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Harmonic Evaluation for Five Level Cascaded H-Bridge Multilevel Inverter Using Specific PWM technique

Namrata Shah[1], Prof. Pankaj Patel[2]

[1]*M.E student, Electrical Engineering Department, L.C.I.T., Bhandu*
[2]*Assistant Prof., Electrical Engineering Department, L.C.I.T., Bhandu*

Abstract- The multilevel voltage source inverter utilization has been increased as an alternative to the normal two level voltage source inverter, especially in the area of high power, medium voltage application due to their ability to synthesize waveforms with better harmonic spectrum and faithful output. For the proper utilization of multilevel inverter topologies, suitable modulation technique is also needed for the best performance. In power electronics, pulse width modulation (PWM) is the best way to obtain the voltage and current waveforms under required conditions. There is no single PWM technique that is the best suited for all the application. With advances in solid state power electronic devices and some advanced controllers, varies PWM techniques have been developed for industrial application. Here, we presents advanced multicarrier PWM techniques- In Phase Disposition, Phase Opposition Disposition and Alternate Phase Opposition Disposition for three phase system with Induction Motor as a load. Simulation is done using MATLAB® Simulink.

Keyword- Multilevel Inverter, Multicarrier PWM Technique, In Phase Disposition, Phase Opposition Disposition, Alternate Phase Opposition Disposition

I. INTRODUCTION

The voltage source inverter produce an output voltage or a current with levels either 0 or $\pm Vdc$. They are known as two level inverters. To obtain a quality output voltage or current waveform with a minimum amount of ripple content, they require high switching frequency along with various pulse width modulation (PWM) strategies [1]. In high power and high voltage application, these two level inverters, however, have some limitations in operating at high frequency mainly due to switching losses and device rating. The semiconductor switching devices should be used in such a manner as to avoid problems associated with their series-parallel combinations that are necessary to obtain capability of handling high voltage and current. The structure of MLI is such that the active devices encounter no voltage sharing problems. Demand for high power converters capable of producing high quality waveforms while utilizing low voltage devices and reduced switching frequencies has to lead to the MLI development with regard to semiconductor power switch voltage limits [2]. MLI become an effective and practical solution for increasing power and reducing harmonics of ac waveforms. They are normally used to medium and high voltage for current applications. The output quality of the current and voltage of MLI can be determined by high frequency switching techniques. When the number of output levels increases, harmonics of the output voltage of the output voltage and current decreases. The harmonics in the output voltage of power electronics inverters can be reduced using pulse width modulation switching techniques.

The output of practical inverters contains harmonics and the quality of an inverter is normally evaluated in term of some performance parameters.

1. The **Total Harmonic Distortion**, which is a measure of closeness in shape between a waveform and its fundamental component.
2. The **Distortion Factor** indicates the amount of harmonic distortion that remains in a particular waveform after the harmonics of that waveform has been subjected to a second order attenuation (i.e. divided by n^2). Thus distortion factor is a measure of effectiveness in reducing unwanted harmonics without having to specify the value of a second order load filter.
3. The **Lowest Order Harmonic** component whose frequency is closest to the fundamental one, and its amplitude is greater than or equals to 3% of the fundamental component.

The most attractive features of multilevel inverters are as follows: They can generate output voltages with extremely low distortion and lower dv/dt. They draw input current with very low distortion. They generate smaller common mode (CM) voltages, thus reducing the stress in motor bearings. In addition, using sophisticated modulation methods, CM voltages can be eliminated. They can operate with a lower switching frequency.

II. FIVE LEVEL CASCADED H-BRIDGE MULTILEVEL INVERTER

A cascaded multilevel inverter consists of a number of series connected H-bridges, also called single phase full bridge inverter. Each of H-bridge unit has its own dc source and each H-bridge [3]. Five level inverter consists of two H-bridges and can produce three different voltage levels: ±V and 0 by connecting the dc source to ac output side by different combination of the four switches of one H-bridge S1, S2, S3, S4 and S5, S6, S7, S8 of other H-bridge. The ac output of each H-bridge is connected in series such that synthesized output voltage waveform is the sum of all of the individual H-bridge's outputs. By connecting the sufficient number of H-bridges in cascade and using proper modulation scheme, a nearly sinusoidal output voltage waveform can be synthesized.

