Symmetrical and Asymmetrical Multilevel Inverter Applied to Induction Machine Drive

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Abstract- **Multilevel voltage source inverters offer several advantages compared to their conventional counterparts. By synthesizing the AC output terminal voltage from several levels of DC voltages, staircase waveforms can be produced, which approach the sinusoidal waveform with low harmonic distortion, thus reducing filter requirements. The need of several sources on the DC side of the converter makes multilevel technology attractive for photovoltaic applications. This paper provides an overview on different multilevel topologies and investigates their suitability for single-phase grid connected photovoltaic systems The "multilevel converter" has drawn tremendous interest in the power industry . The general structure of the multilevel converter is to synthesize a sinusoidal voltage from several levels of voltages, This paper presents a three-phase, five-level and seven level cascaded multilevel voltage source inverter based active filter for power line conditioning to improve power quality in the distribution network. The active filter compensates both reactive power and harmonic currents drawn by non-linear loads; additionally it facilitates power factor corrections. The compensation process is based on concept of p-q theory. This proposed cascaded five level and seven level active power filter system is validated through MATLAB/SIMULINK Platform.**

Keywords- **Multi level inverters, photovoltaic cells, medium voltage drives, harmonic analysis, Total Harmonic Distortion(THD).**

I. Introduction

Photo Voltaic (PV) power supplied to the utility grid is gaining more and more visibility, while the world's power demand is increasing [1]. Not many PV systems have so far been placed into the grid due to the relatively high cost, compared with more traditional energy sources such as oil, gas, coal, nuclear, hydro, and wind. Solid-state inverters have been shown to be the enabling technology for putting PV systems into the grid

A renewable energy application such as photovoltaic (PV) system has been widely used for a few decades since PV energy is free, abundant and distributed throughout the earth. The focus of the Engineers is to make use of abundantly available PV energy and so to design and control an inverter suitable for photo voltaic applications. Power electronic circuits with pulse width modulation (PWM) are mostly used in energy conversion systems to achieve closed loop control. But even updated pulse width modulation (PWM) techniques; do not produce perfect waveforms [2], which strongly depend on the semiconductors switching frequency. Also, it is well known that distorted voltages and currents waveforms produce harmonic contamination, additional power losses, and high frequency noise that can affect not only the load power but also the associated controller. When this output is fed to the induction drives it causes heating which in turn causes increased losses and low efficiency. The presence of harmonics not only increase losses, but also produces opposite torques (fifth order harmonic) in the motor and may overload motor if their amplitude is very high [3]. So, sinusoidal supply is mandatory for enhancing the motor performance which results in minimizing the power line transmission and distribution losses.

Recently, multilevel inverters have become more attractive to researchers and industrial companies due to fast developing of high power devices, and related control techniques. Different multilevel inverter structures are cascaded H-bridge, diode clamped and flying capacitor [4]. Increasing the number of levels in the inverter without requiring higher ratings on individual devices can increase the power rating [5]. The advantages of multilevel inverters are an enhanced output voltage, reduced total harmonic distortion, and reduced voltage stress on semiconductor switches and a decrease in EMI problems [6].

With the advancement of power electronics and emergence of new multilevel converter topologies, it is possible to work at voltage levels beyond the classic semiconductor limits. The multilevel converters achieve high-voltage switching by means of a series of voltage steps, each of which lies within the ratings of the individual power devices. Among the multilevel Converters [1-4], the cascaded H-bridge topology (CHB) is particularly attractive in high-voltage applications, because it requires the least number of components to synthesize the same number of voltage levels.

II. ABOUT PHOTO VOLTAIC SYSTEMS

A Photovoltaic (PV) system directly converts sunlight into electricity. The basic device of a PV system is the PV cell. Cells may be grouped to form panels or arrays. The voltage and current available at the terminals of a PV device may directly feed small loads such as lighting systems and DC motors. [7] 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.

