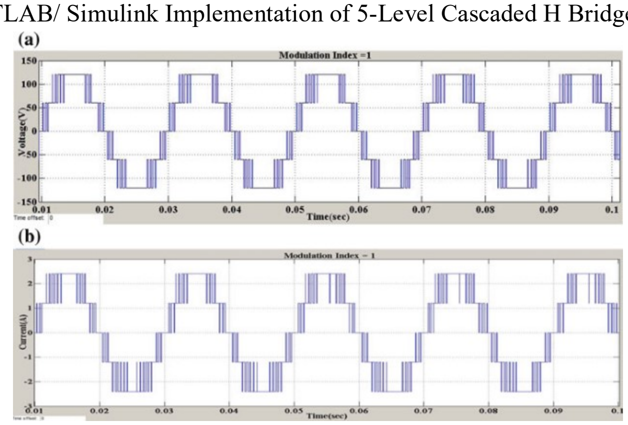
I-V characteristics of solar panel



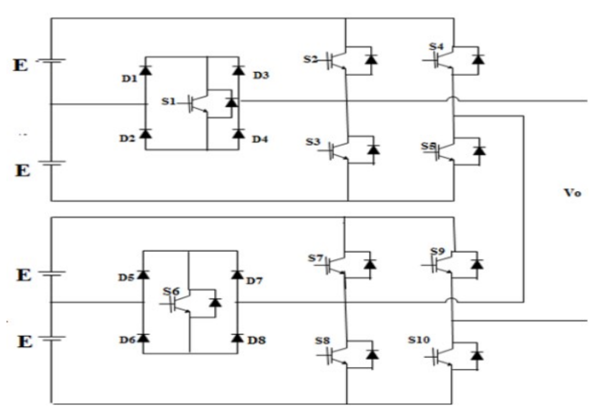
. P-V characteristics of solar panel



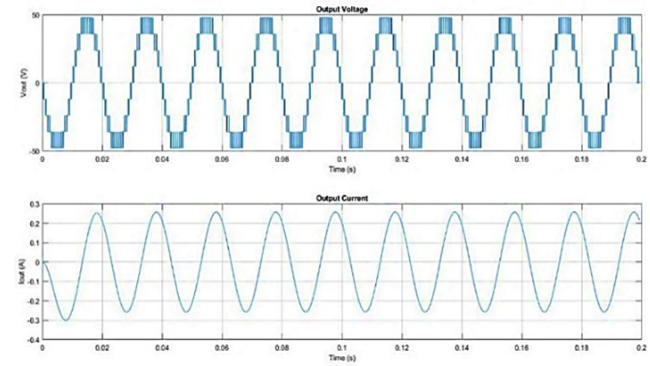
MATLAB/ Simulink Implementation of 5-Level Cascaded H Bridge MLI



9-Level Cascaded H Bridge Multi Level Inverter



MATLAB/ Simulink Implementation of 9-Level Cascaded H Bridge MLI



Output Waveform (Voltage & Current) of 9-Level MLI

Simulation results: The simulations for this paper include the 5-levels, 7-levels and 9-levels inverter and also a separated DC source. The %THD content for inverters of different voltage level are then compared and analyzed. The results show that the %THD decreased when the level of MLI increases. This indicates the increase of the output efficiency.

Variations of THD with various numbers of levels:

S.No	No. of levels	THD
1.	9	14.46 %
2.	7	18.95 %
3.	5	29.64 %

5. Conclusions

The research encompassed the effective realization of three various level (5,7,9) cascaded H-bridge multilevel inverter powered by solar energy, accomplished using MATLAB/Simulink. %. It shows that the percentage of THD decreased abruptly when the number of level increased. This meant that the harmonic distortion is decreased as the voltage level of a Cascaded H-Bridge MLI is increased. This contributes to the enhancement of power quality within the system, making it suitable for applications requiring grid integration and improved power quality. These studies pave the way for more efficient and reliable operation of renewable energy sources. In terms of upcoming research directions, several possibilities for attractive power quality in PV systems are measured. Suggestions include exploring hybrid control strategies, investigating real-time operational scenarios with experimental validation, integrating with the grid, and enhancing cost-effectiveness and scalability.

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