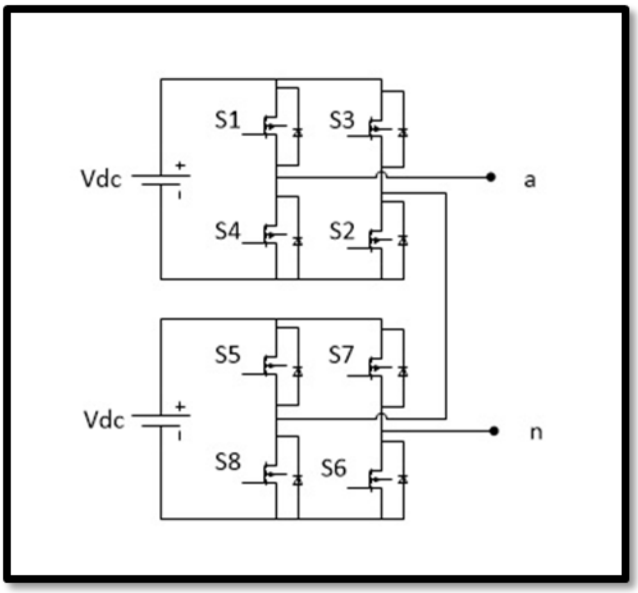

Figure 1. Five level CHB MLI

The Cascaded H-bridge inverter synthesized its output nearly sinusoidal voltage waveforms by combining different voltage levels. It can be obtained using the different PWM techniques for turn ON and OFF the switch for desire duration. Among all three topologies- Diode Clamped, Flying Capacitor and Cascaded H-Bridge inverter, the **Cascaded Multilevel Inverter** has the most reliable and easy method, because it consist of **less number of components** compare to another two types.
The operation for obtaining ±2V, ±V, 0Vare describes here:

- S1, S2, S5, S6 conduct, the output voltage of the bridges 1 and 2 will be equal to V and the resultant will become 2V.
- S3, S4, S7, S8 conduct, then voltage will be equal to (–V) and the resultant will become (-2V).
- When S1, S3, S5, S7 conduct then the output voltages will becomes 0.

III. MULTICARRIER PWM TECHNIQUE

To synthesize multilevel output AC voltage using different levels of DC inputs, semiconductor devices must be switched ON and OFF in such a way that desired fundamental is obtained with minimum harmonic distortion. The output voltage waveform of the multilevel inverter can be controlled using different PWM techniques. Duty cycle is defined as the ratio of ON time to the TOTAL (on + off) time of the switch (t_{on}/T). Pulse Width Modulation is a powerful technique for controlling analog circuits with a power sent to a load. The PWM technique involves generation of a digital waveform, for which the duty cycle is modulated such that the average voltage of the waveform corresponds to a pure sine wave [4]. The simplest way of producing the PWM signal is through comparison of a low power reference sine wave with a triangular wave. **Multicarrier PWM** methods uses high switching frequency carrier waves in comparison to the reference waves to generate a sinusoidal output wave. The method PWM is the most common for comparing a modulating wave (generally sinusoidal). The phenomenon of rapid and repeated switching at high speed causes the frequency of appearance of lowest order harmonic in the output voltage. The PWM inverters are advancing to the square wave inverter in following points:

- The ability of reducing total harmonic distortion
- Capable of controlling the output voltage
- Higher power quality factor

I. FEATURE OF PWM METHOD

Some of the important criteria to evaluate different modulation techniques are as follows:

- **Switching loss**: Power loss across the device increases with the increase in the switching frequency. A modulation technique should have least switching losses.
- **Harmonic Distortion**: Because of high switching frequency, modulation techniques induce multiples of the fundamental frequency (called harmonics) in the output voltage. A good modulation technique should have least THD.