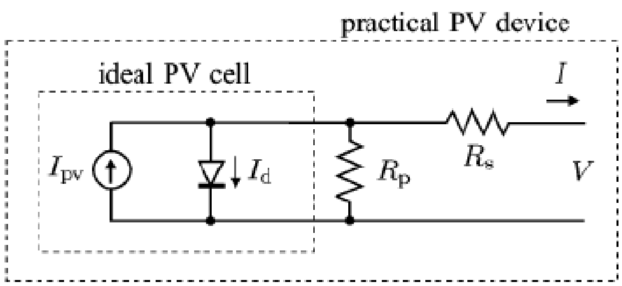

Figure1: Equivalent Circuit of a PV Device including the series and parallel Resistances.

The equivalent circuit of PV cell is shown in figure 1. In the above diagram the PV cell is represented by a current source in parallel with diode. Rs and Rp represent series and parallel resistance respectively. The output current and voltage from PV cell are represented by I and V

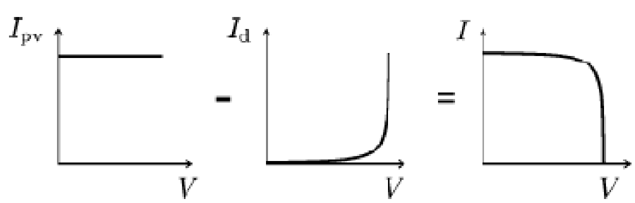

Figure 2: Characteristic of V-I of PV Cell

The I-V Characteristics of PV cell [7] is shown in figure 2.. The net cell current I is composed of the light- generated current Ipv and the diode current Id

$$I = Ipv - Id \tag{1}$$

Where

Id ▪ Io exp ▪ qV/akT ▪

Io = leakage current of the diode

q= electron charge

k = Boltzmann constant

T= temperature of pn junction

a= diode ideality constant

The basic equation (1) of the pv cell does not represent the *I*–*V* characteristic of a practical PV array. Practical arrays are composed of several connected PV cells and the observation of the characteristic at the terminals of the PV array requires the inclusion of additional parameters to the basic equation.

$$I = Ipv - \left[\exp\left(V + \frac{RsI}{Vta}\right) - 1\right] - \frac{V + RsI}{Rp} \tag{2}$$

Where

$$Vt = NskT/q$$

Is the thermal voltage of the array with Ns cells connected in series. Cells connected in series provide greater output voltages. The I-V characteristic of a practical PV cell with maximum power point(MPP), Short circuit current(Isc) and Open circuit voltage (Voc) is shown in figure 3. The MPP represents the point at which maximum power is obtained.

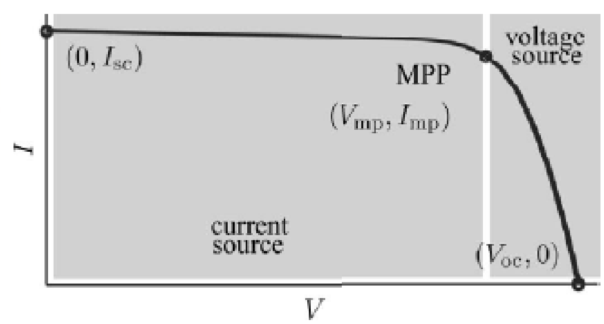

Figure 3:I-V Characteristic of Practical PV Module

Vmp and Imp 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 insolation (amount of radiation). Hence with varying temperature and insolation maximum power should be tracked so as to achieve the efficient operation of PV system.

III. CASCADED H BRIDGE INVERTER

A. Symmetrical Cascaded H Bridge (CHB) inverter:

The cascaded H Bridge (CHB) multilevel converters are simply a number of conventional two level bridges, whose AC terminals are simply connected in series to synthesize the output waveforms. Figure 4(a) shows the power circuit for a symmetrical nine – level inverter with four cascaded cells. The CHB inverter needs several independent DC sources which may be obtained from batteries, fuel cells or solar cells . Through different combinations of the four switches of each cell, each converter outputs, +Vdc, 0 ,-Vdc. The AC output is the sum of the individual converter outputs. The number of output phase voltage levels is defined by n= 2N+1, where N is the number of DC sources, For instance the output voltage swings from -4Vdc to +4Vdc with nine levels.

