FUZZY CONTROLLED PV CELL FED MULTI LEVEL INVERTER FOR INDUCTION MOTOR DRIVE

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ABSTRACT: The studies on the photovoltaic system are extensively increasing because of a large, secure, essentially exhaustible and broadly available resource as a future energy supply. Various converter topologies have been developed from many years for the effective operation of solar photo voltaic (SPV) systems especially boost converters. Induction motor application using SPV source requires an efficient converter which can produce higher value of AC voltage output from the PV input and also implement with reduced dv/dt stress and wide range of speed control. Here a Multilevel inverter for V/f control of induction motor driven from a Solar PV system with fuzzy controlled boost converter is presented. Using the proposed converter topology, voltage levels higher than the input value can be obtained. This can be utilized in SPV applications for obtaining required DC voltage for the inverter. PV based Multilevel inverter with fuzzy controlled boost converter is presented for the induction motor application. This topology is found to have better performance compared to the conventional inverters. The topology is evaluated with different voltage levels and it is found to give satisfactory results compared to conventional less number of voltage level multi level inverters..

KEYWORDS: Solar photovoltaic (SPV) Multilevel inverter (MLI), Boost converter and Fuzzy controller.

INTRODUCTION

Utilization of renewable energy resources is the demand of today and the necessity of tomorrow. With advancement in power electronic technology, the solar photovoltaic energy has been recognized as an important renewable energy resource because it is clean, abundant and pollution free. But the Pv cells from low voltage in order to step up the dc voltage a boost converter has to be used than connecting the number of solar cells in series. To utilize the Dc supply from the Pv cells for Ac loads a dc-ac converter, also known as the inverter has to be used. An inverter or dc-ac converter is a circuit which converts dc supply to ac power at preferred output voltage and frequency. The dc power input to the inverter is attained from an accessible power supply network or from a rotating alternator from side to side rectifier or a battery, fuel cell, photovoltaic array or magneto hydrodynamic generator. Inverters can be generally categorized into two types, voltage source and current source inverters. A voltage–fed inverter (VFI) or more generally a voltage–source inverter (VSI) is one in which the dc source has tiny or insignificant impedance. It consists of constant voltage at the input terminals. A current–source inverter (CSI) is fed with adaptable current from the dc source of towering impedance that is from a constant dc source.

A VSI make use of thyristors as switches, some type of forced commutation is required, while the VSIs manufactured by using GTOs, power transistors, power MOSFETs or IGBTs, natural commutation with base or gate drive signals for their controlled turn-off and turn-on. A typical single-phase current source or voltage source inverter can be in the half bridge or full-bridge configuration. The single-phase units can be united to have three-phase or multiphase topologies. A few industrial applications of inverters are for adjustable-speed ac drives, induction heating, standby aircraft power supplies, UPS (uninterruptible power supplies) for computers, HVDC transmission lines, etc. The perception of Pulse Width Modulation (PWM) for inverters is described with analyses comprehensive to dissimilar kinds of PWM strategies.

To end with the simulation results for a single-phase inverter using the PWM strategies described are presented. The schematic of inverter system is as shown in Figure 1, in which the battery or rectifier provides the dc supply to the inverter. The inverter is used to control the fundamental voltage magnitude and the frequency of the ac output voltage. AC loads may require constant or adjustable voltage at their input terminals, when such loads are fed by inverters, it is essential that the output voltage of the inverters is so controlled as to fulfill the requirement of the loads. For example if the inverter supplies power to a magnetic circuit, such as a induction motor, the voltage to frequency ratio at the inverter output terminals must be kept constant. This avoids saturation in the magnetic circuit of the device fed by the inverter.

HIGH POWER CONVERTERS CLASSIFICATIONS

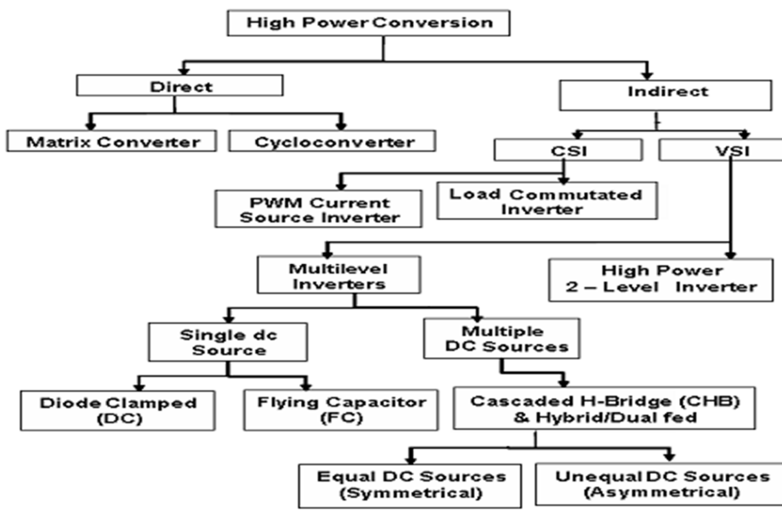

Figure 1. Classification of High power Converters

Cascaded H-bridge multilevel inverter

The CHB with N-level multilevel inverter comprises ½(N-1) series connected single phase H-bridges per phase, for which each H-bridge has its individual inaccessible dc source. Three output voltages are possible, ±Vs, and zero, giving a total number of states of 3½(N−1), where N is odd. Figure 2 shows one phase of a n-level cascaded H-bridge inverter.

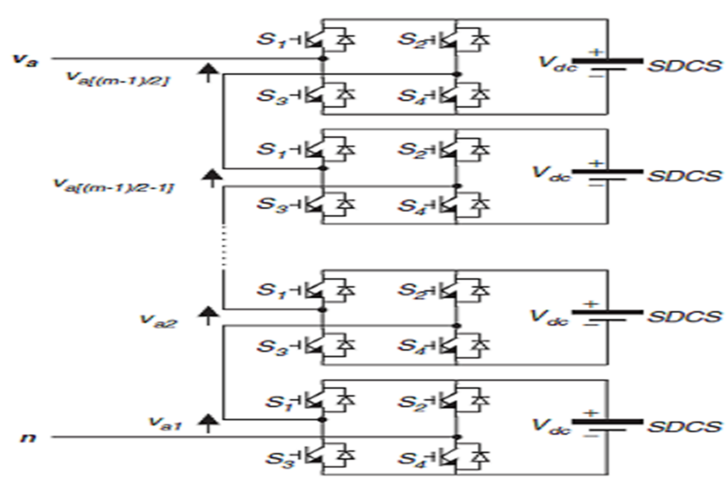

Figure 2. Single-phase configuration of a cascaded H-bridge multilevel Inverter

The cascaded H-bridge multilevel inverter is based on multiple two level inverter outputs (each H-bridge), with the output of each phase shifted. Despite four diodes and switches, it achieves the greatest number of output voltage levels for the fewest switches. Its main limitation lies in its require for remote power sources for every level and for each phase, even though for VA compensation, capacitors restore the dc supplies, and the necessary capacitor energy is only to replace losses due to inverter losses. Its modular structure of identical H bridges is a positive feature.

- The number of levels in the line-to-line voltage waveform will be k = 2N −1.
- While the number of levels in the line to load neutral of a star (wye) load will be p = 2k −1.
- The number of capacitors or isolated supplies required per phase is Ncap = ½(N −1).
- The number of possible switch states is n states= N phases.