- **DC bus Utilization**: In high voltage application it is important to use DC bus voltage as much as possible. Injecting zero sequence to reference waveform increases DC bus usage, as well as decreasing harmonic distortion under low modulation indices.
- **Number of Switches**: An efficient modulation technique gives the better performance with least number of switches used.

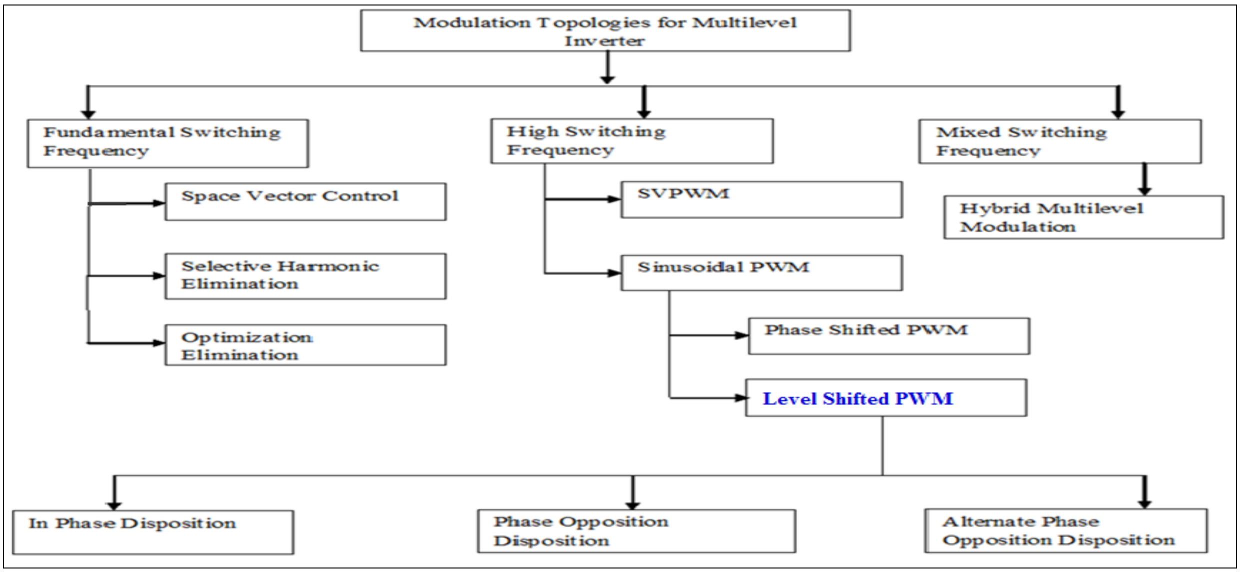

Figure 2. Different Modulation Techniques

II. IN PHASE DISPOSITION METHOD

In this method all the carriers above and below zero reference line are in same phase. If all the carriers are selected with the same phase, the method is known as Phase Disposition (PD) method.

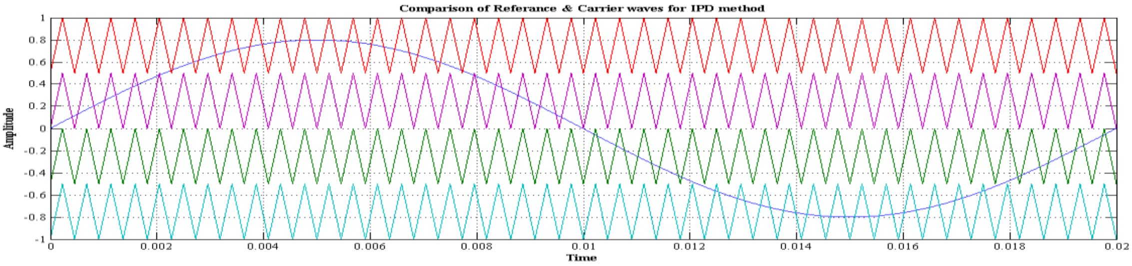

Figure 3. IPD method for 2200Hz in MATLAB®

III. PHASE OPPOSITION DISPOSITION METHOD

In this method all the carriers have the same frequency and the adjustable amplitude (different or unequal amplitudes). But all the carriers above the zero value reference are in phase among them but in opposition (180 degrees phase shifted) with those below.

