International Journal of Scientific Engineering and Technology Research
ISSN 2319-8885
Vol.04,Issue.03
February-2015,
Pages:0469-0476
www.ijsetr.com

Advanced of Induction Motor with PV Cell Fed Multilevel Inverter with Various Voltage Levels

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Abstract: Harmonic reduction in inverters fed from a standalone PV system is currently becoming important in induction motor applications. This paper focuses on the design and analysis NPC based multi level inverter fed induction motor drive. In this concept three, nine and fifteen level multi level inverters are designed and analyzed to reduce the total harmonic distortion of the proposed system. A simplified Pulse Width Modulation (SPWM) method for a multilevel inverter that supplied an induction motor is developed. The controller equations are such that the SPWM pulses are generated automatically for any number of levels. A comparison study of the total harmonic distortion reduction with the above proposed NPC multi level inverter with Cascaded-H-bridge multi level inverter is done. Further, the paper attempts to show that the use of Cascaded-H-bridge multi level inverter with a standalone PV system can highly improve the performance of the Induction motor. Results are verified using simulations in MATLAB-SIMULINK environment.

Keywords: Induction Motor, Multilevel Inverter, Energy Management, PV Battery, Multilevel SPWM, THD.

I. INTRODUCTION

Solar power is the abundantly available source which has no noise and pollution during its production compared with conventional energy sources hence the solar power is the upcoming source of energy for future needs. Solar Energy is trapped and converted in to electricity with the help of PV cells. PV cells are more useful for remote areas where conventional energy sources are not reachable. Rapid evolution in semiconductor devices has revolutionized the industry for increasing in the production of high power applications. The above mentioned reasons lead to the development of multilevel inverter. Difficulties of commutation failure, harmonics and total input voltage problems are minimized as the level of inverter is increased. Different Control Algorithms are used by the multi level inverter [2-4] of which Sinusoidal Pulse Width Modulation (SPWM) appears most suitable. In multi level inverter as the level increases the THD decreases, also the output signals will have good spectral quality. Multi level inverters are mostly suited for high power applications [3-6].Disadvantage of multi level inverter design of control circuit is much complex and due to which it is not widely used for industrial applications [7-8].

The traditional inverters are Voltage Source Inverter (VSI) and Current source Inverter (CSI), which consist of diode rectifier front end, DC link and Inverter Bridge. In order to improve power factor, either an AC inductor or DC inductor is normally used. The DC link voltage is roughly equal to 1.35 times the line voltage and the Voltage source inverter is a buck converter that can only produce an AC voltage limited by the dc link voltage. Because of this nature, the Voltage source inverter based PWM VSI and CSI are characterized by relatively low efficiency because of switching losses and considerable Electromagnetic Interference (EMI) generation.

A. Photovoltaic System

The PV cell characteristics are strongly nonlinear in nature; its most referred equivalent circuit [8] is shown in fig.2. The Related expression is given in equation (1) [9] as follows:

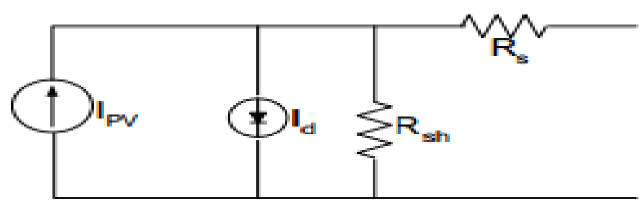

Fig.1. Equivalent circuit of solar PV.

As shown in the fig.1, IPV stands for PV shortcircuits current, Id is a diode current, Rs means the series resistance of photovoltaic cells, Rsh represents the photovoltaic battery parallel resistance; the internal value is less than 1 Ω. The equation governing the behavior of photovoltaic cell is expressed as

$$I = I_{PV} - I_0\left[e^{\frac{q}{AKT}\frac{V+IR_s}{}} - 1\right] - \frac{V+IR_s}{R_{sh}} \quad \textbf{(1)}$$

Where,
IPV= Photo-generated current (A)

I= Cell output current (A)
I_0=Diode Saturation Current (A)
V=Cell Output Voltage (V)
R_s=Series Resistor (Ω)
e= Electron Charge 1.6×10-19 (coul)
K=Boltzman Constant (j/K)
T=cell temperature

Many research works are focusing in the development of the efficient control algorithms for high performance variable speed induction motor (IM) drives. Induction motor has been operated as a work horse in the industry due to its easy build, high robustness and generally satisfactory efficiency. Recent development of high speed power semi conductor devices, three phase inverters take part in the key role for variable speed AC motor drives. Traditionally, Three Phase inverters with six switches (SSTP) have been commonly utilized for variable speed IM drives; this involves the losses of the six switches as well as the complexity of the control algorithms and interface circuits to generate six PWM logic signals. So far researchers mainly concentrated on the development of new control algorithms. However, the cost, simplicity and flexibility of the overall drive system which are some of the most important factors did not get that much attention from the researchers. That is why, despite tremendous research in this area, most of the developed control system failed to attract the industry. Thus, the main issue of this work is to develop a cost effective, simple and efficient high performance IM drive.

