

Simulation and Study of Multilevel Inverter System Fed by Photovoltaic Source

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Abstract:

This paper proposes a simulation of Photovoltaic energy used to supply an induction motor with a comparison of two types of inverters. In general, the greater number of motors which are used in commercial and industrial applications are induction motors. To use PV source to run the induction motor, an interface circuits are used which are a dc-dc converter and an inverter, the PV cell has nonlinear behavior, a dc-dc converter is used along with Maximum Power Point Tracker controller to improve the efficiency by boosting the output voltage of the PV module and to match the load demand. The dc output voltage of PV module then converted to AC, two types of inverter are presented, A conventional Voltage Source Inverter system and multilevel inverter system which employ selective harmonic elimination method fed three phase induction motor, these two types of inverters are simulated using Matlab/Simulink and their results are presented. The FFT spectrum is presented of the output currents to analyze the harmonics reduction, which shows that the multilevel inverter is better than VSI system according to harmonics reduction and increment in output voltage and power.

Keywords: Induction motor, PV module, MPPT algorithm, Voltage source multilevel inverter.

الخلاصة

هذه الورقة تقترح محاكاة استخدام الطاقة الشمسية لتغذية محرك حثي وتقارن عمل نوعين من العاكسات. بصورة عامة، اغلب المحركات المستعملة في المجالات الصناعية والتجارية هي محركات حثية. لتشغيل هكذا نوع من المحركات بأستخدام الطاقة الشمسية، يجب توفر محول dc-dc و عاكس. وبما ان الحلايا الشمسية تمتلك سلوك لاخطي، لذلك يجب توفر محول dc-dc مع متحكم (MPPT) لتحسين كفاءة الطاقة الشمسية وعمل متوافق مع متطلبات الحمل. لتحويل الفولتية الخارجة المستمرة من مصدر الطاقة الشمسية الى متناوبة تم استعمال نوعان من العاكسات. عاكس فولتية المصدر التقليدي و عاكس متعدد المستويات وتم اخذ النتائج بالنسبة لكلا النوعين والمقارنة بينهما.

الكلمات المفتاحية: محرك حثي، وحدة شمسية مركبة، خوارزمية (MPPT) ، عاكس متعدد المستويات .

1. Introduction

In industry field, AC motors are the work horse and preferred to DC motors, specially, the induction motors are preferred due to many features like availability, low cost, low and cheap maintenance, light weight and high efficiency. All the mentioned features make the induction motors are preferred in industry and in commercial applications. The improvement in Power electronics industry and semiconductor technology made an easy way to develop of high rating power and fast switching semiconductor devices, which are used to obtain a continuous, smooth and less variation in control of motor speed. Inverters are widely used to feed the variable speed induction motor in industrial applications. When inverters feed induction motor an amount of harmonics is present and this will cause heating in the motor and torque pulsation (Mohan *et.al.*, 2003). To reduce the harmonics then large filters should be used, which as a result will increase the cost and size of the system. However, due to the improvement power electronics field the harmonics can be reduced with multilevel inverters, by increasing the inverters levels number instead of large size filters. As a resource of energy, the solar energy has many features like has no effect on the environment, there is no fuel cost and low maintenance. That is why it is popular and widely used in the recent years (Santhosh *et.al.*, 2009). Dc-Dc converters are used along with the PV source due to nonlinear behavior of the photovoltaic cell when the load is connected and matched with the PV module. Many converter configurations are available. Single ended primary inductance converter is presented (Chavarria *et.al.*, 2013;Jamri and Wei, 2010). The output power of the PV module

dependent on the solar insolation and temperature. Maximum power point is used to get the maximum efficiency of the PV module for different irradiance conditions. Several MPPT algorithm are used, MPPT algorithm of Perturb and Observe is used (Esram and Chapman, 2007). In this algorithm, the single ended primary inductance converter duty ratio is varied, which means dc-dc converter output voltage changes. Inverter is used to convert the DC output voltage of the converter to ac voltage with specific magnitude and frequency. Two types of inverter is used to drive three induction motor which are VSI and multilevel inverter. This paper present three phase induction motor fed by PV module as source, SEPIC converter and two types of inverters as interface circuits. An algorithm of Perturb and Observe (P&O) MPPT is presented to get the maximum efficiency of PV module (Ismail , 2013;Vitorino and Correa, 2009). The multilevel inverters performance is better than VSI inverter according to the results.