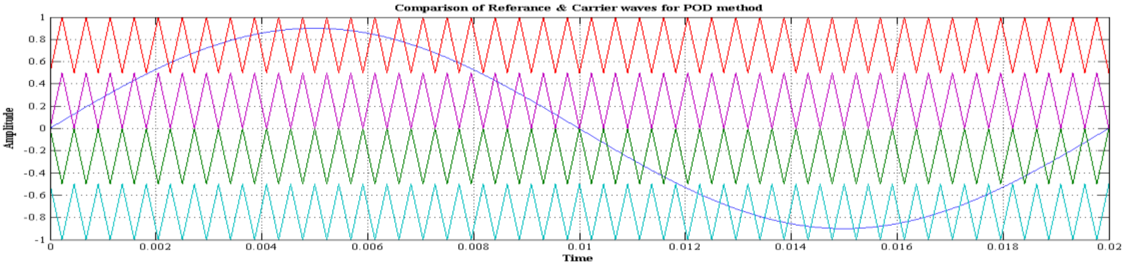

Figure 4. POD method for 2200Hz in MATALB®

IV. ALTERNATE PHASE OPPOSITION DISPOSITION METHOD

In this method all the carriers have the same frequency and the adjustable amplitude (different or unequal amplitudes). All carriers has180· Phase shift between them.

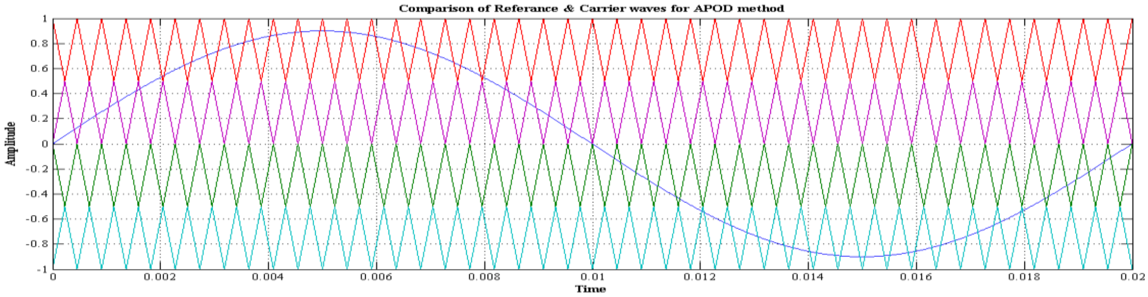

Figure 5. APOD method for 2200Hz in MATALB®

IV. SIMULATIONS AND RESULTS

The simulation is done using *MATALB®* Simulink. The name *MATALB®* stands for MATrix LABoratory. MATLAB [14] is a high-performance language for technical computing. Simulink model, output voltage and current graph, rotor speed v/s time graph, torque v/s time graph as well as FFT analysis for five CHB MLI with load as an induction motor is described in this section. The modulation index is varies from 0.6 to 1.0 for all three Carrier based PWM methods.