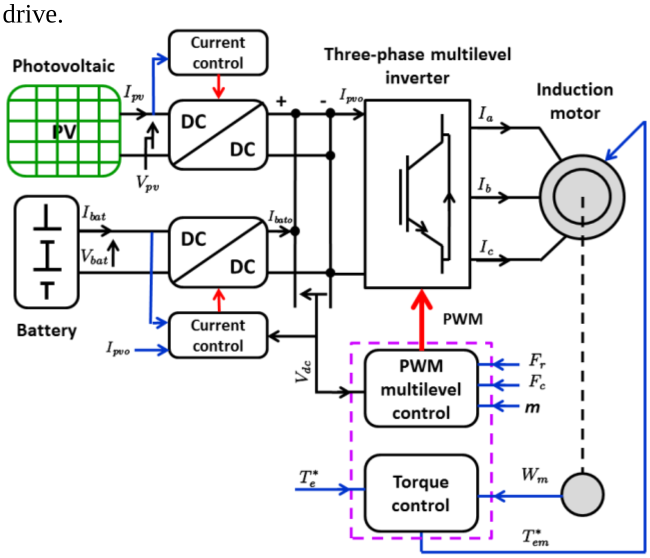

Fig.2.Induction motor driven by PV-batteries standalone system using a controlled multilevel inverter.

II. MULTILEVEL INVERTER CONTROL STRATEGIES

A. The Three-Level Inverter Control Strategy

Fig.3 shows a three-phase three-level inverter. It has three arms. Each arm has four switches. Every switch is connected in anti-parallel with a diode. This paragraph describes the operation of one of the legs shown at Fig. 4. The voltage Vao between the phase "a" and the neutral point O is defined entirely by the switches position (0 'open' or 1'closed'). Switch sets [S11, S13], and [S12, S14] have complementary positions. When [S11, S13] are open [S12, S14] are closed. The three-level NPC inverter is mostly used [10] for medium-voltage high-power applications. In this converter, the number of commutation sequences (Seq) is equal to 2^4= 16. Where 4 stands for the number of switches per arm and 2 is the number of state per switch (0, 1). V_{dc} is the DC-bus voltage. Only three commutation sequences are possible. They are represented at Table 1. Fig. 4 shows the configurations of the inverter's arm which correspond to the three possible commutation sequences:- Sequence 1: S11, S12 conduct and S13, S14 open (Fig.4. A). Va0=+V_{dc}/2.- Sequence 2: S12, S13conduct and S11, S14 open (Fig.4. B). Va0 = 0.- Sequence 3: S13, S14 conduct and S11, S12 open (Fig.4.C. Va0=-V_{dc}/2. Sequences 1, 2 and 3 are applied in this order periodically.

A pulse width modulation is used to control the switches. Consider Fig. 5 and Fig.6, the reference Voltage V_{ra} is compared to the positive and negative sawtooth carrier V_{cx} and V_{cy} respectively. The comparator output is sent to the switches (Insulated Gate Bipolar Transistor or IGBT) to generate the machine phase voltage. The modulated SPWM voltage has the following characteristics, SPWM pulses frequency is the same as the sawtooth carrier f_c. The magnitude is 1 (fSPWM= fC, |Vpwm|=1)- The fundamental frequency is controlled by Fr which is the same as the reference voltage where A_r and A_r are the peak to peak value of V_{ao} and V_c respectively frequency.

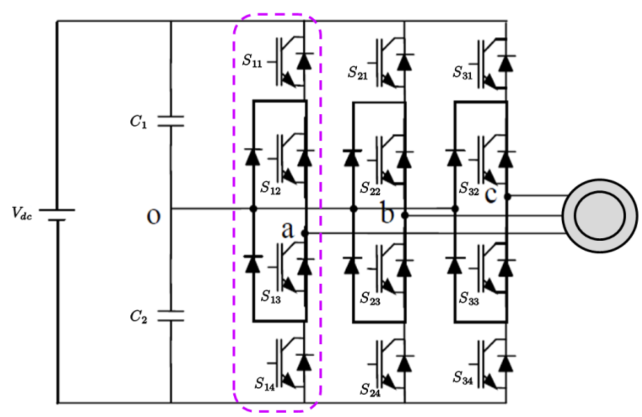

Fig. 3. Three-level three phase inverter.

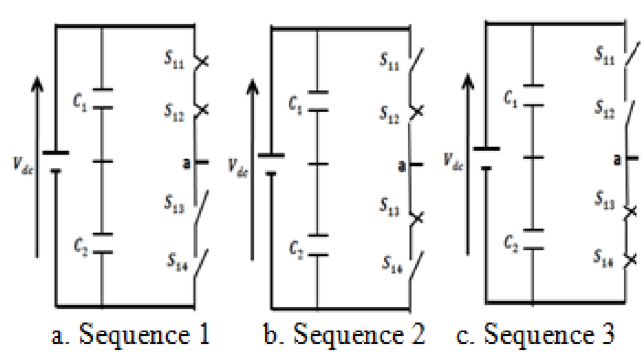

Fig. 4. Different possible configurations for one arm.