Advantages:

1. The number of likely output voltage levels is additional than twice the number of dc sources (m = 2s +1).
2. The series of H-bridges creates for modularized layout and packaging. This will facilitate the developed process to be done more speedily and economically.

Disadvantages:

Separate dc sources are obligatory for each of the H-bridges. This will edge its application to products that already have many SDCSs willingly obtainable.

PV ARRAY MODELLING

The power that one unit can fabricate is seldom enough to gather requirements of a home or a business, so the modules are linked together to form an array. The majority PV arrays use an inverter to convert the DC power formed by the modules into alternating current that can powerlights, motors, and other loads. The modules in a PV array are normally first combined in series to get the desired voltage; the individual strings are then connected in shunt to make the system to produce huge current. The PV array is made up of number of PV modules connected in series called string and number of such strings connected in parallel to accomplish desired voltage and current.

PV Model

The electrical equivalent circuit model of PV cell consists of a current source in parallel with a diode as shown in Fig. 3

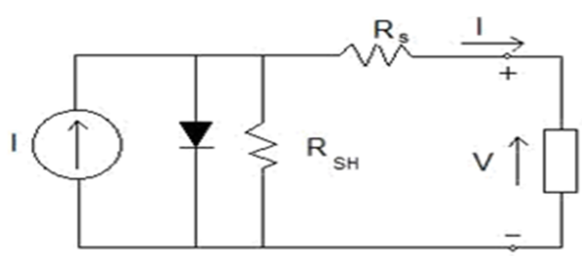

Figure 3. Electrical Equivalent Circuit Model of PV Cell

$$I_{PV} = I_{ph} - I_0(e^{\frac{q(V_{PV}+I_{PV}R_S)}{\eta kT}} - 1) \quad (1)$$

The parameters *q, η, k and T* denote the electronic charge, ideality factor of the diode, Boltzmann constant and temperature in Kelvin respectively. *Iph* is photocurrent, I_o is diode reverse saturation current, *IPV* and *VPV* are the PV output current and voltage respectively. As the value of *Rsh* is very large, it has a negligible effect on the I-V characteristics of PV cell or array.

FLC CONTROLLER

Fuzzy logic is widely used in control technique. The expression "fuzzy" refers to the detail that the logic implicated can contract with models that cannot be expressed as "right" or "wrong" but rather as "somewhat true". Even though substitute advances such as genetic algorithms and neural networks can achieve just as well as fuzzy logic in a lot of cases, fuzzy logic has the benefit that the way out to the problem can be direct in terms that human operators can appreciate, so that their knowledge can be used in the plan of the controller of predictive current control. The linguistic variables are defined as (NB, NS, Z, PS, PB) which mean big, negative small, zero, positive small and positive big respectively. The membership functions are shown in Fig.4.

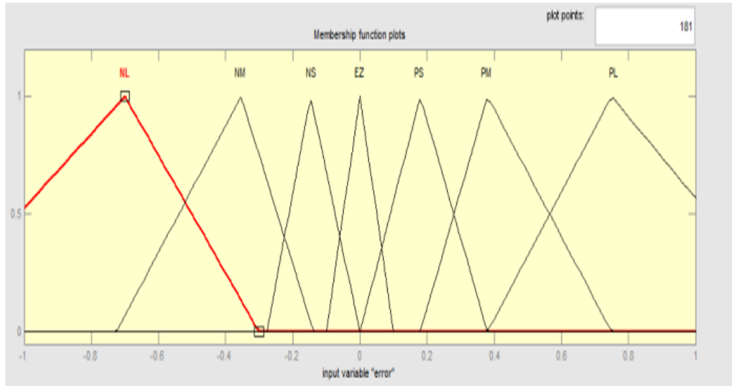

Figure 4. Membership functions of FLC

Table 1. The decision table of FLC

u		**e**						
		NB	NM	NS	Z	PS	PM	PB
	PB	**Z**	PS	PM	PB	PB	PB	PB
	PM	NS	**Z**	PS	PM	PB	PB	PB
Δe	PS	NM	NS	**Z**	PS	PM	PB	PB
	Z	NB	NM	NS	**Z**	PS	PM	PB
	NS	NB	NB	NM	NS	**Z**	PS	PM
	NM	NB	NB	NM	NM	NS	**Z**	PS
	NB	NB	NB	NB	NB	NM	NS	**Z**

As seen from table I, each interval of each variable is divided into seven membership functions:
Negative Big (*NB*), Negative Medium (*NM*), Negative Small (*NS*), Zero (*Z*), Positive Small (*PS*), Positive Medium (*PM*) and Positive Big (*PB*).

SEVERAL MODULATION SCHEMES

Many PWM techniques were developed to control the power inverter gain, and tried to improve the inverter operation, based on minimum harmonic contents in the output voltage. They are quite popular in industrial applications. In that PSPWM and LSPWM methods are merely preferred by many industrial applications.

Phase Shifted Pulse Width Modulation Scheme (PSPWM)

Phase shifted PWM (PS-PWM) is used with cascaded H-bridge (CHB) and flying capacitor (FC) inverters, Using sinusoidal unipolar PWM and bipolar PWM each cell is modulated independently, supplying an uniform distribution of power among the cells. An angle of 180^0/m and 360^0/m for the Cascaded H-Bridge and for the FC is commenced across the cells to create the stair case multilevel output waveform with minor distortion (where m is the number of cells).

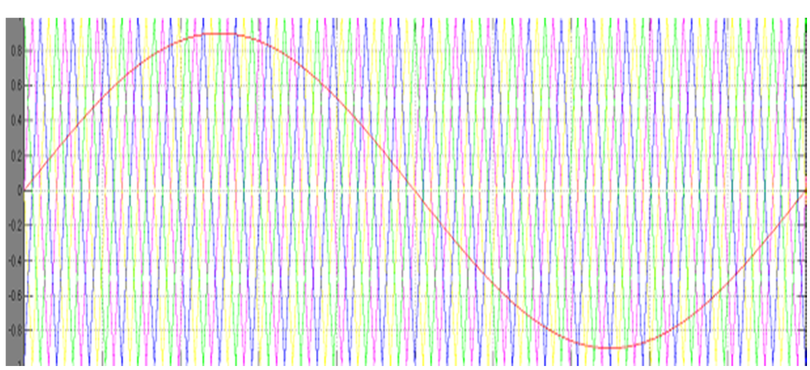

Figure 5. PSPWM Scheme

Level Shifted PWM Scheme (LSPWM)

Level shifted PWM (LS-PWM) is used for controlling voltage of a diode clamped multilevel inverter. The control principle of the level shifted SPWM is to use numerous triangular carrier signals maintaining only single modulating sinusoidal signal. For a three level inverter two carriers and for a 5-level inverter, 4 triangular carriers are desirable. In universal if an m-level inverter is engaged, (m-1) carriers are needed. The carriers have the same frequency f_c and the same peak-to-peak amplitude A_C. In the middle of the carrier set zero reference is positioned. The f_m and A_m are the sinusoid frequency and amplitude of the modulating signal.