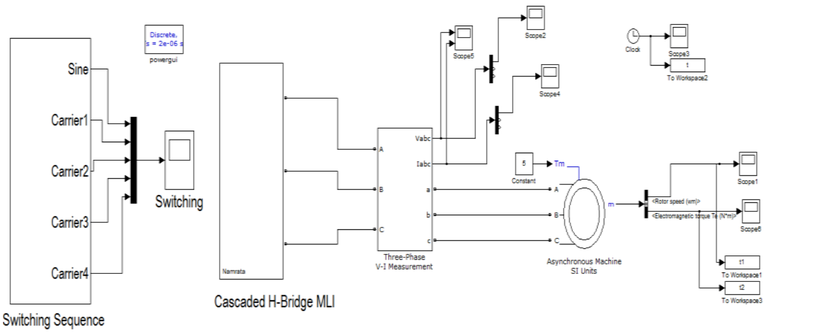

Figure 6. Simulink Model for IPD, POD, APOD method

- Same as the Simulink model, the output voltage and current waveform for all three PWM methods remains same in nature.
- The switching methods for generation of PWM gate signals are different for IPD, POD and APOD.
- We simulate the model for Modulation Index of 0.8.

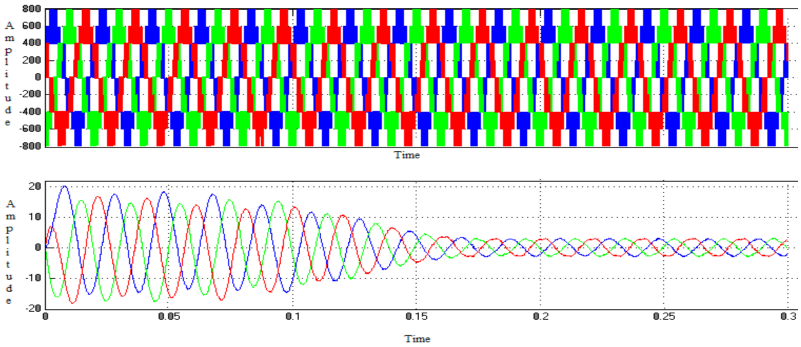

Figure 8. Output voltage & current waveforms for all three phases

- Figure8 shows the output voltage and current waveforms for all the three phases.
- Because of the nature of Induction Motor, up to some cycles the current became 3 to 7 times more than the rated currents.
- Starting current of I.M. is depend on the motor ratings.