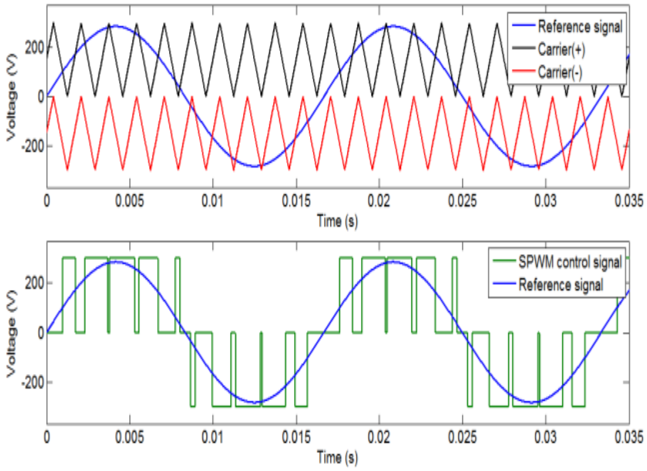

Fig.5. Three-level SPWM control method.

TABLE I: Sequences Of Control Vectors

S	$[S_{11}\ S_{12}\ S_{13}\ S_{14}]$	V_{ao}
1	[1 1 0 0]	V_{ao}
2	[0 1 1 0]	$V_{ao}=0$
3	[0 0 1 1]	V_{ao}

The inverter output voltages are written as follow (2):

$$\begin{cases} V_{ao} = \frac{1}{3}(V_{ab} - V_{ca}) \\ V_{bo} = \frac{1}{3}(V_{bc} - V_{ab}) \\ V_{co} = \frac{1}{3}(V_{ca} - V_{bc}) \end{cases} \quad (2)$$

Modulation index (ma) is defined by (3):

$$m_a = \frac{A_r}{(n-1)A_c} \quad (3)$$

B. The Higher Level Inverter Control Strategy

The previous study for the three-level voltage inverter is now extended to higher level inverters. For an n-level inverter, it is possible to determine the number of components that are needed per arm (number of switches, diodes, carrier, etc).

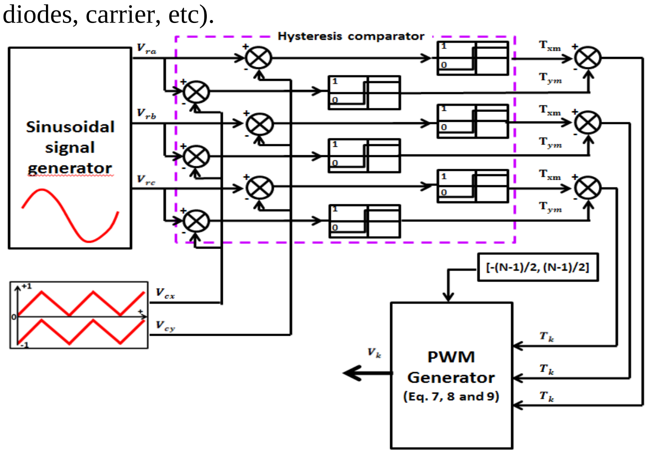

Fig. 6. Principle SPWM multilevel inverter control.

Numbers of inverter components calculation: Define Seq as the number of commutation sequence possibilities. S is the number of secondary voltage sources. K stands for the number of switches per phase. D is the number of diodes loop including the diode switches per phase. C represents the magnitude of the voltage across each capacitor and P is the number of carriers. The following equations provide how these quantities are calculated and table 2 shows the values for several multilevel inverters.

$$\begin{cases} S_{eq} = 2^{(n+1)} \\ S = P = n-1 \\ K = 2(n-1) \\ D = 4n-6 \\ C = \frac{V_{dc}}{n-1} \end{cases} \quad (4)$$

TABLE II: Sequences Of Control Vectors

n	S_{eq}	S=P	K	D	C
3	16	2	4	6	$V_{dc}/2$
5	64	4	8	14	$V_{dc}/4$
7	256	6	12	22	$V_{dc}/6$
9	1024	8	16	30	$V_{dc}/8$
11	4096	10	20	38	$V_{dc}/10$
15	65536	14	28	54	$V_{dc}/14$

Calculation Of Carrier: A bipolar sawtooth carrier is illustrated at Fig.7. The voltages V_c, xand V_c, y have the expression given by equation (5):

$$\begin{cases} V_{cx} = \sum_{x=2}^{h} V_{cx-1} + 1 \\ V_{cy} = \sum_{y=-2}^{-h} V_{cy-1} - 1 \end{cases} \quad (5)$$

Calculation Of Reference Voltages: The balanced three-phase reference voltage is given by (6):