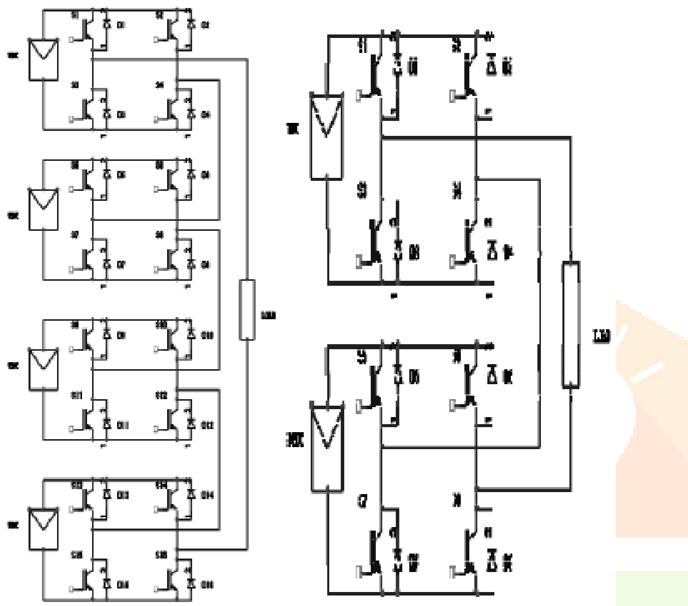

Figure 4: (a) symmetrical b)Asymmetrical CHB nine level inverter with PV cells

B. *Asymmetric Cascaded H Bridge (CHB) Inverter:*

The above discussed H bridge inverter topology is known as symmetric CHB inverter in which H bridges are fed by separate DC sources having same magnitude. An asymmetrical multilevel inverter shown in Figure 4(b) can be defined as a multilevel converter fed by a set of DC voltage source where at least one of them is different to the other one. The main advantage of an asymmetrical multi level converter is, it uses less number of semiconductor switches compared with symmetrical topology. One interest of the asymmetrical configurations is that the number of levels is higher with the same number of cells. The number of levels grows proportionally to the number of cells in the symmetrical case, whereas it grows exponentially, in the asymmetrical case. The asymmetrical topology requires only eight switches to obtain nine level output voltage, whereas in case of symmetrical topology sixteen switches are needed.

IV. RELATED CONCEPTS TO PROPOSED TOPOLOGY

A. *Simulation of PV Module:*

The modeling of PV cell is done based on [7] and related electrical parameters are given in Appendix. The simulink model of PV is developed with irradiation and temperature as two input parameters. The photo voltaic current Ipv and diode current Id are modeled using equations (1) and (2).Series resistance Rs and parallel resistance Rp are calculated by considering MPP as operating point. The detailed subsystem modeling is shown in the Figure 5.

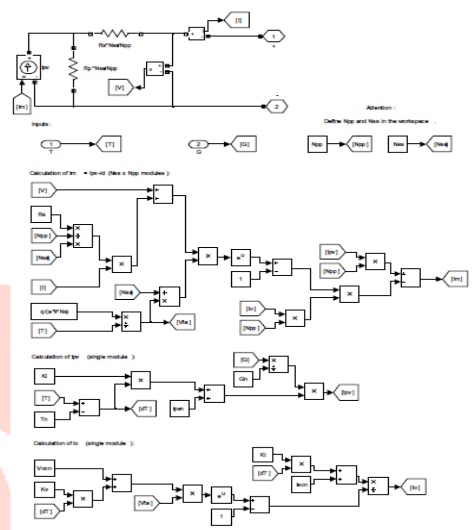

Figure 5: Basic Model of PV Configuration

B. *Simulation of PV Fed CHB Inverter:*

Five-level to fifteen-level CHB MLIs are simulated in MATLAB-Simulink and a detailed performance analysis is done in terms of harmonic contents, voltage stress across the switches and number of switches needed. Different symmetrical and asymmetrical MLI topologies with RL load are tried out to achieve target output voltage. Out of them, analysis results of significant cases are listed out in Table I. It shows many combinations of asymmetrical input to get the specified output voltage. Also, number of switches required for the operation and voltage stress across the switches is compared up to 15 levels.

1) *Number of Switches required:*

To achieve seven and nine levels output voltage minimum 8 switches are required whereas higher levels i.e; 11, 13 and 15 can be achieved through 12 switches if asymmetrical topologies are used. At the same time, if the voltage is achieved through- symmetrical type, number of switches required will be more.

