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Simulation Of Cascaded H-Bridge Multilevel Inverters For PV Applications

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Abstract: Now a days the renewable energy such as wind, solar, ocean, Biomass and geothermal powers are getting more attention with the increasing demand on energy, high oil prices and concern of environmental impacts increased. Among them Photovoltaic(PV) generation getting more importance due to absence of fuel cost, low maintenance, no noise, no moving parts and long life time. Multilevel inverters became more popular in the power conversion systems for high power and power quality demanding applications. Among different topologies of MLIs, Cascaded H-Bridge MLIs are more suitable converters for PV applications since each PV panel can act as a separate DC source for each CHB module. This paper presents a simulation analysis 5-level to 13-level CHBMLI for PV applications with the SPWM control technique using MATLAB/SIMULINK.
Key words: Photo voltaic (PV) cells; multilevel inverter (MLI); SPWM; THD.

I Introduction:

In recent years, there has been an increasing interest in electrical power generation from renewable-energy sources, such as photovoltaic (PV) or wind-power systems[1,10]. Among the different renewable-energy sources, solar energy has been one of the most active research areas in the past decades, both for grid-connected and Stand-alone applications. The basic concept of PV cell is to collect solar energy from sun and transfer it for distribution as electrical power[3]. However this collected solar energy requires conversion techniques to make them usable to the end users. Basically the output of the PV cell is DC form. For commercial purpose it needs to convert to AC form because most of the loads are AC loads.

Different topologies MLIs for the conversion from DC to AC are available such as Neutral point clamped MLI (NPC-MLI), Flying capacitor MLI (FC-MLI), Cascade H-Bridge MLI (CHB-MLI) and Asymmetrical Cascade H-Bridge Multilevel inverters. Among them CHB-MLIs are mostly used for PV applications because each cell of CHB-MLI requires separate DC sources which can be easily supplied by individual PV arrays and each H-Bridge cell will be available in a single module[6]. The number of levels of the output wave form increased by cascading the no. of H-Bridge cells.

There is a large no. of control techniques developed so far to control the operation of multilevel inverters such as SVPWM, SPWM, OHPWM, SHE-PWM, Hybrid modulation. In these techniques SPWM is the easy to increase the no. of levels in the output waveform with lower harmonic content[5]. In SPWM control technique the gate pulses generated by comparing the sinusoidal reference waveform with the Triangular carrier waveforms. This paper presents the simulation results of a 7-level CHB-MLI with SPWM control techniques for PV applications.

II. Photovoltaic system

A Photovoltaic (PV) system directly converts solar energy into electrical energy. The basic device of a PV system is the PV cell. Cells may be grouped to form arrays[1,7,10]. The voltage and current available at the terminals of a PV device may directly feed small loads such as lighting systems and DC motors or connect to a grid by using proper energy conversion devices.

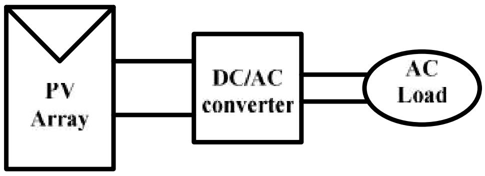

Figure 1: Block diagram representation of Photovoltaic system

This photovoltaic system consists of three main parts which are PV module, balance of system and load. The major balance of system components in this systems are charger, battery and inverter. The Block diagram of the PV system is shown in Fig. 1.

A. Photovoltaic cell

A photovoltaic cell is basically a semiconductor diode whose *p–n* junction is exposed to light. Photovoltaic cells are made of several types of semiconductors using different manufacturing processes. The incidence of light on the cell generates charge carriers that originate an electric current if the cell is short circuited[1].

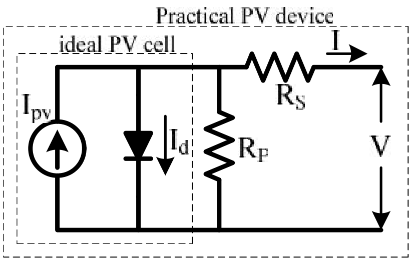

Figure 2: Practical PV device

The equivalent circuit of PV cell is shown in the fig. 2. In the above figure the PV cell is represented by a current source in parallel with diode. R_s and R_p represent series and parallel resistance respectively. The output current and voltage form PV cell are represented by I and V.

The I-V characteristics of PV cell are shown in fig.3. The net cell current I is composed of the light generated current I_{PV} and the diode current I_D.