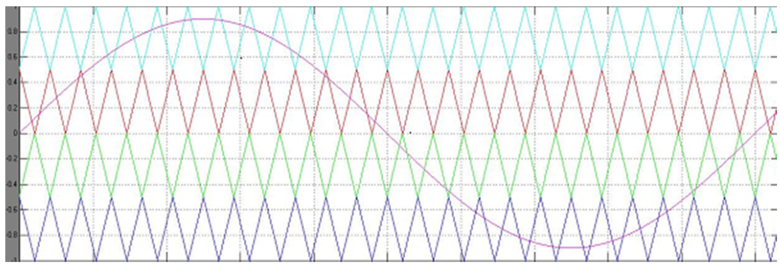

Figure 6. LSPWM Scheme

MATLAB/SIMULINK RESULTS

three-level

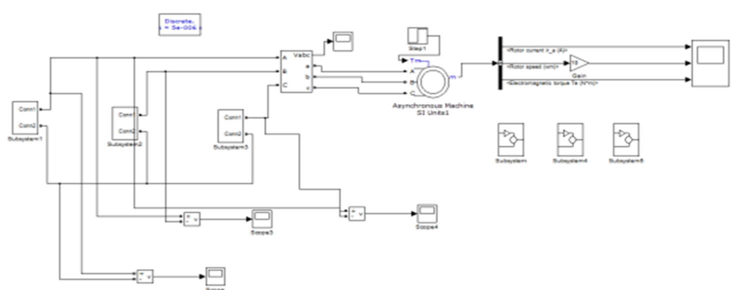

Figure 7. Matlab/Simulink model of three phase three level PWM inverter fed induction motor.

Figure7 demonstrates the three level three phase PWM inverter fed induction motor.

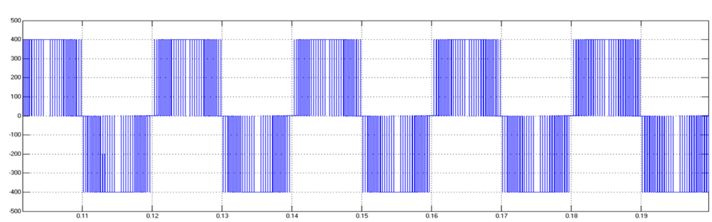

Figure 8. line voltage of the three level PWM inverter fed induction motor.

Figure 8 Shows line Voltage of the Three Level PWM Inverter Fed Induction Motor.

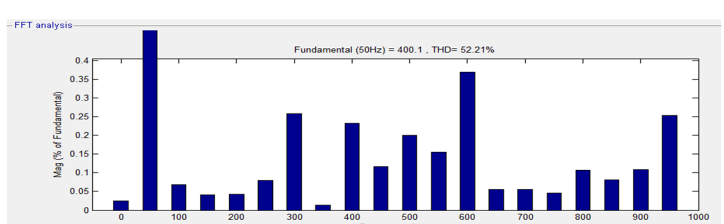

Figure 9. Spectrum analysis three level line voltage of H-Bridge inverter

Figure9 illustrates the FFT analysis of three level line voltage of H-Bridge inverter

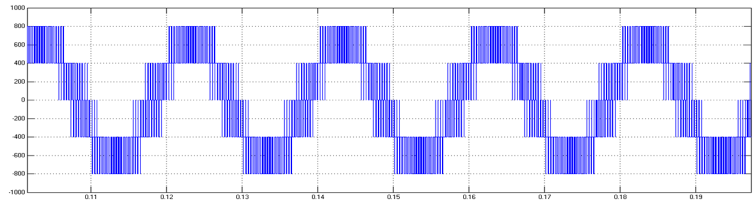

Figure 10. phase voltage of three level PWM inverter fed induction motor.

Figure 10 Shows The Phase To Phase Voltage Of Three Level PWM Inverter Fed Induction Motor.

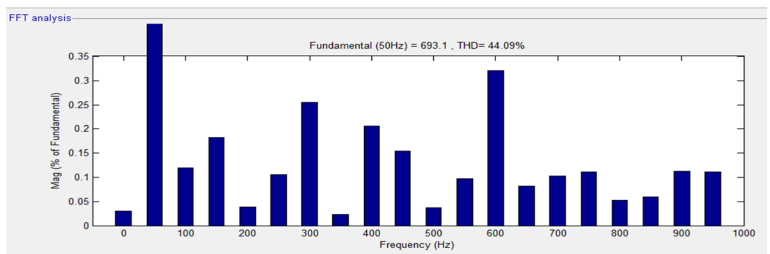

Figure 11.Spectrum analysis of phase voltage of cascaded three level H-Bridge inverter

Figure11 illustrates the FFT analysis of phase voltage of cascaded three level H-Bridge inverter.

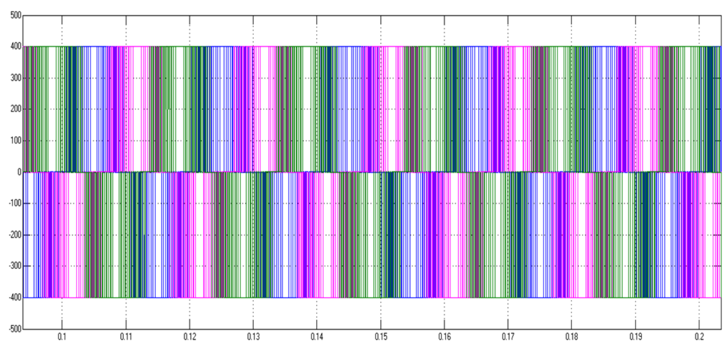

Figure 12. Phase voltage of three phase three level PWM inverter fed induction motor.

Figure12 shows the phase voltage of three phase three level PWM inverter fed induction motor.

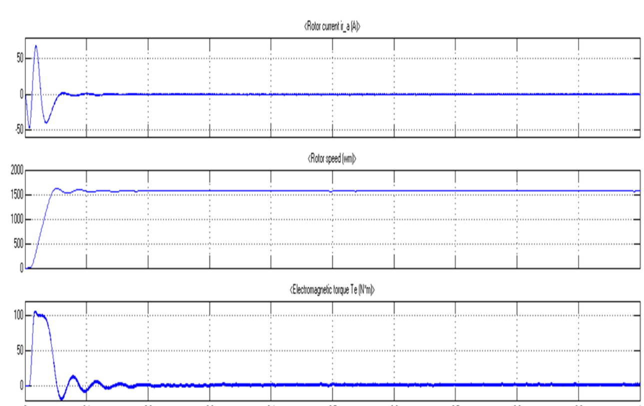

Figure 13. The generated current, torque and output speed of the three phase three level fed induction motor level shifted carrier PWM.

Five Level

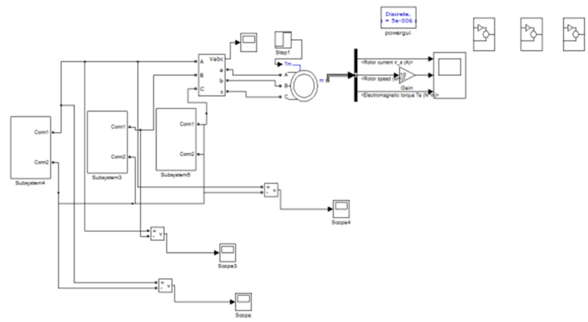

Figure 14. Three phase five level PWM inverter of Matlab/Simulink model fed to induction motor drive.

Figure14 shows the Matlab/Simulink model of three phase five level PWM inverter fed induction motor.