2) Voltage Stress:

The main advantage of MLI over conventional two level inverter is the voltage stress on each switch is reduced due to series connection of the switches. While considering five level topology, the maximum voltage stress of each switch is limited to V_{in1}. Suppose the same output level has to be produced, by using conventional two level inverter each switch has to withstand $2V_{in1}$.One thing should be noted that in symmetrical CHB inverter the value of separate DC sources are same.

Therefore the voltage of each switch is limited to the value of DC source. But as asymmetrical topology uses separate DC sources whose values are different, the voltage stress among the switches will be asymmetrically distributed. Hence care should be taken while selecting switch rating in case of asymmetrical CHB topology.

3) Harmonic Analysis:

The harmonics present in the output voltage is analyzed up to 23rd harmonic content for various topologies shown in Table II. The individual harmonics shown in the Table II is represented with respect to the fundamental component' s magnitude in percentage. It means that fundamental harmonics is taken as reference.

One can easily observe the dominant harmonics in various levels. The harmonic order which has harmonic content less than 4 % is ignored as their effect is negligible. The dominance of the harmonics in decreasing order for various levels of CHB inverter is tabulated in Table III.

C. Performance Comparison Symmetrical Vs Asymmetrical:

To produce the same output voltage two level, symmetrical and asymmetrical CHB MLI are constructed. Three PV arrays are considered each with output voltage of 32.9V. Two level inverter needs only 4 switches but develops high voltage stress across the switch. Also, THD content is very high (48.02%) as expected. On the other hand, seven level symmetrical CHB inverter requires more number of switches (12) with a minimum voltage stress of 32.9V and minimum THD. In terms of efficiency, Asymmetrical topology is best but with respect to voltage stress and THD its performance is better than 2 level.

V.MATLAB/SIMULINK MODELLING AND SIMULATION RESULTS

Here the simulation is carried out by seven cases

1. Cascaded H Bridge Multilevel Asymmetrical Single phase Five Level inverter 2. Cascaded H Bridge Multilevel Asymmetrical Single phase Seven Level inverter 3. Cascaded H Bridge Multilevel Asymmetrical Single phase Nine Level inverter 4. Cascaded H Bridge Multilevel Asymmetrical Single phase Eleven Level inverter 5. Cascaded H Bridge Multilevel Asymmetrical Single phase Fifteen Level inverter 6. Cascaded H Bridge Multilevel Asymmetrical Three phase Five Level inverter with Grid connection 7. Cascaded H Bridge Multilevel Asymmetrical Three phase Seven Level inverter with Grid connection.

Case 1: Cascaded H Bridge Multilevel Symmetrical Single phase Five Level inverter:

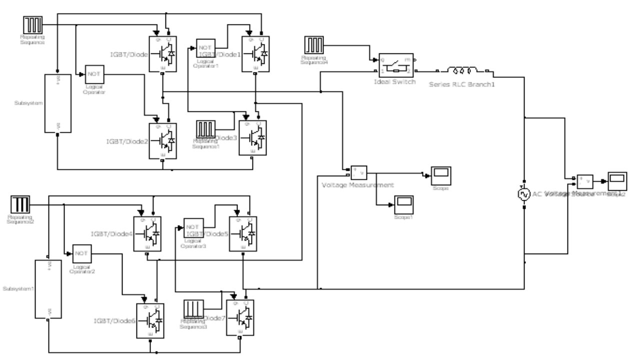

Figure 6: Matlab/Simulink model Cascaded H Bridge Multilevel Symmetrical Single phase Five Level inverter

Figure-6 shows the Matlab/Simulink model Cascaded H Bridge Multilevel Symmetrical Single phase Five Level inverter.