2. Photovoltaic Module and MPPT

PV cell converts the sunlight to electricity. PV arrays or modules can be made by connecting PV Cells in parallel and series is such a way to get the desired power. to get the maximum efficiency from the PV module MPPT algorithm is used Many applications require DC-DC converters to match the voltage of the PV module with the load.

2.1. PV Module

The equivalent circuit of PV cell is shown in figure (1) (Esram and Chapman , 2007), and the output characteristics of PV module are shown in figure (2). To make large PV system, PV modules are connected in series and parallel to get the desired voltage and current.

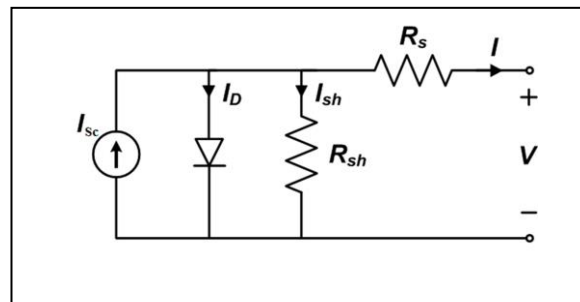


Figure (1) the equivalent circuit of PV cell

The PV module characteristic equation which presents PV module V-I characteristic is given below (Jamri and Wei, 2010).

$$I = I_{pv} - I_o \left[\exp\left(\frac{V + IR_s}{V_t n}\right) - 1 \right] - \frac{V + IR_s}{R_p} \quad (1)$$

Where the PV cell voltage and current are V and I respectively, the photovoltaic current is I_{pv} , the diode reverse saturation current is I_o , the array thermal voltage is given as $V_t = N_s kT/q$ along with (N_s) series connected cells, the Boltzmann constant (k) is given as ($1.3806 \cdot 10^{-23}$ J/K), (T) is the p-n junction temperature, the electron charge is (q) and the ideality constant of the diode is (n). the equations to find I_{pv} and I_o are as follows (Jamri and Wei , 2010).

$$I_{pv} = \left[(1 + a(T - T_{ref})) I_{sc} \right] \left[\frac{G}{1000} \right] \quad (2)$$

$$I_o = I_o(T_{ref}) \left[\frac{T}{T_{ref}} \right]^3 \times \exp \frac{qE_g}{nk} \left(\frac{1}{T_{ref}} - \frac{1}{T} \right) \quad (3)$$

The I_{sc} coefficient of temperature is a , the irradiance G is in W/m^2 and the silicon E_g band gap energy ($1.16eV$ for Si). Figure (2) illustrates P-V and I-V characteristics of PV module.

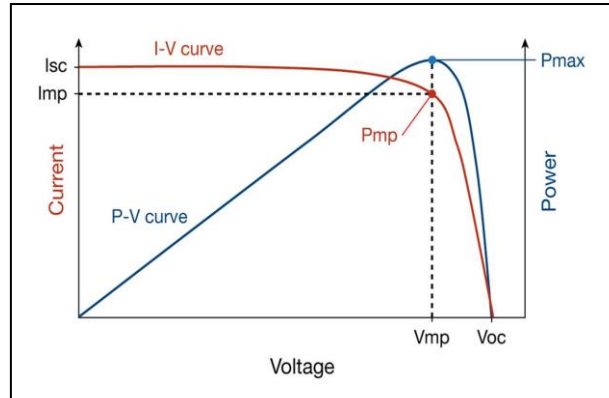


Figure (2) PV module typical output characteristics

As shown in the figure (2) there is a single point of maximum power in power versus voltage curve and this maximum power get along with certain level of voltage and current. So, the system efficiency would be low, it would be better to make the PV module works in the peak power point to convey the load with maximum power under different insolation and temperature conditions and this leads to improve the efficiency of the PV module (Jamri and Wei, 2010, Santhosh B., *et al.*, 2009). To extract the maximum power in PV module maximum power point tracker (MPPT) is presented.