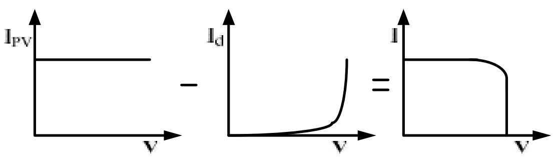

Figure 3: Characteridtics *I-V* curve of the PV cell

$I_{PV} - I_D = I$ (1)

Where,

$I_D = I_0 \exp(qV/akT)$

I_0= Leakage current of the diode

q= Electron charge

k= Boltzmann constant

T= Temperature of P-N junction

a= diode ideality constant

The basic equation of the PV cell does not represent the I-V characteristics of the PV cell. Practically PV arrays are composed of several connected PV cells and the observation of the characteristics at the terminals of PV array requires the inclusion of additional parameters to the basic equation.

$$I = I_{pv} - \left[\exp\left(V + \frac{R_s I}{V_t a}\right) - 1\right] - \frac{V+I}{R} \quad (2)$$

Where $V_t = N_S kT/q$ is the thermal voltage of array with N_S cells connected in series. Cells connected in parallel increase the current and cells connected in series provide greater output voltages[1-3]. The I-V characteristics of a practical PV cell with maximum power point (MPP), short circuit current (I_{SC}) and open circuit voltage is shown in fig. 3. The MPP represent the point at which maximum power is obtained.

V_{MP} and I_{MP} are voltage and current at MPP respectively. The output from PV cell is not the same throughout the day. It varies with varying temperature and amount of radiation. Hence with varying temperature and insolation maximum power should be tracked so as to achieve the efficient operation of PV system.

B. Cascaded H-Bridge Inverter

Cascaded H-Bridge multilevel converters formed by the series connection of two or more single phase H-Bridge inverters. Each H-Bridge corresponds to two voltage source phase legs, where the L-L voltage is the converter output. Therefore, a single H-bridge converter is able to generate three different voltage levels[4-6]. Each leg has only two possible switching states, to avoid dc-link capacitor short-circuit. Since there are two legs, four different switching states are possible, although two of them have redundant output voltage.

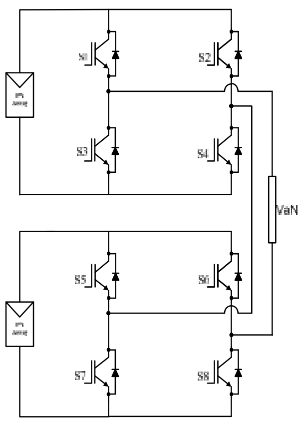

Figure 4: CHB Five level inverter with PV cell

When two or more H-Brides are connected in series, their output voltages can be combined to form different output levels, increasing the total inverter output voltage and also its rated power. The two H-Bridges connected in series is shown in fig. 4. The total converter output voltage is also illustrated presenting 5 different voltage levels is shown in fig. 7. In general terms when connecting *n* H-Bridges in series 2*n*+1 different voltage levels are obtained.

III. Simuation Study:

Five-level to thirteen-level CHBMLIs are simulated in MATLAB/SIMULINK and the THD of the line voltage and line current are analyzed by taking a simple R-L load. The control techniques adopted to control the IGBT switches of the CHBMLIs are a SPWM with PD, POD and APOD techniques.

The modeling of PV cell is done based on related electrical parameters and simulink model of PV is developed with irradiation and temperature as two input parameters. The photo voltaic current I_{PV} and diode current I_d are modeled using equation (1) and (2). Series resistance R_S and parallel resistance R_P calculated by considering MPP as operating point. The I-V characteristics and P-V characteristics of a PV array is shown in fig. 5 and fig. 6 respectively. The influence of the solar irradiation on the solar cell voltage, current and maximum power point is shown. It can be observed from the figures that as the irradiation increases the maximum power level also increases. Similarly the curves will effect to the changes in temperature, series resistance and diode reverse saturation current.