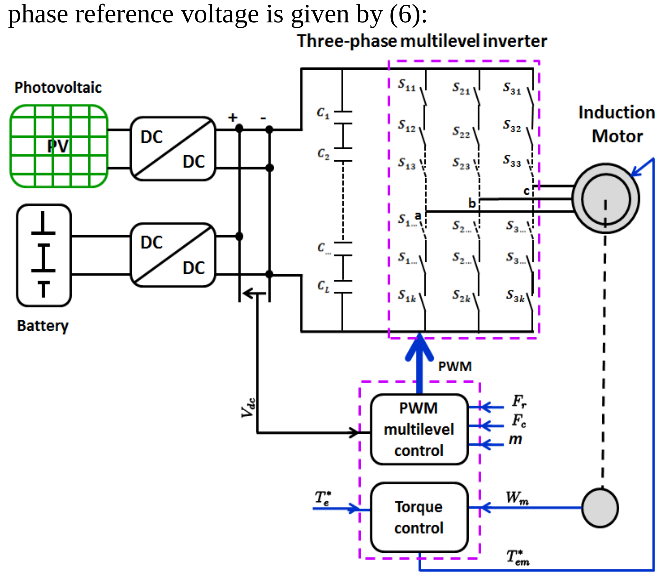

Fig.7. Diagram of the induction motor control principle based on the multilevel inverter.

$$V_r : \begin{cases} V_{ra}(t) = A_r Sin(2\pi f_r t) \\ V_{rb}(t) = A_r Sin\left(2\pi f_r t - \frac{2\pi}{3}\right) \\ V_{rc}(t) = A_r Sin\left(2\pi f_r t - \frac{4\pi}{3}\right) \end{cases} \quad (6)$$

Where Vr is the three phase reference voltage.

Calculation Of The Comparator: The comparator uses the reference and carrier signals to Generate a binary signal according to the following equation:

$$\begin{cases} If\ V_r \geq V_{cx} => T_{xm} = 1 \\ or \\ If\ V_r < V_{cx} => T_{xm} = 0 \\ and \\ If\ V_r \leq V_{cy} => T_{ym} = 1 \\ or \\ If\ V_r > V_{cy} => T_{ym} = 0 \end{cases} \quad (7)$$

Where matrices Txm and Tym are the comparator output**.**

Calculation Of The Adder: The parameter T_k is the difference between T_{xm} and T_{ym}. It is therefore calculated as follows.

$$T_k = T_{xm} - T_{ym} \quad (8)$$

Calculation Of Inverter Control Vectors: The generation of the pulse vector that controls the inverter is very important. The pulse vector can be generated by applying the G_n vector for each T_k according equation (9). The inverter output voltage V_k is given by equation (10).

$$If\ T_k = \frac{n-1}{2} - i => \begin{cases} G_1 = [0 \ldots 0\ 1 \ldots 1] \\ G_2 = [1 \ldots 0\ 0 \ldots 1] \\ G_3 = [1 \ldots 0\ 0 \ldots 1] \\ \ldots \\ G_n = [1 \ldots 1\ 0 \ldots 0] \end{cases} \quad (9)$$

$$V_k = \frac{h-i}{n-1} V_{dc} \quad (10)$$

Where $h = \frac{n-1}{2}, i = \{0, 1, 2, \ldots, n-1\}$ and G_n is 1x2(n-1) vector. It contains 1x(n-1) zero vector and 1x(n-1) ones vector.

III. MATLAB MODELEING AND SIMULATION RESULTS

Simulation results of this paper is shown in bellow Figs.8 to 26.

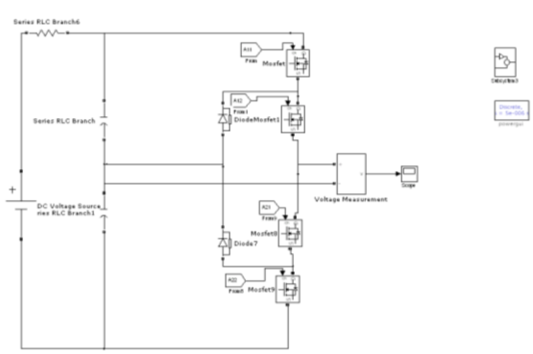

Fig.8. Matlab/Simulink model of 3-level NPC.

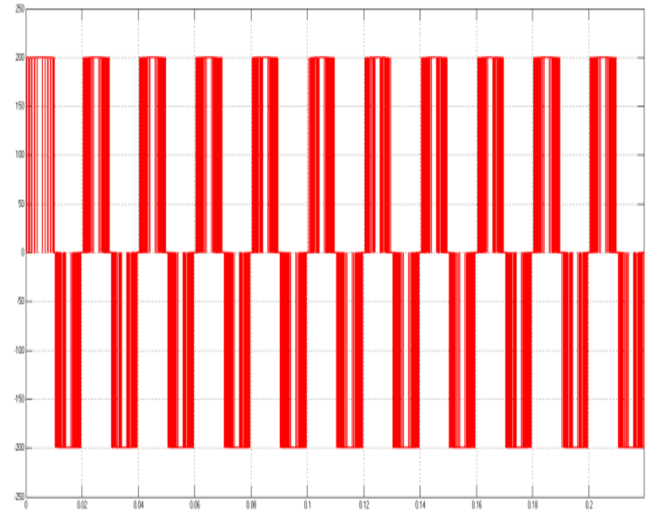

Fig.9. Output Voltage wave forms of 3-Level NPC.