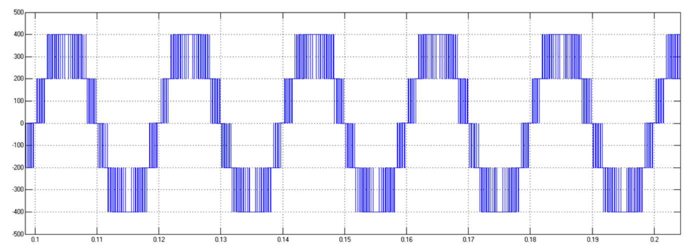

Figure 15. line voltage of the five level PWM inverter fed induction motor.

Figure15 Shows line Voltage of the five Level PWM Inverter Fed Induction Motor.

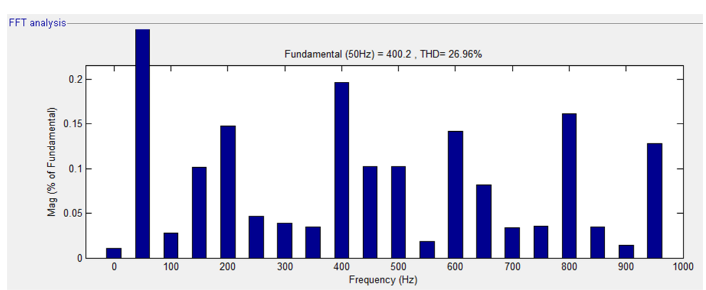

Figure 16. Spectrum analysis of line voltage of cascaded five level H-Bridge inverter

Figure16 illustrates FFT analysis of line voltage of cascaded five level H-Bridge inverter.

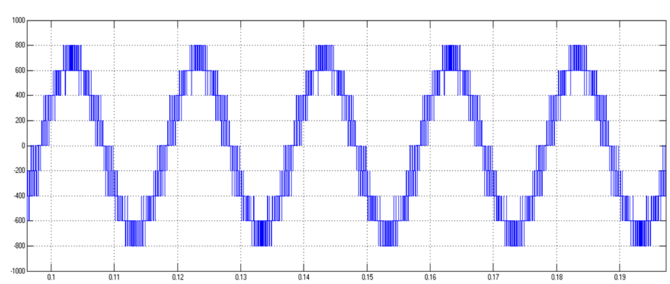

Figure 17. phase voltage of five level PWM inverter fed induction motor.

Figure17 Shows the Phase Voltage of five Level PWM Inverter Fed Induction Motor.

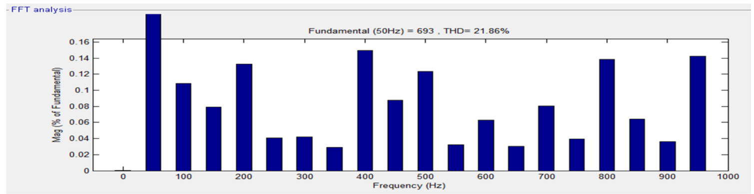

Figure 18.Spectrum analysis of phase voltage of five levels H-Bridge inverter with sinusoidal PWM.

Figure18 illustrates the FFT analysis of phase to phase voltage of cascaded five level H-Bridge inverter

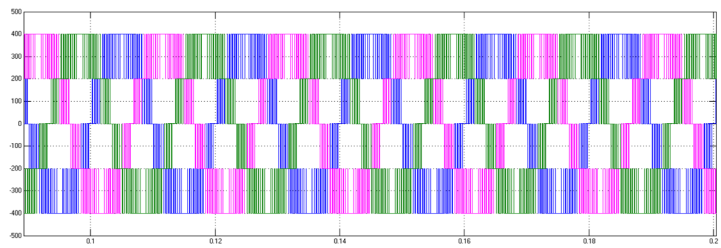

Figure 19. phase voltage of three phase five level PWM inverter fed induction motor.

Figure19 shows the phase voltage of three phase five level PWM inverter fed induction motor.

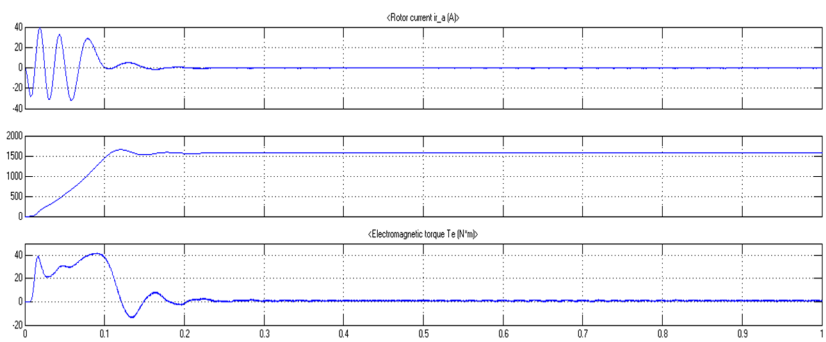

Figure.20. The generated current, torque and output speed of the three phase five level CHB inverter fed induction motor level shifted carrier PWM.

7-Level Lsc Pwm

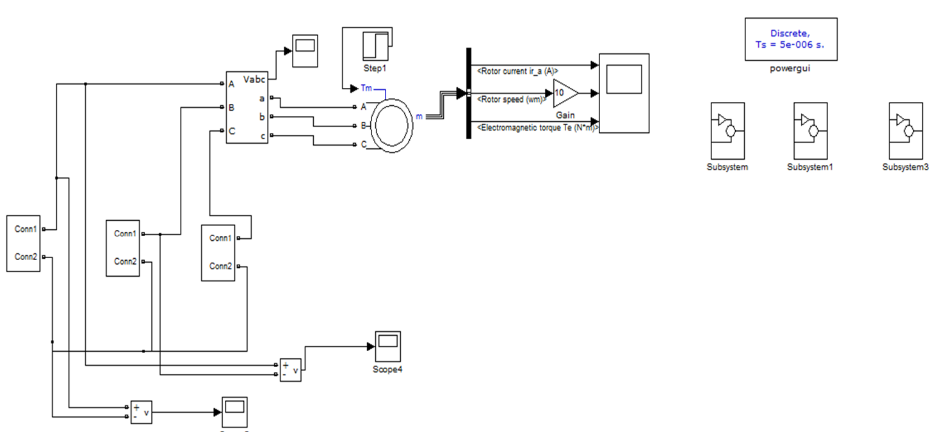

Figure 21. Matlab/Simulink model of three phase seven level PWM inverter fed induction motor.

Figure21 shows the three phase seven level PWM inverter of Matlab/Simulink model fed to induction motor.

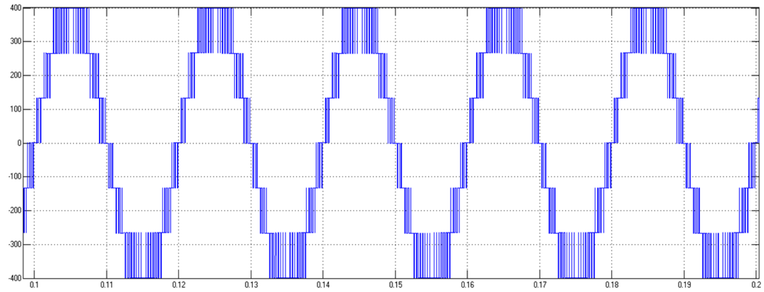

Figure 22. line voltage of the seven level PWM inverter fed induction motor.