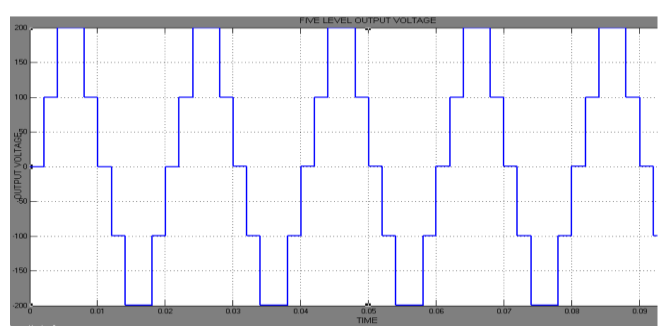

Figure 7: Five level output voltage

Figure 7 shows the Output Voltage of Five Level Cascaded Symmetrical Single Phase Multilevel Inverter

Case 2:. Cascaded H Bridge Multilevel Symmetrical Single phase Seven Level inverter:

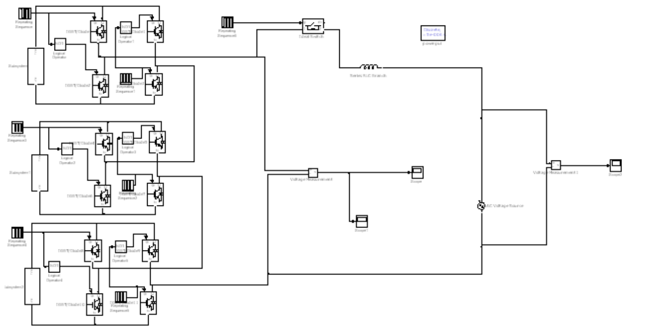

Figure 8: Matlab/Simulink Model of Cascaded H Bridge Multilevel Symmetrical Single phase Seven Level inverter

Figure-8 shows the Matlab/Simulink model Cascaded H Bridge Multilevel Symmetrical Single phase Seven Level inverter.

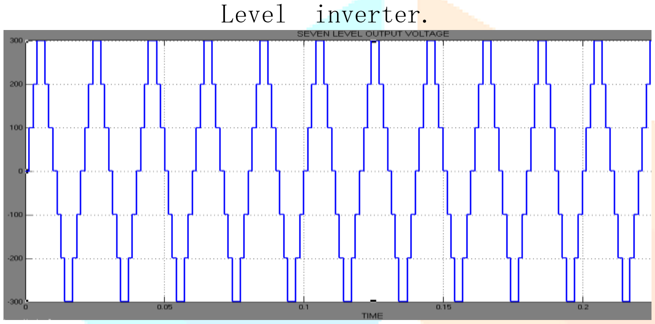

Figure 9: Seven level output voltage

Figure 9 shows the Output Voltage of Seven Level Cascaded Symmetrical Single Phase Multilevel Inverter

Case 3: Cascaded H Bridge Multilevel Asymmetrical Single phase Nine Level inverter

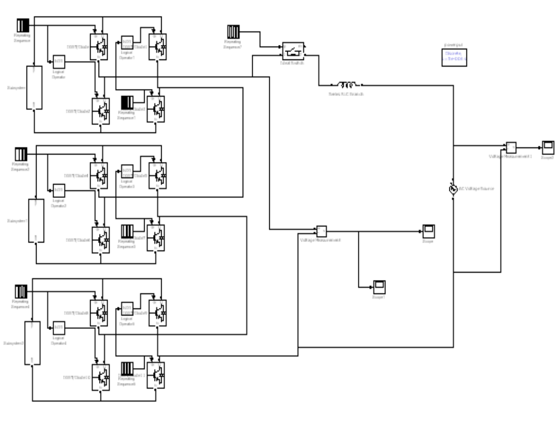

Figure 10: Matlab/Simulink Model of Cascaded H Bridge Multilevel Asymmetrical Single phase Nine Level inverter

Figure 10 shows the Output Voltage of Nine Level Cascaded asymmetrical Single Phase Multilevel Inverter By using three bridges.At the same bridge we get Nine level by using symmetrical Configuration.

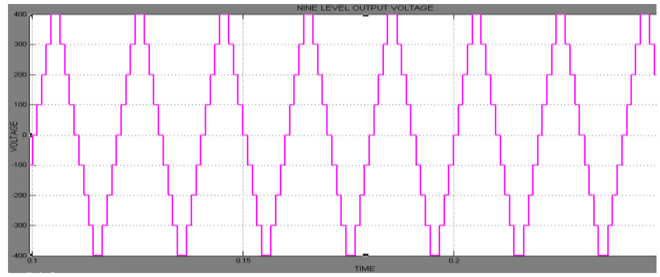

Figure 11: Nine level output voltage

Figure 11 shows the Output Voltage of Nine Level Cascaded ASymmetrical Single Phase Multilevel Inverter.