2.2. MPPT Control Algorithm

Many and various types of maximum power point tracking algorithms are there. Perturb and Observe (P&O) algorithm is used for the presented simulation, as it has many features like low cost, high tracking efficiency, easy implementation and low cost. The principle of working of this algorithm is by inserting little perturbation in the voltage system. Because of this perturbation, PV module power changes (Esrarn and Chapman, 2007). In case of the PV module power increase as a result of the perturbation then it is continued in the same direction for next perturbation. When peak power reached then the power decreases at next instant after that perturbation direction is reversed. When reaching steady state then the algorithm start fluctuate round the peak point (Santhosh *et al.*, 2009). The size of perturbation is kept very small to make the power variation small. The algorithm is improved to set the PV module reference voltage get along with peak voltage of the PV module. The algorithm flow chart is shown in figure (3). As shown in figure (2) the voltage is approximately constant and the power slope is negative in the right side of the curve ($\Delta P/\Delta V < 0$) but in the other left side power slope become positive. ($\Delta P/\Delta V > 0$). There are low duty cycle and high duty cycle, low duty cycle is at right side of the power curve and high ducty cycle is at left side of the power curve. After doing subtraction

which depends on the sign of ΔP [$P(k+1) - P(k)$] and ΔV [$V(k+1) - V(k)$], the algorithm will decide whether to increase or decrease the duty cycle.

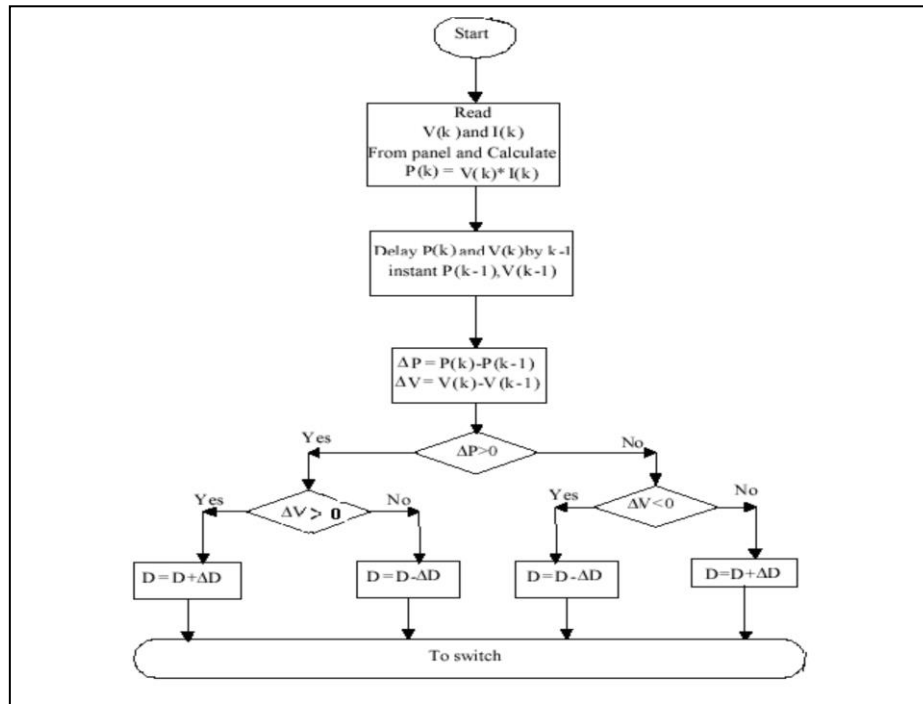


Figure (3) flow chart of P&O algorithm

2.3. DC-DC converter

The buck– boost converters is used when the load require low or high voltage than the voltage of the PV module. But this type of converter suffering from pulsating currents in the input and the load, and the voltage of the load is inverted with buck–boost converter or CUK converter. However, SEPIC converter supply the same conversion function of the buck–boost converter and polarity reversal and it has a feature of low content of current ripple on the load and source sides. The SEPIC is operated in continuous current mode (Chavarria *et.al.*,2013). The SEPIC designed to have two pairs of capacitors and inductors. The first capacitor (C1) is used to isolate the input from the output. The SEPIC converter exchanges the power of the PV module among capacitors and the inductors to switch the voltage of the system from one level to another different level. To control the flow of energy a switch is used, that is typically transistor such as an IGBT. The following equation is to determine the duty cycle (D) :