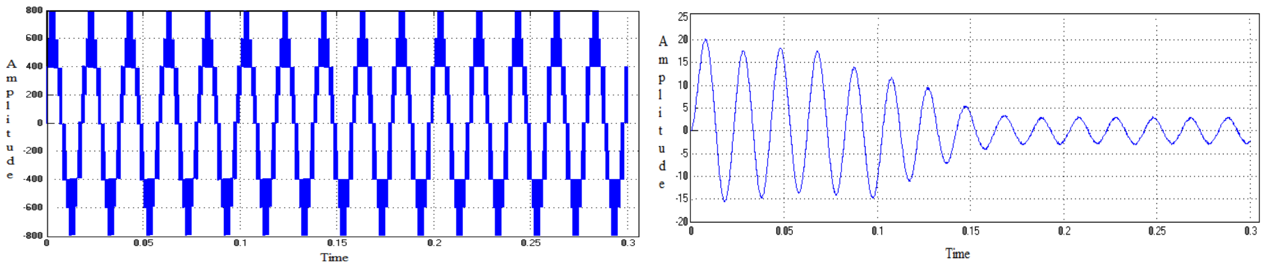

Figure 7. Output voltage & current waveforms for M.I. 0.8

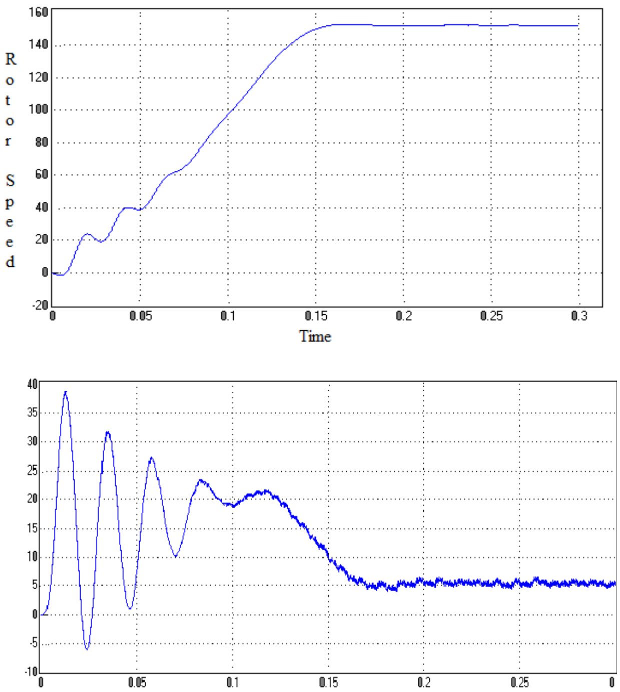

Figure 9. Rotor speed v/s time graph (upper side), Torque v/s time graph (lower side)

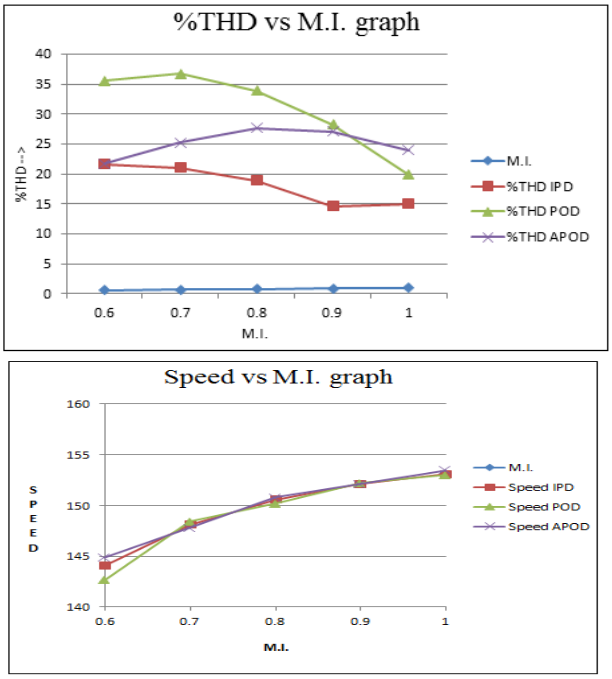

Figure 10. %THD v/s M.I. graph (upper side), Speed v/s M.I. graph (lower side)

"Table 1. Speed & %THD values for voltage at T=5Nm"

M.I.	IPD			POD			APOD		
	Speed	%THD for voltage	%THD for torque	Speed	%THD for voltage	%THD for torque	Speed	%THD for voltage	%THD for torque
0.6	144.1	21.60	6.86	142.7	35.54	8.34	144.9	21.75	5.85
0.7	148.1	21.07	18.45	148.4	36.77	16.34	147.8	25.25	14.00
0.8	150.6	18.89	23.01	150.2	33.89	26.27	150.8	27.66	23.32
0.9	152.6	14.68	21.08	152.2	28.29	32.89	152.1	27.05	27.63
1.0	153.1	14.92	21.45	153	19.89	32.33	153.5	23.95	28.29

V. CONCLUSION

The five level inverter using Sine PWM method consist high %THD in reference of the IEEE standard. %THD for voltage and current using In Phase Disposition, Phase Opposition Disposition and Alternate Phase Opposition Disposition method can be decrease to a desire value is obtained. Further decreases the value of total harmonic distortion is obtained using close loop operation. From the above discussion it is clear that the %THD value is also depends on the modulation index and motor load condition.

VI. FUTURE WORK

Simulation of different PWM multicarrier techniques-In Phase Disposition, Phase Opposition Disposition and Alternate Phase Opposition Disposition for five level Cascaded H-bridge inverter for close loop condition and compare the results-%THD for voltage, Rotor speed, Torque fluctuations and relative graphs with open loop manner.

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