Case 4: Cascaded H Bridge Multilevel Asymmetrical Single phase Eleven Level inverter:

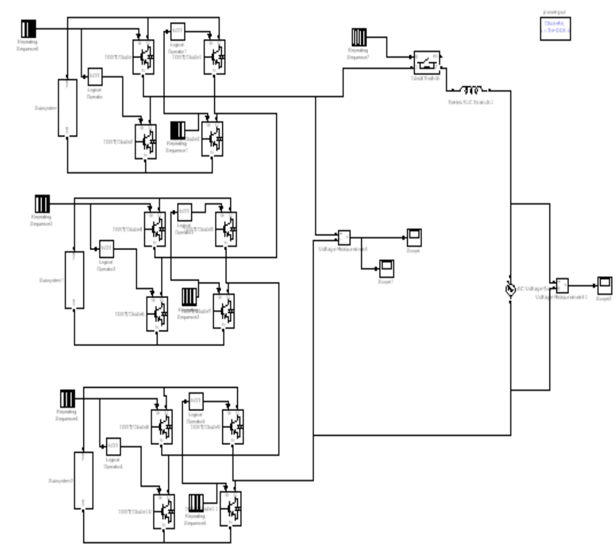

Figure 12: Matlab/Simulink Model of Cascaded H Bridge Multilevel Asymmetrical Single phase Eleven Level inverter

Figure 12 shows the Output Voltage of Eleven Level Cascaded asymmetrical Single Phase Multilevel Inverter By using three bridges.At the same bridge we get eleven level by using symmetrical Configuration

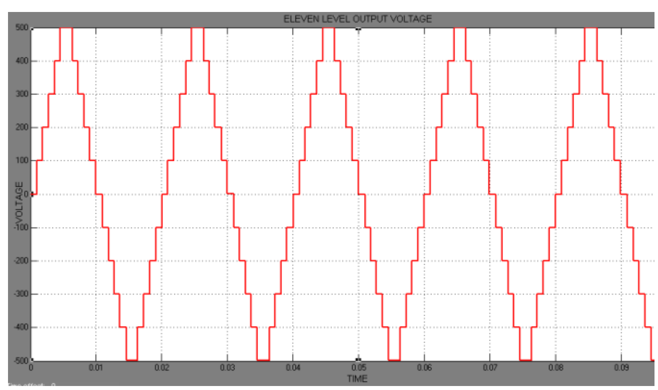

Figure 13: Eleven level output voltage

Figure 11 shows the Output Voltage of Eleven Level Cascaded ASymmetrical Single Phase Multilevel Inverter, Here the same configuration we get eleven level output voltage.

Case 5: Cascaded H Bridge Multilevel Asymmetrical Single phase Fifteen Level inverter:

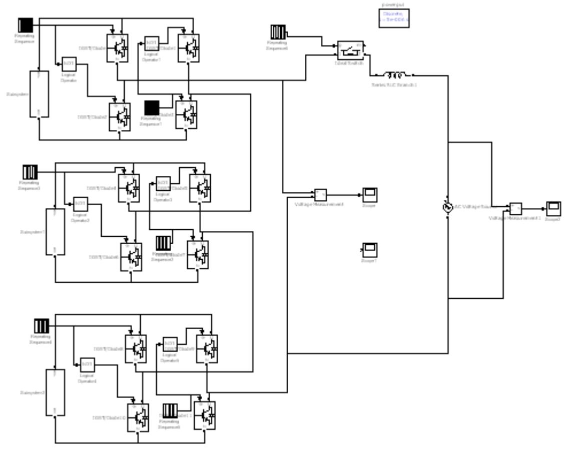

Figure 14: Matlab/Simulink Model of Cascaded H Bridge Multilevel Asymmetrical Single phase fifteen Level inverter

Figure 14 shows the Output Voltage of Fifteen Level Cascaded asymmetrical Single Phase Multilevel Inverter By using three bridges.At the same bridge we get Fifteen level by using symmetrical Configuration