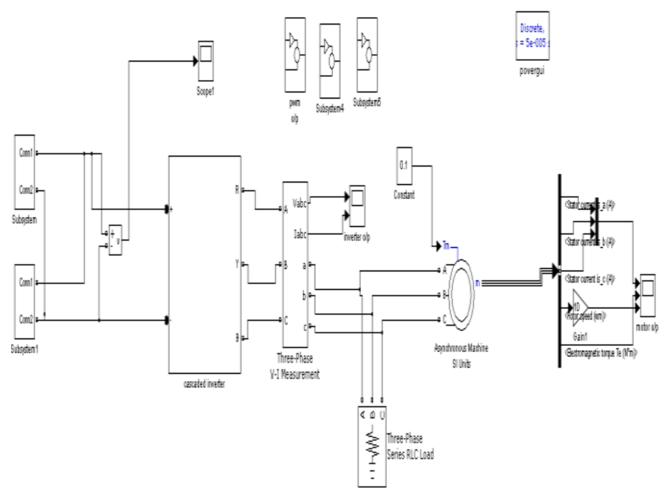

Fig.10. Matlab/Simulink model of 3-Level NPC Controlled of Induction motor.

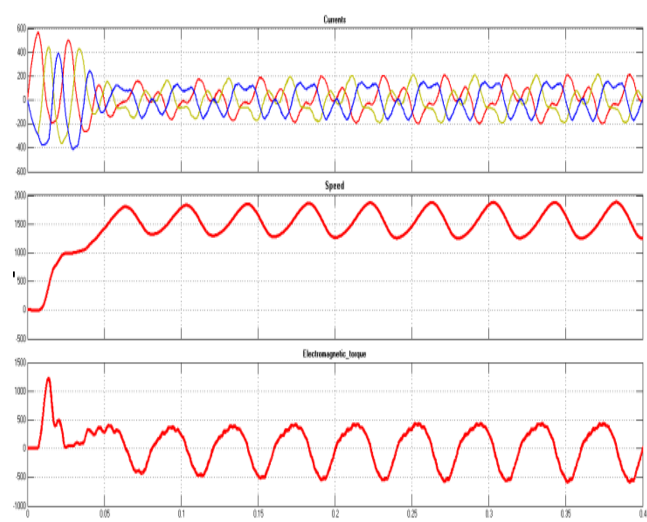

Fig.11. Output wave forms of Stator currents, Speed and Torque of 3-level NPC connected Induction motor.

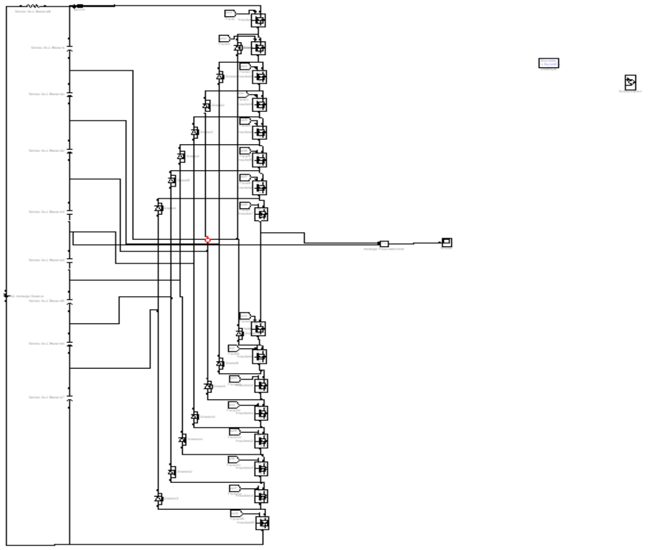

Fig.12. Matlab/Simulink model of 9-level NPC.

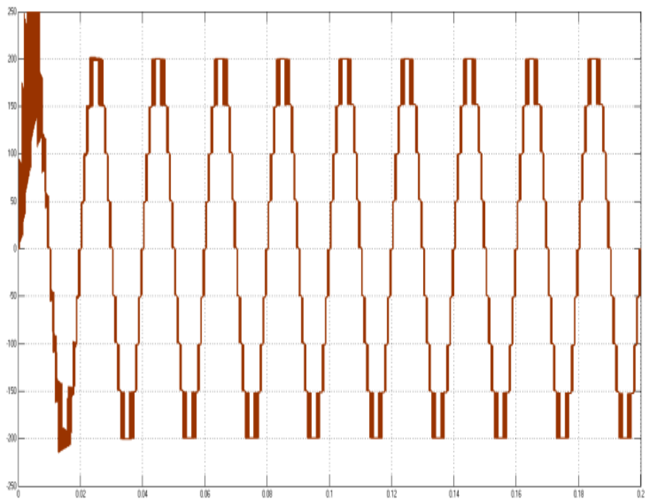

Fig.13. Output Voltage wave forms of 9-Level NPC.

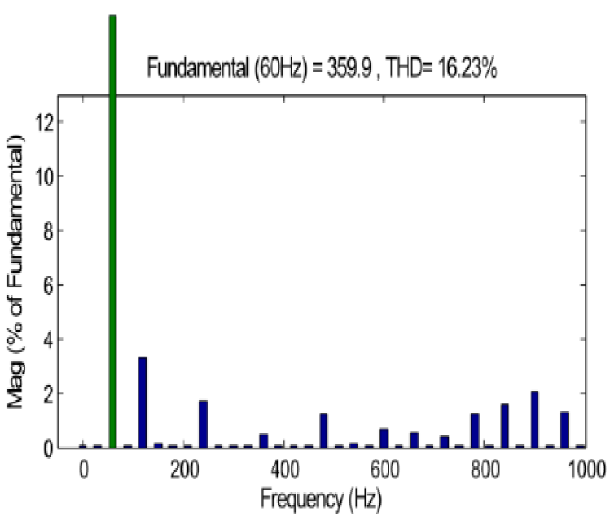

Fig.14. Total Harmonic Distortion 16.263Value of 9 level output Voltage of NPC.