Figure22 Shows line Voltage of the seven Level PWM Inverter Fed Induction Motor.

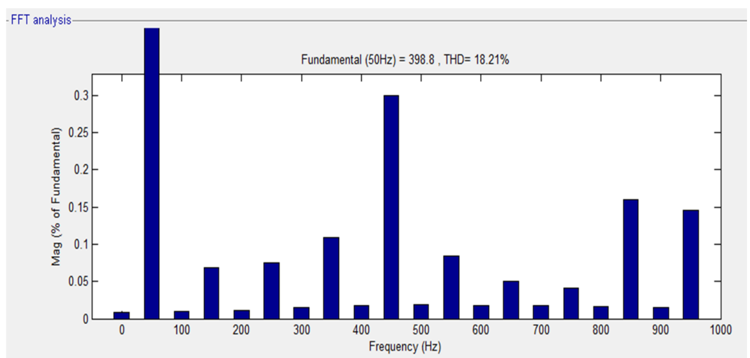

Figure 23. Spectrum analysis of line voltage of seven levels H-Bridge inverter with sinusoidal PWM.

Figure23 illustrates FFT analysis of line voltage of cascaded H-Bridge seven level inverter

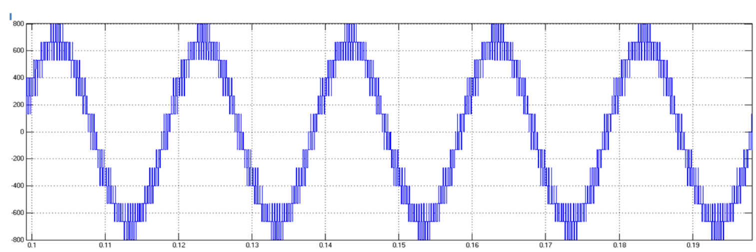

Figure 24. phase voltage of seven level PWM inverter fed induction motor.

Figure24 Shows the Phase Voltage of seven Level PWM Inverter Fed Induction Motor.

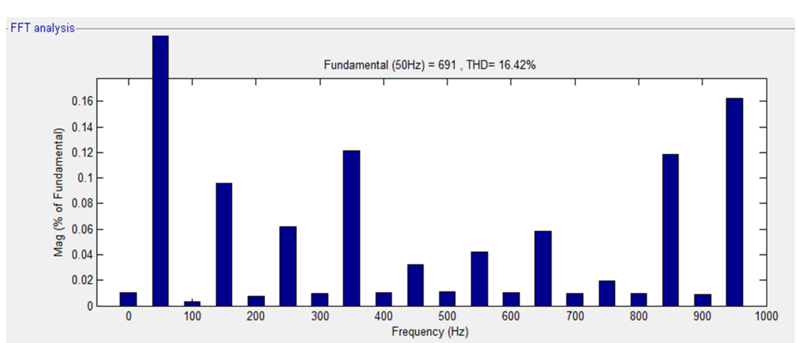

Figure 25. Spectrum analysis of phase voltage of cascaded H-Bridge seven level inverter

Figure25 illustrates the FFT analysis of phase to phase voltage of cascaded H-Bridge seven level inverter.

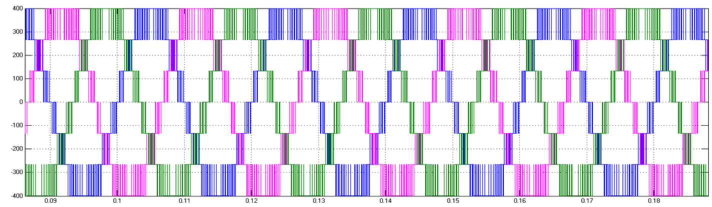

Figure 26. Phase voltage of three phase seven level PWM inverter fed induction motor.

Figure 26 shows the phase voltage of three phase seven level PWM inverter fed induction motor.

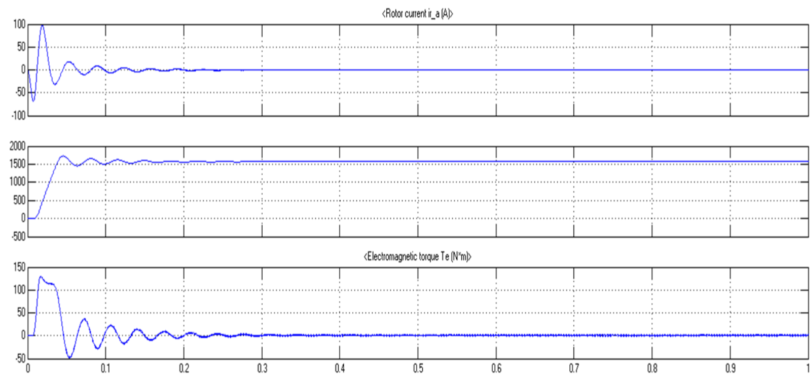

Figure 27. The generated current, torque and output speed of the three phase seven level fed induction motor level shifted carrier PWM.

Fig.27 shows the three phase seven level PWM inverter output speed, generated current and torque with level shifted carrier PWM concept fed to induction motor.

Nine Level

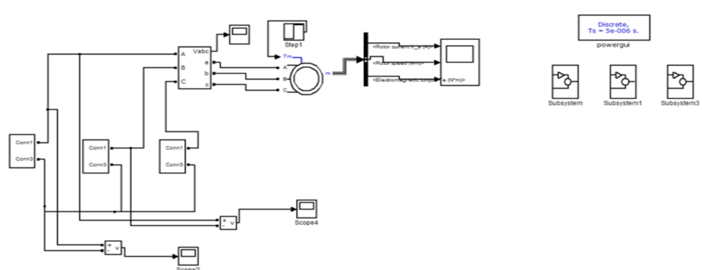

Figure 28. Matlab/Simulink model of three phase nine level PWM inverter fed induction motor.

Figure28 illustrates the Matlab/Simulink model of nine level three phase PWM inverter fed induction motor.

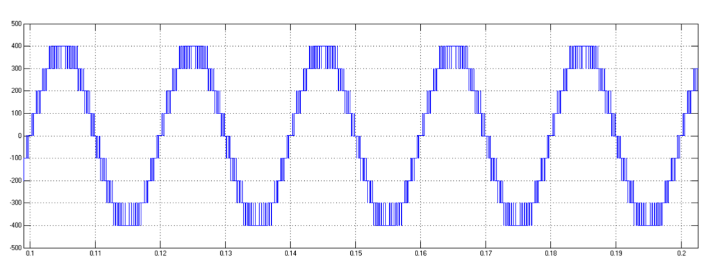

Figure 29. Line voltage of the nine level PWM inverter fed induction motor.

Figure29 Shows line Voltage of the nine Level PWM Inverter Fed Induction Motor.

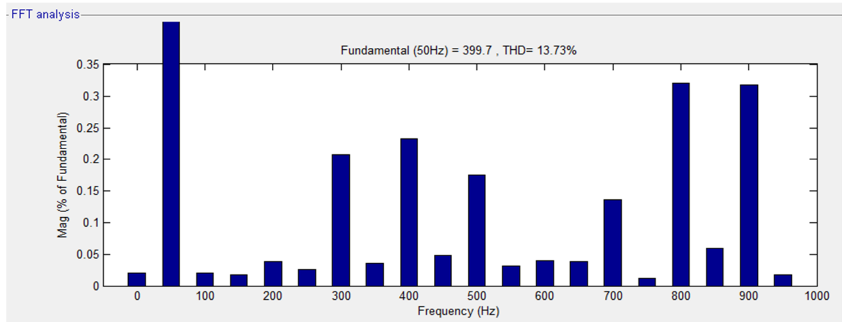

Figure 30. Spectrum analysis of line voltage of nine levels H-Bridge inverter with sinusoidal PWM

Figure30 illustrates the FFT analysis of line voltage of CHB nine level inverter.