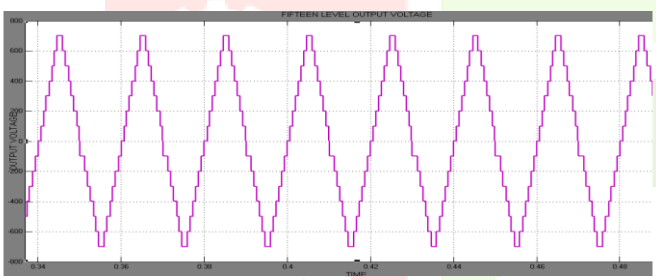

Figure 15: Fifteen level output voltage

Case 6: Cascaded H Bridge Multilevel Asymmetrical Three phase Fifteen Level inverter Applied to Induction Machine Drive:

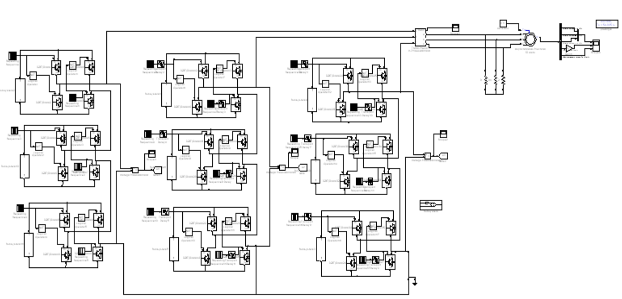

Figure 16: Matlab/Simulink Model of Cascaded H Bridge Multilevel Asymmetrical Three phase Fifteen Level inverter Applied to Induction machine drive

Figure 16 Shows the Matlab/simulink model of the Cascaded H Bridge Multilevel Asymmetrical Three phase Fifteen Level inverter Applied to Induction Machine Drive.

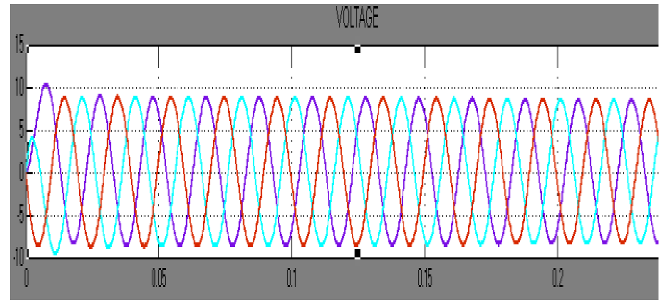

Figure 17: output voltage for Cascaded H Bridge Multilevel Asymmetrical Three phase Fifteen Level inverter Applied to induction machine drive

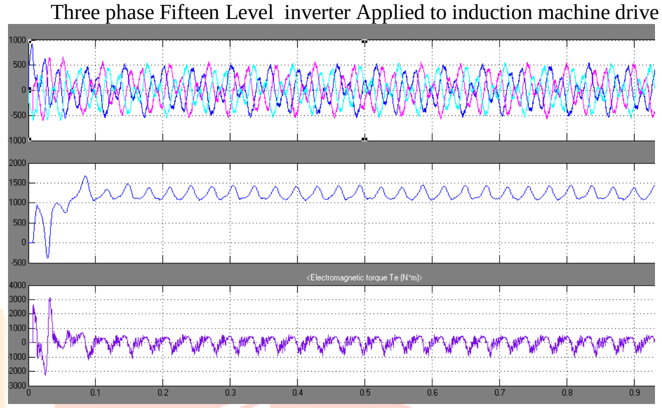

Figure 18: Stator current, Speed ,Torque of the induction machine drive.

V CONCLUSION

Multi level cascaded H bridge inverters from five levels to fifteen level Applied to induction machine drive have been simulated using Matlab/Simulink. The following conclusions can be made from the analysis. CHB multilevel inverter has low stress, high conversion efficiency and can also be easily interfaced with renewable energy sources (PV, Fuel cell etc.). Asymmetrical CHB multilevel inverter uses least number of devices to produce higher voltage level. 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. When irradiation reduces, output voltage also proportionately decreases whereas it increases with decrease in temperature. Small variation in THD and percentage of harmonics experienced during the change in irradiation. And the Cascaded H Bridge Multilevel Asymmetrical Three phase Fifteen Level inverter is connected Induction machine drive and we get Pure Sinusoidal Voltage, whenever we get pure sinusoidal voltage nothing but harmonic Free.

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