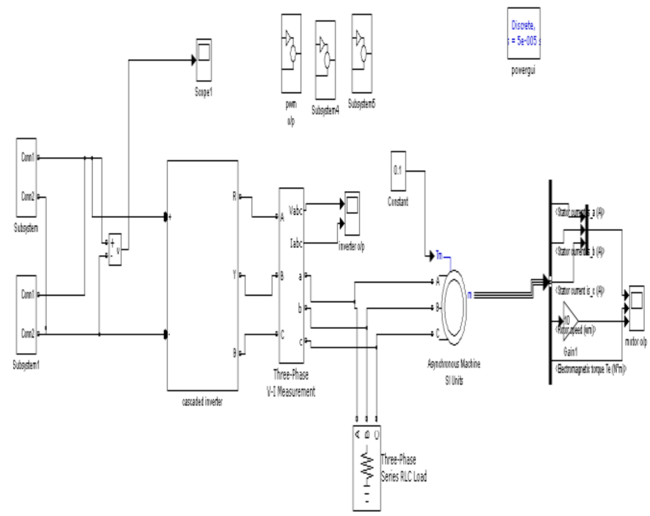

Fig.15. Matlab/Simulink model of 9-Level NPC Controlled of Induction motor.

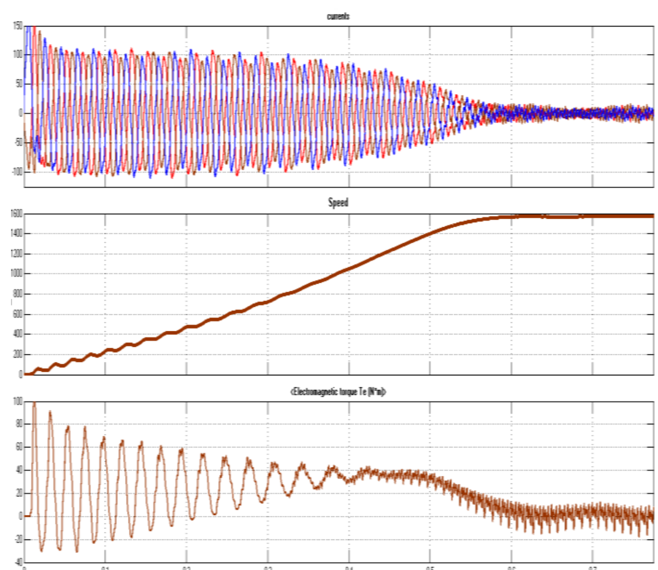

Fig.16. Output wave forms of Stator currents, Speed and Torque of 9-level NPC connected Induction motor.

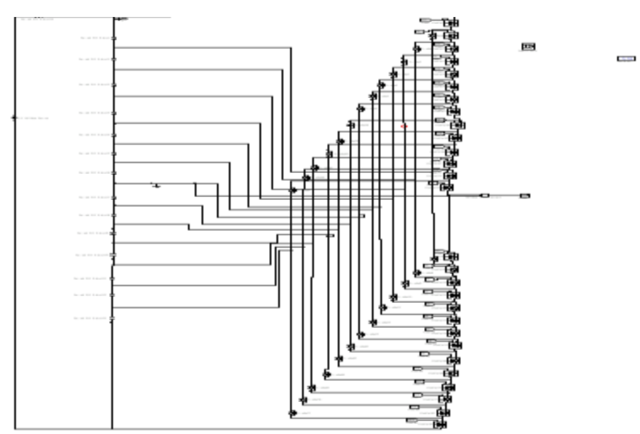

Fig.17. Matlab/Simulink model of 15-level NPC.

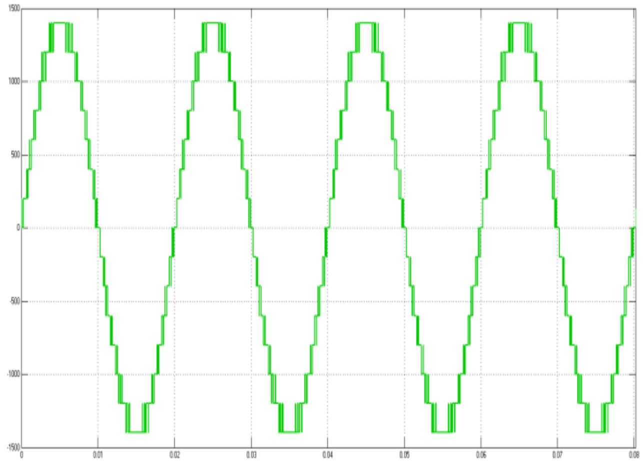

Fig.18. Output Voltage wave forms of 15-Level NPC.