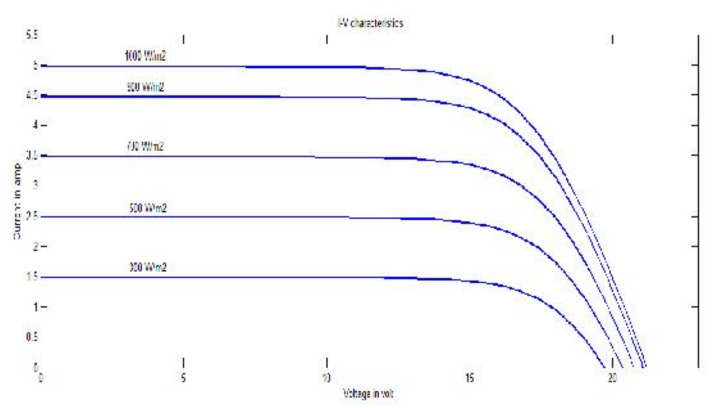

Figure 5: I-V characteristics of PV array

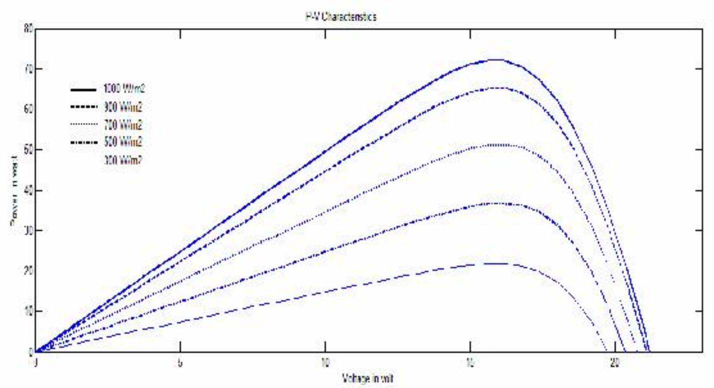

Figure 6: P-V characteristics of PV array

In this paper, we are using PD control technique for giving the pulses to the respective switches. Here 4 carrier signals are compared with reference sine wave to generate a 5 level o/p voltage. In this all the carriers are in same phase, hence it is said to be all the carriers are in phase disposition. The PD control technique of a 5 level cascade H-bridge multilevel inverter is shown in fig. 7. A simple R-L load is connected to the inverter and the corresponding line voltage and line currents are shown in fig. 8.

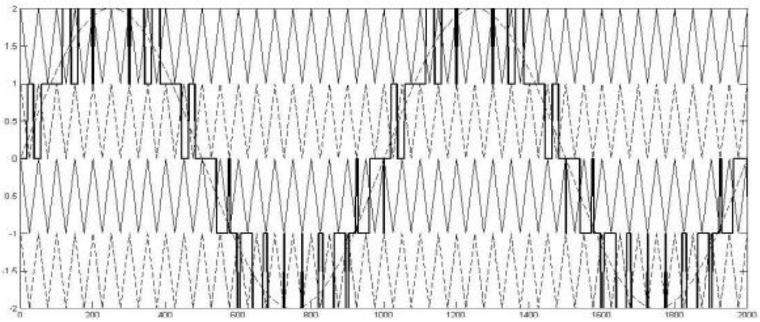

Figure 7: PD control technique for 5-level CHB-MLI

5-level to 13-level CHB-MLIs are simulated in MATLAB/Simulink and a detailed performance analysis is done in terms of harmonic content.

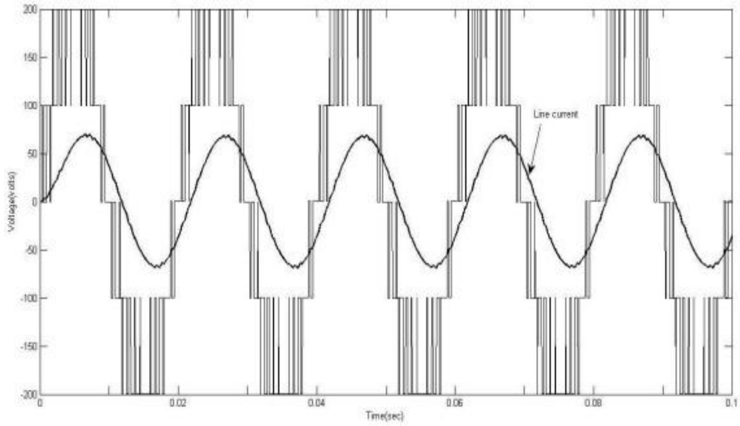

Figure 8: Voltage and Line current for 5 level CHB-MLI

The harmonics present in the output voltage and currents are analyzed upto 23 rd harmonic content for various levels are shown in Table 1 and Table 2 respectively.

Table 1: Harmoncs in output voltage for various levels of CHB-MLI.

Number of levels	THD (%)	Individual Harmonic Content(%)										
		3rd	5th	7th	9th	11th	13th	15th	17th	19th	21st	23rd
5	26.70	0.68	0.84	0.43	0.05	0.34	1.64	3.31	3.26	0.25	3.41	3.83
7	23.33	1.02	2.31	3.64	0.78	2.01	1.02	2.57	1.59	1.30	17.19	2.22
9	16.31	2.48	0.54	1.29	0.60	0.36	0.94	1.10	0.05	1.74	11.66	2.71
11	12.49	2.03	2.37	0.72	1.13	1.19	1.06	1.30	1.76	1.41	8.73	1.25
13	10.69	0.43	0.81	1.00	1.34	0.20	0.47	0.14	0.88	0.20	0.59	0.84

Table 2: Harmoncs in output current for various levels of CHB-MLI.