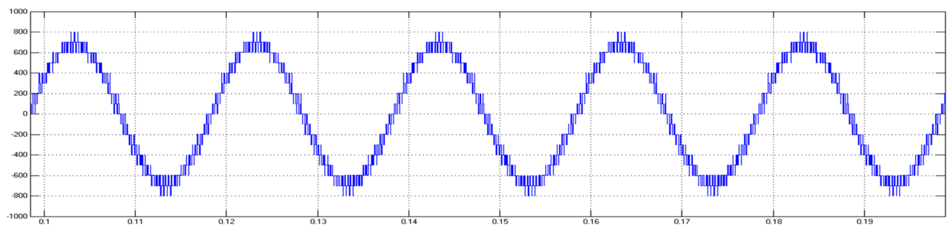

Figure 31. Phase voltage of nine level PWM inverter fed induction motor.

Figure31 Shows the Phase to Phase Voltage of nine Level PWM Inverter Fed Induction Motor.

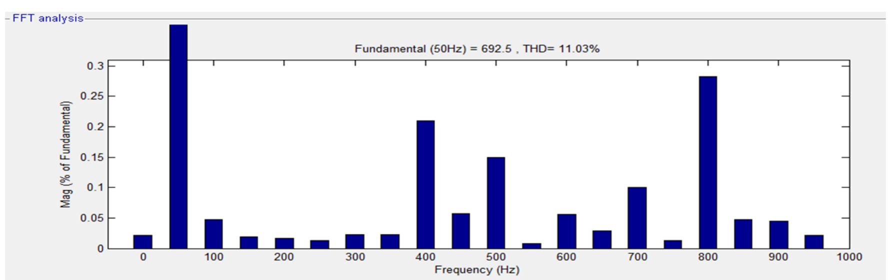

Figure 32. Spectrum analysis of phase to phase voltage of CHB nine level inverter.

Figure32 illustrates the FFT analysis of phase to phase voltage of CHB 9-level inverter with sinusoidal PWM.

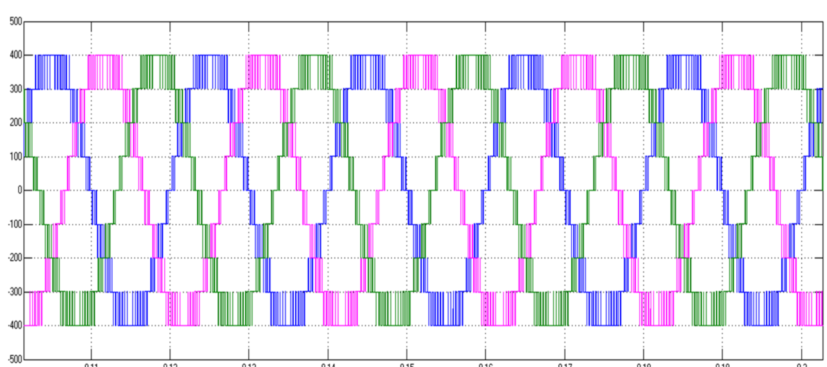

Figure 33. Phase to phase voltage of three phase nine level PWM inverter fed induction motor.

Figure33 shows the phase to phase voltage of three phase nine level PWM inverter fed induction motor.

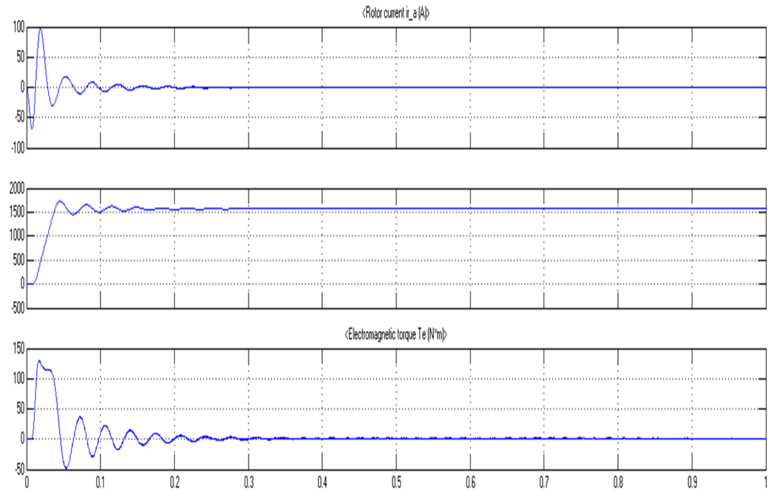

Figure 34. the generated current, torque and output speed of the three phase nine level fed induction motor level shifted carrier PWM.

Fig.34. shows the generated current, torque and output speed of the level shifted carrier PWM three phase nine level fed induction motor.

Eleven Level

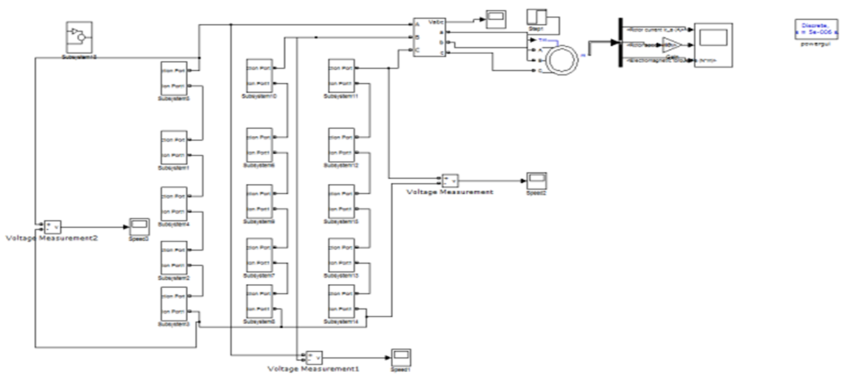

Figure 35. Matlab/Simulink model of three phase eleven level PWM inverter fed induction motor.

Figure35 illustrates the Matlab/Simulink model of eleven level three phase PWM inverter fed induction motor.

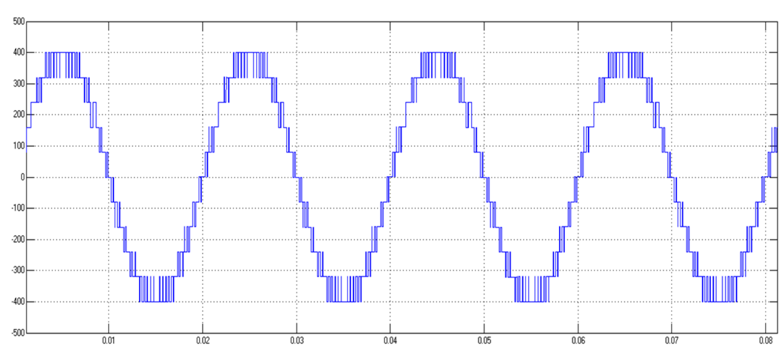

Figure 36. Line voltage of the eleven level PWM inverter fed induction motor.