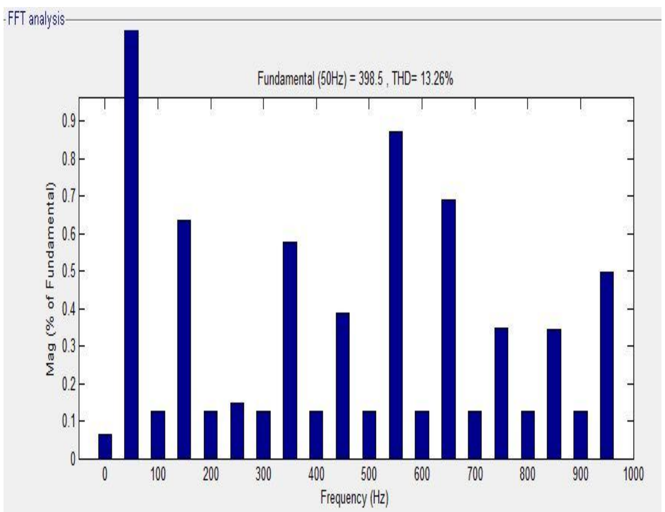

Fig.19. Total Harmonic Distortion 13.26% Value of 15 level output Voltage of NPC.

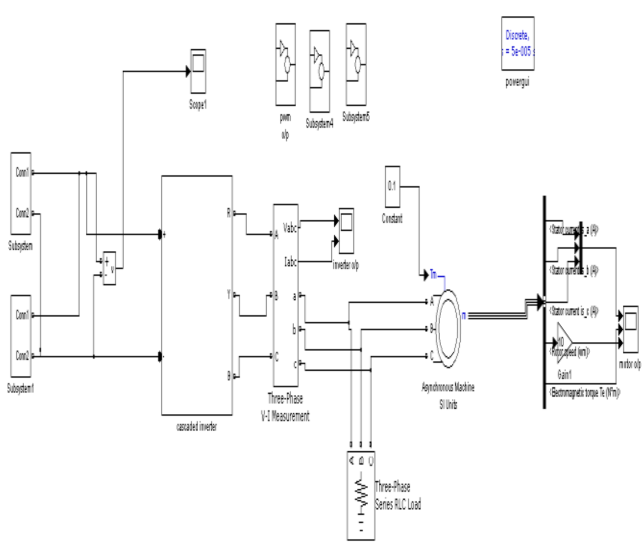

Fig.20. Matlab/Simulink model of 15-Level NPC Controlled of Induction motor.

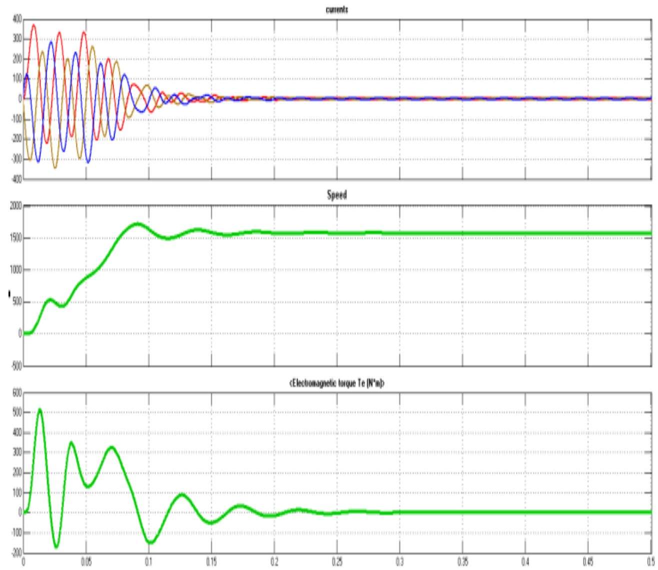

Fig.21. Output wave forms of Stator currents, Speed and Torque of 15-level NPC connected Induction motor.

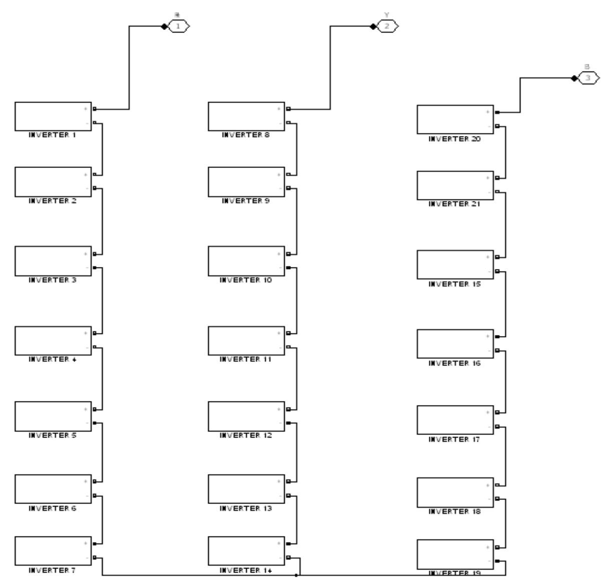

Fig.22. Matlab/Simulink model of 15-level Cascaded H-Bridge Inverter.