Number of levels	THD (%)	Individual Harmonic Content(%)										
		3rd	5th	7th	9th	11th	13th	15th	17th	19th	21st	23rd
5	1.63	0.68	0.30	0.11	0.01	0.06	0.24	0.41	0.36	0.02	0.30	0.31
7	1.56	0.22	0.42	0.18	0.27	0.27	0.42	0.17	0.24	0.06	0.15	0.14
9	1.28	0.50	0.52	0.37	0.30	0.03	0.19	0.09	0.09	0.10	0.13	0.06
11	1.22	0.91	0.18	0.30	0.07	0.19	0.06	0.06	0.07	0.08	0.06	0.03
13	0.68	0.24	0.29	0.26	0.28	0.03	0.07	0.02	0.10	0.02	0.05	0.07

The THD of voltage and current of a 13-level CHB-MLI are shown in fig.9 and fig10 respectively.

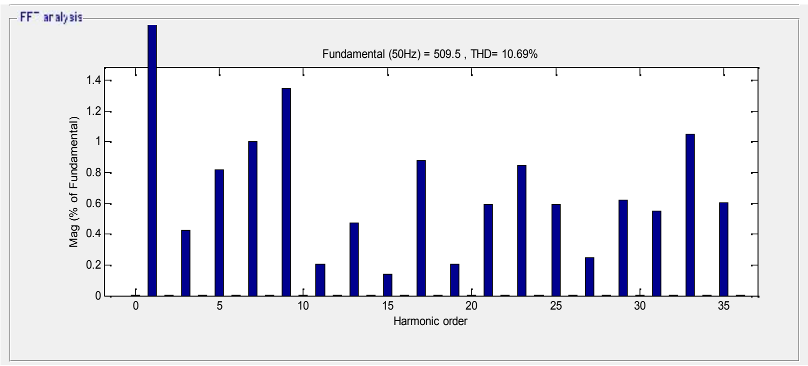

Figure 9: THD for voltage of a 13-level CHB-MLI.

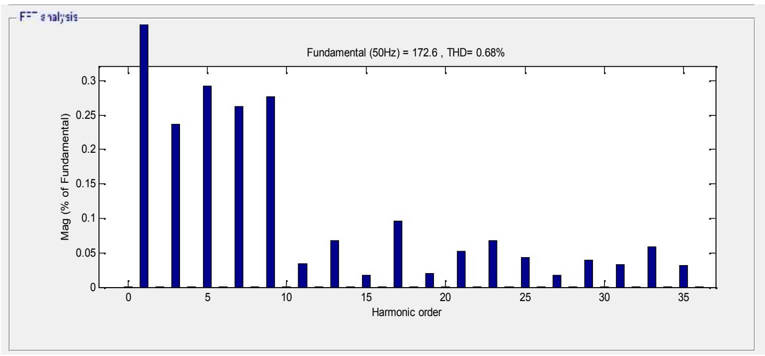

Figure 10: THD for current of a 13-level CHB-MLI

From the fig. 9, fig. 10, table 1 and table 2 we can observe that in 13 levels CHB-MLI the lower order harmonics are completely eliminated. Hence one can find that the output voltage obtained from 13-level will have best quality than other levels mentioned in the tables.

IV. Conclusion:

The photovoltaic (PV) module is an electrical device that converts sunlight into electrical DC power. Solid-state power electronic inverters have been used to connect PV modules to the AC utility grid since the early seventies. The inverter has two major tasks: to inject a sinusoidal current into the grid, and to optimize the operating point of the PV modules, to capture the maximum amount of energy. Large, megawatt, PV systems were connected to the grid in the eighties, but the trend is now to connect smaller systems to the grid, in order to overcome certain problems.

Multi level cascaded H bridge inverters from 5- levels to 13- levels have been simulated using Matlab/Simulink. The following conclusions can be made from the analysis

- As number of level increases, the THD content approaches to small value as expected. Thus it eliminates the need for filter.
- Though, THD decreases with increase in number of levels, some lower or higher harmonic contents remain dominant in each level. These will be more dangerous in induction drives. Hence the future work may be focused on implementing closed loop control with suitable harmonic elimination technique to achieve better performance of the converter.

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