Figure36 Shows Single Bridge Voltage o the eleven Level PWM Inverter Fed Induction Motor.

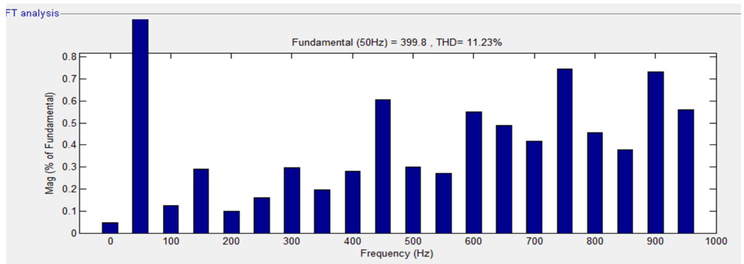

Figure 37. Spectrum analysis of line voltage 11 level CHB inverter with sinusoidal PWM.

Fig 37 shows FFT analysis of single bridge 11 level voltage of CHB inverter with sinusoidal PWM.

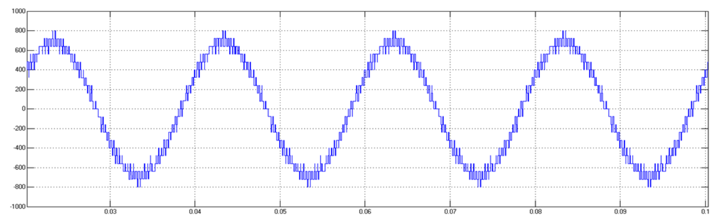

Figure 38. phase voltage of eleven level PWM inverter fed induction motor.

Fig 38 illustrates the Phase to Phase Voltage of eleven Level PWM Inverter Fed Induction Motor.

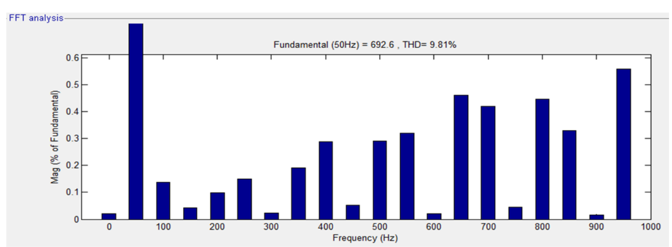

Figure 39. Spectrum analysis of phase voltage of CHB 11-level inverter with sinusoidal PWM.

Fig 39 illustrates FFT analysis of phase voltage of CHB 11 level inverter with sinusoidal PWM.

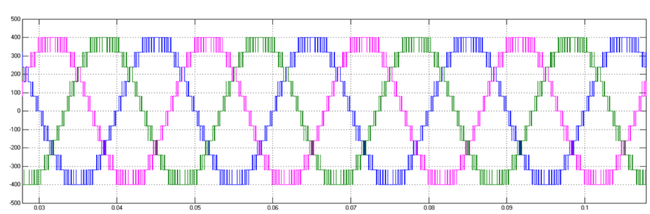

Figure 40. Phase to phase voltage of three phase eleven level PWM inverter fed induction motor.

Fig 40 illustrates the phase to phase voltage of three phase eleven level PWM inverter fed induction motor.

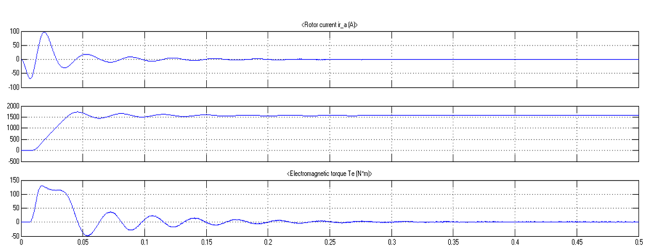

Figure 41. the generated current, torque and output speed of the three phase eleven level fed induction motor level shifted carrier PWM.

Here we need give a vital importance to the behavior of the generated electromagnetic torque. Fig.41 shows the output speed, generated current and torque of the level shifted carrier PWM three phase eleven level fed induction motor.

PI Controlled PV Cell Fed Eleven level Inverter

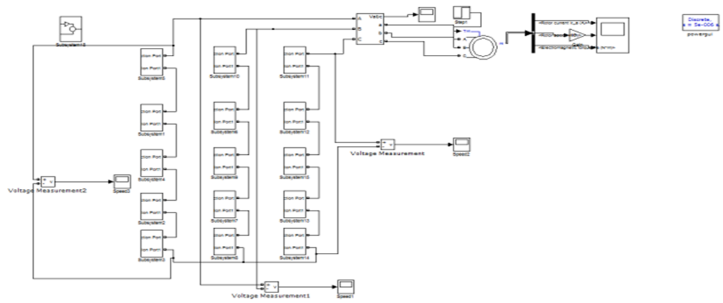

Figure 42. Matlab/Simulink model of three phase PI controlled Pv cell based eleven level PWM inverter fed induction motor.

Figure42 illustrates the Matlab/Simulink model of three phase eleven level PWM inverter fed induction motor.

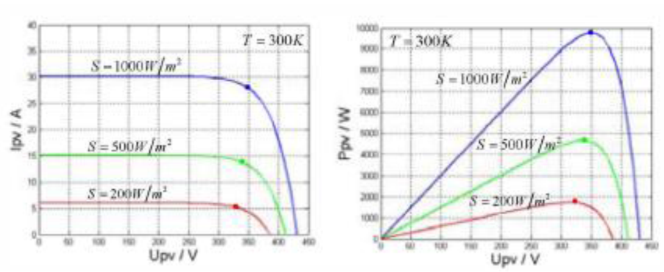

Figure 43. I-V and P-V curve obtained for Pv cell.

Figure 43 show the matlab/Simulink output wave form of the pv cell

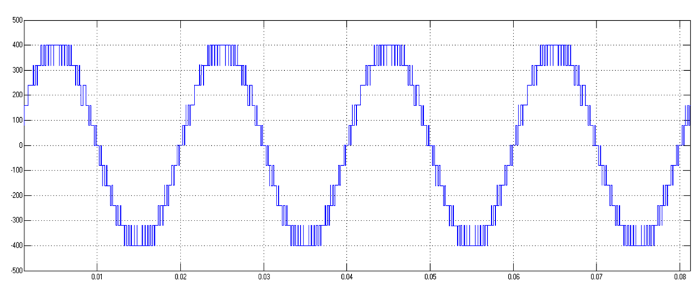

Figure 44. PI Controlled PV cell fed of the eleven level PWM inverter phase voltage.

Figure44 Shows Single Bridge Voltage of the eleven Level PWM Inverter Fed Induction Motor.

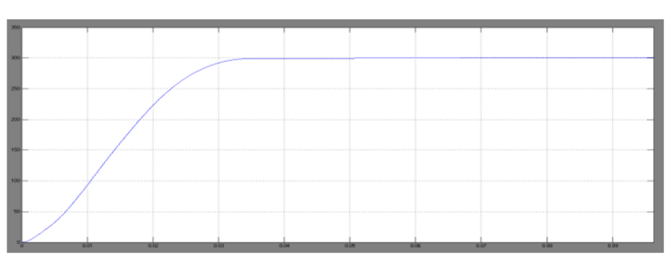

Figure 45. DC Output Voltage with PI Controller

Figure 45 shows the DC Output Voltage with PI Controller, due to the classical controller requires 0.03 sec for attaining the steady state.