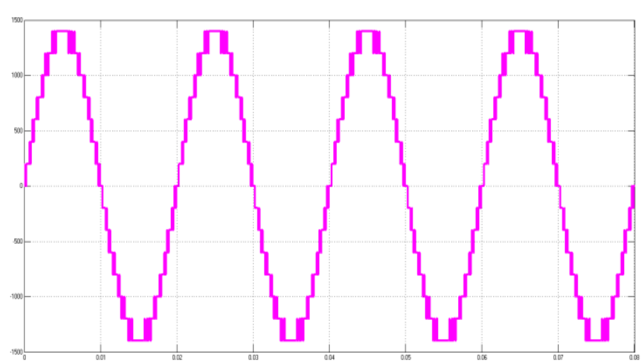

Fig.23. Output Voltage wave forms of 15-Level level Cascaded H-Bridge Inverter.

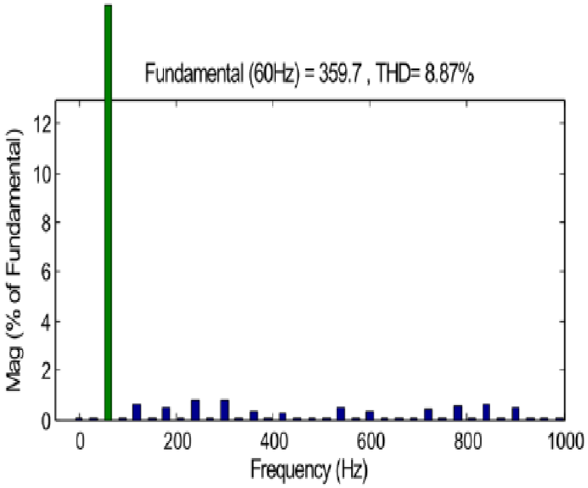

Fig.24. Total Harmonic Distortion 8.87% Value of 15 level output Voltage of Cascaded H-bridge Inverter.

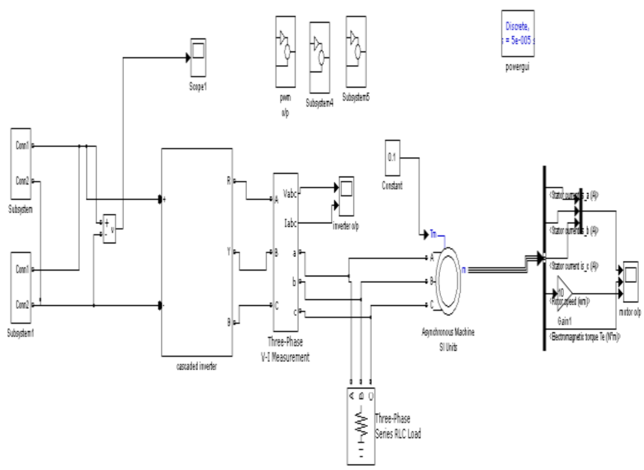

Fig.25. Matlab/Simulink model of 15-Level Cascaded Controlled of Induction motor.

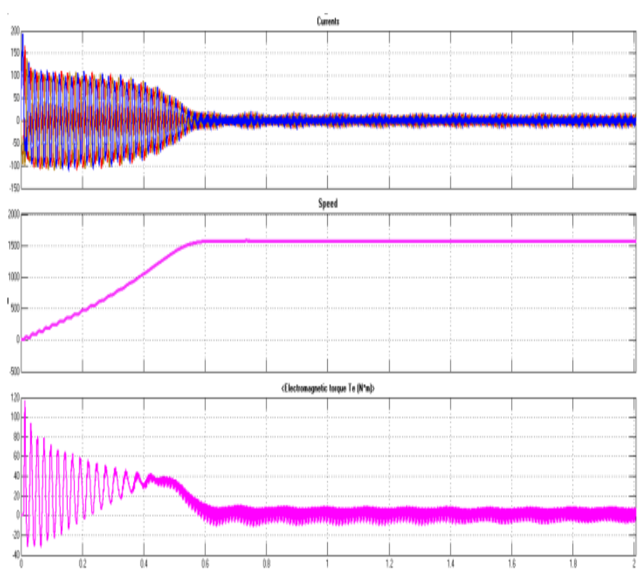

Fig.26. Output wave forms of Stator currents, Speed and Torque of 15-level Cascaded connected Induction motor.

IV. CONCLUSION

In this paper, a general multilevel SPWM control algorithm for n-level inverter has been modeled and simulated using Matlab®/Simulink. This algorithm can generate automatically SPWM pulses for any level of inverter by changing only a parameter n which is the number of inverter level. Simulation of 3, 9, and fifteen level inverter connected to induction motor has been performed and the generated signals THD are analyzed. The system is supplied by a PV panel and batteries bank. That gives energy autonomy to the system. Simulation results give a better quality of stator current in terms of low harmonics, thus reducing the adverse effects on of the machine life and eventually the electrical network which supplies it. Base to THD analyze for three different index of modulation, we have also highlighted that at fifteen-level, the harmonics are very low. The Performance characteristics of the Induction motor have been improved by using 15 levels Cascaded H-bridge Inverter. The simulation results of it has been shown and studied.

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