$$\frac{I_{L1}}{I_{L2}} = \frac{D}{1-D} = \frac{I_{in}}{I_o} \quad (4)$$

3. Multilevel Inverter

Multilevel inverter has dragged massive concern in the industrial power applications. They have many features as they are suit to use in the compensation of the reactive power, they reduce the harmonics amount and they increase the output power and voltage without using step up transformer (Chen *et.al.*, 1999). A multilevel inverter designed to consist series of H-bridge units inverter which connected to the induction motor. Multilevel inverter used to get the required voltage from sundry dc sources. Each bridge of the inverter are connected in series to get the

total output voltage. The cascaded inverters do not require flying capacitors and diode clamp unlike the flying capacitor inverter and diode clamp inverter (Mohaiminul and Gazi, 2009). So, such configuration is convenient for applications which require a constant level of frequency such as active power filters, active front-end rectifiers and reactive power compensation. In such a case, space vector based control strategy is preferred to use and implemented by digital signal processor (Vitorino and Correa, 2009 ; Ismail *et.al.*, 2013). Conventional VSI with SPWM control is proposed. This paper compares between the VSI system and multilevel inverter system performance.

4. Simulation Results

The PV source with VSI system feed three phase induction motor is show in figure (4a). a capacitive filter along with a diode is used as voltage source. Three phase inverter is working in 120 degree to match the requirement of the three pahse induction motor. The waveforms of Phase voltages, stator phase currents, variation in speed of the rotor FFT analysis and its corresponding spectrum of the stator current are shown in figures (4b), (4c), (4d) and (4e) respectively. X-axis is the time in seconds and Y-axis is the magnitudes of the mentioned results. The results show that the rotor speed increases and stabilized at (1470 r.p.m) and the FFT analysis figure shows that the value of the fundamental current is 28 amperes and the total harmonic distortion is 12.8 percent.