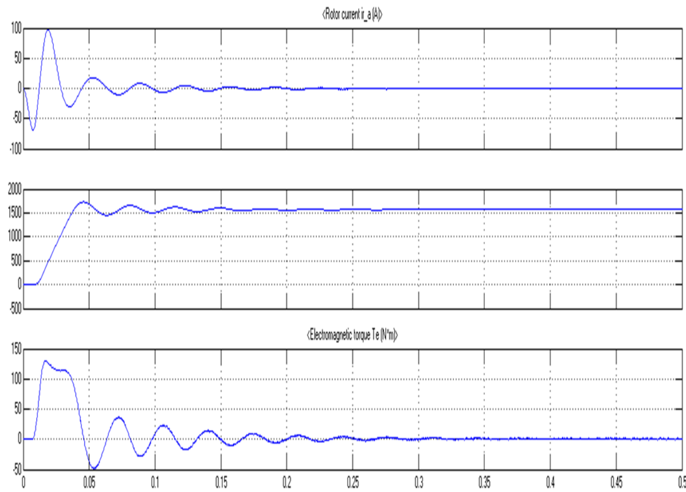

Figure 46. the generated current, torque and output speed of the three phase eleven level fed induction motor level shifted carrier PWM for PI controlled pv cell based multi level inverter.

Fuzzy Controlled PV Cell Fed Eleven level Inverter

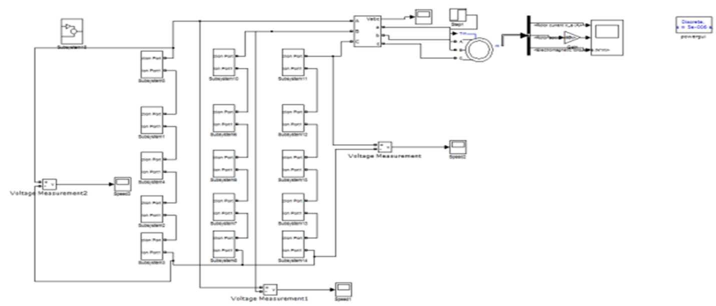

Figure.47. Matlab/Simulink model of three phase fuzzy controlled Pv cell based eleven level PWM inverter fed induction motor

Figure47 demonstrates the Matlab/Simulink model of three phase eleven level PWM inverter fed induction motor.

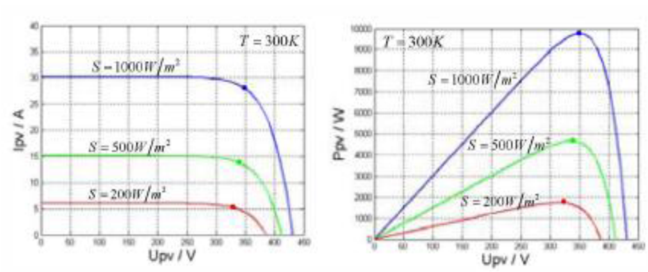

Figure 48. I-V and P-V curve obtained for Pv cell.

Figure 48 show the matlab/Simulink output wave form of the pv cell

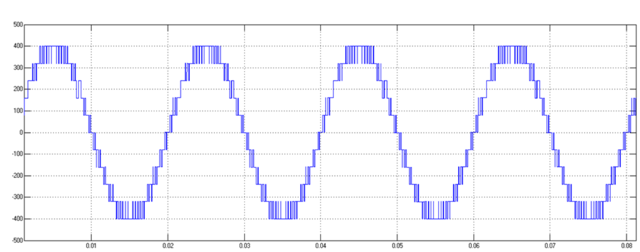

Figure 49. Fuzzy Controlled PV cell fed of the eleven level PWM inverter phase voltage.

Figure49 Shows Single Bridge Voltage of the eleven Level PWM Inverter Fed Induction Motor.

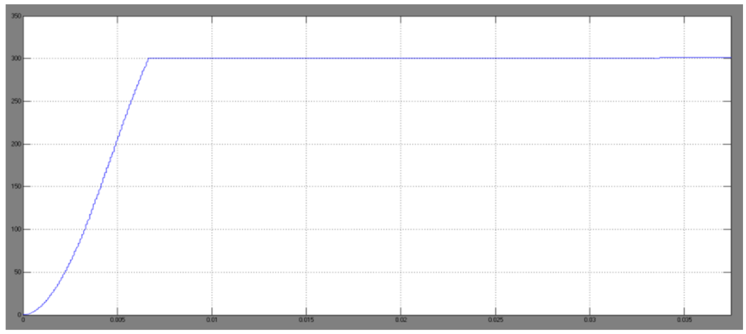

Figure 50. DC Output Voltage with Fuzzy Controller

Figure 50 shows the DC Output Voltage with Fuzzy Controller, due to the classical controller requires 0.005 sec for attaining the steady state.

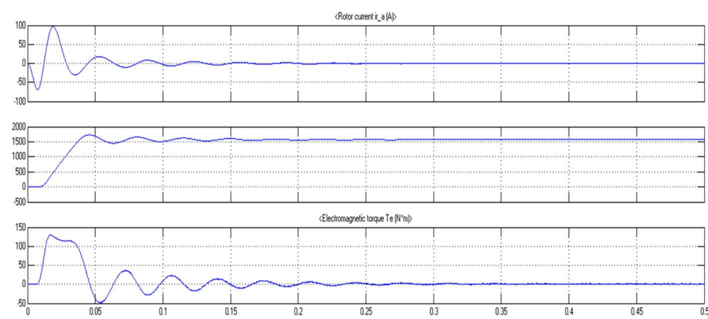

Figure 51. the generated current, torque and output speed of the three phase eleven level fed induction motor level shifted carrier PWM for Fuzzy controlled pv cell based multi level inverter.

Table 2. Comparison of line voltage THD and phase voltage THD

Levels	dv/dt	Line voltage THD%	Phase voltage THD%
3-level	Vdc	52.21	44.09
5-level	Vdc/2	26.96	21.86
7-level	Vdc/3	18.21	16.42
9-level	Vdc/4	13.73	11.03
11-level	Vdc/5	11.23	9.81

Table 3. Comparison of Dc link voltage steady state time

Controller	Steady state time
PI	0.03 sec
Fuzzy	0.005 sec

CONCLUSION

This paper has provided a brief summary of multilevel inverter circuit topologies (3-level, 5-level, 7-level, 9-level, and 11-level) and their analysis with respect to induction motor drives. Each MLI has its own blend of rewards and drawbacks and for any one meticulous application, one topology will be more appropriate than the others. Frequently, topologies are elected based on what has left earlier, even if that topology may not be the finest selection for the application. The compensations of the body of research and awareness within the engineering area may offset further technical shortcomings. Multilevel converters can accomplish an effectual amplify in overall switch frequency through the abolition of the lowest order switch frequency terms. There are a lot of modulation techniques for multi level inverters. But carrier based modulation technique is easy and efficient. The proposed converter has controlled with PI and Fuzzy logic controllers and it has been shown that Fuzzy time 0.005 sec reaches steady state where PI time reaches by 0.03sec. From these results it has been shown that Fuzzy controlled pv based 11 level inverter is efficient for Induction motor applications.

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