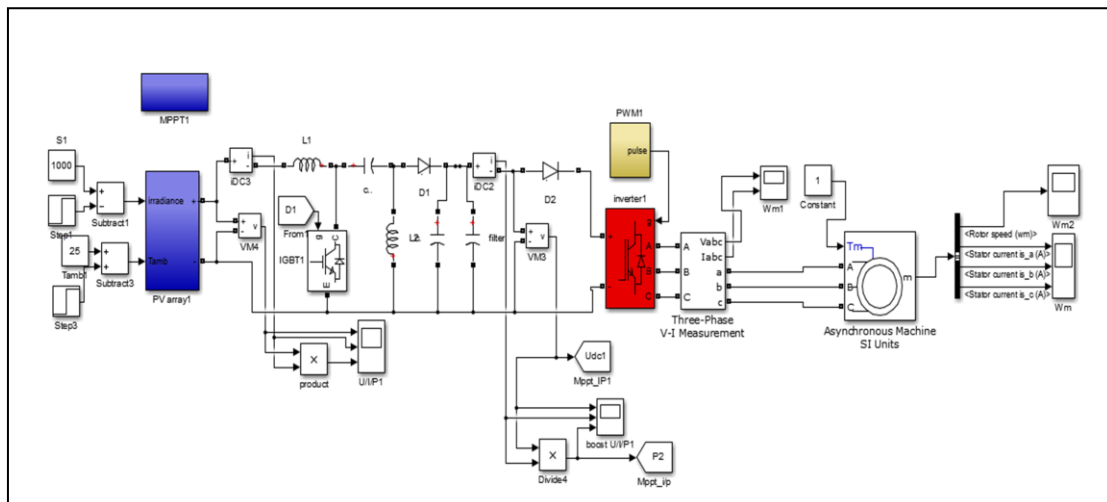


Figure (4a) PV system connected to VSI fed induction motor

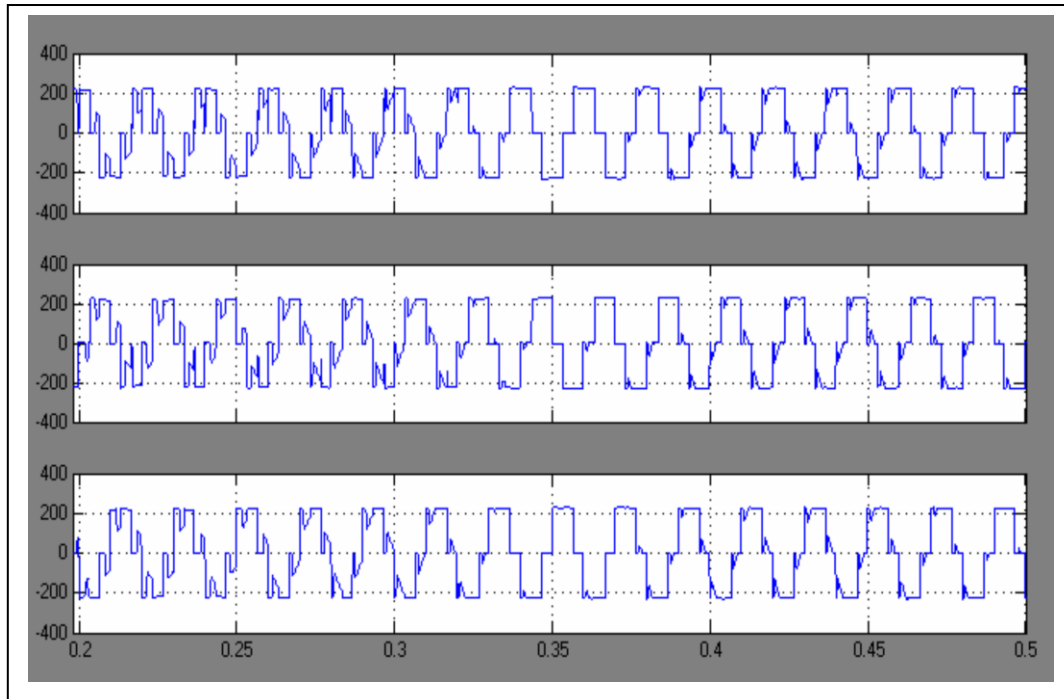


Figure (4b) the waveforms of phase voltages with time in seconds

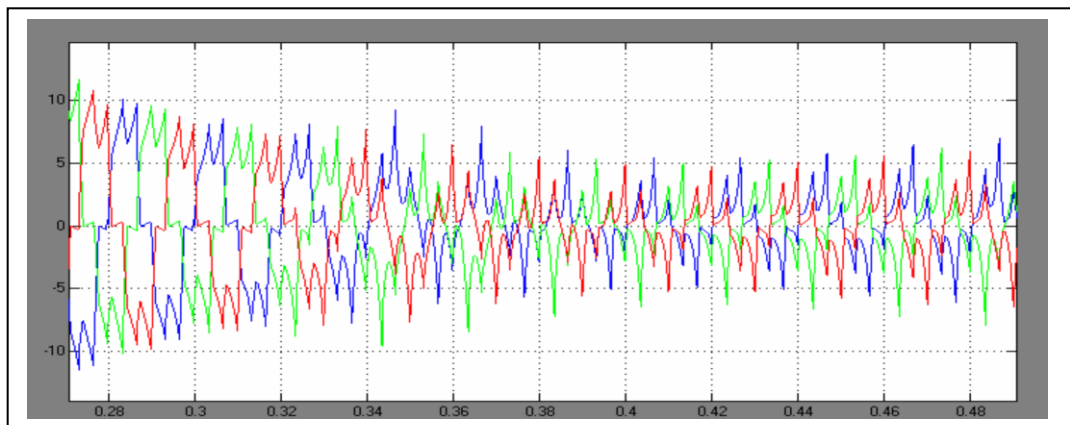


Figure (4c) the waveforms of stator current with time in seconds

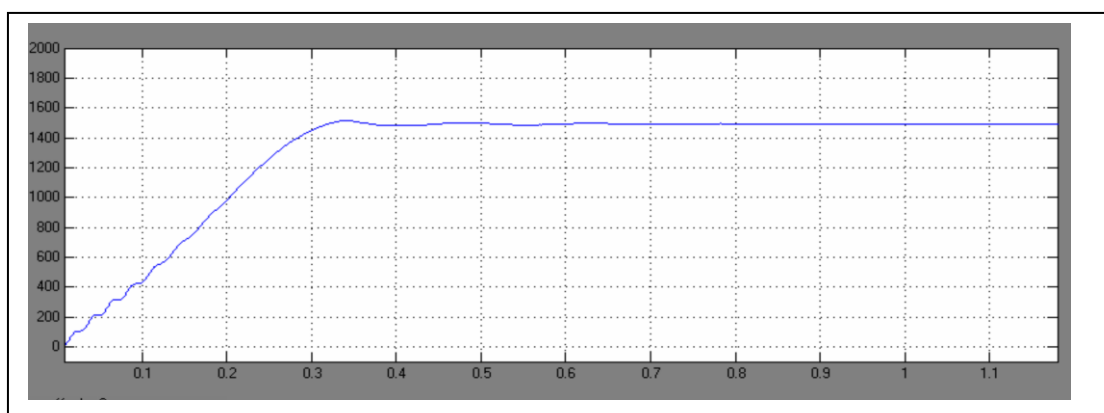


Figure (4d) the rotor speed in r.p.m with time in seconds

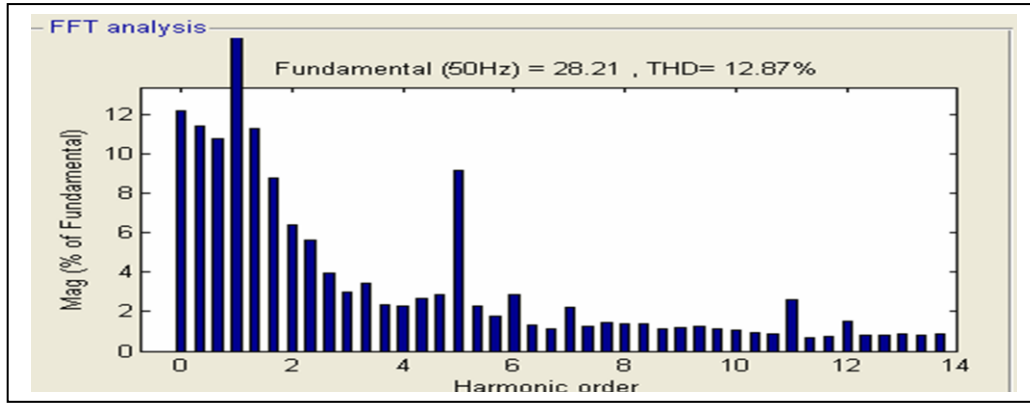


Figure (4e) the FFT analysis of the current

PV source with multilevel inverter system feed the three phase induction motor is shown in figure (5a). second inverter firing pulses are displaced from the first inverter by 36 degrees. The waveforms of Phase voltages, stator phase currents, variation in speed of the rotor FFT analysis of the stator current and the corresponding spectrum are shown in figures (5b), (5c), (5d) and (5e) respectively. X-axis is the time in seconds and Y-axis is the magnitudes of the mentioned results. It is observed that the total harmonic distortion in the figure (5e) magnitude is only 7.4 percent. Hence, the reduction in THD value is 42 percent in multilevel inverter as compared to VSI system. The spectrum shows the amplitude of components of low frequency is bigger than the components amplitude of high frequency.

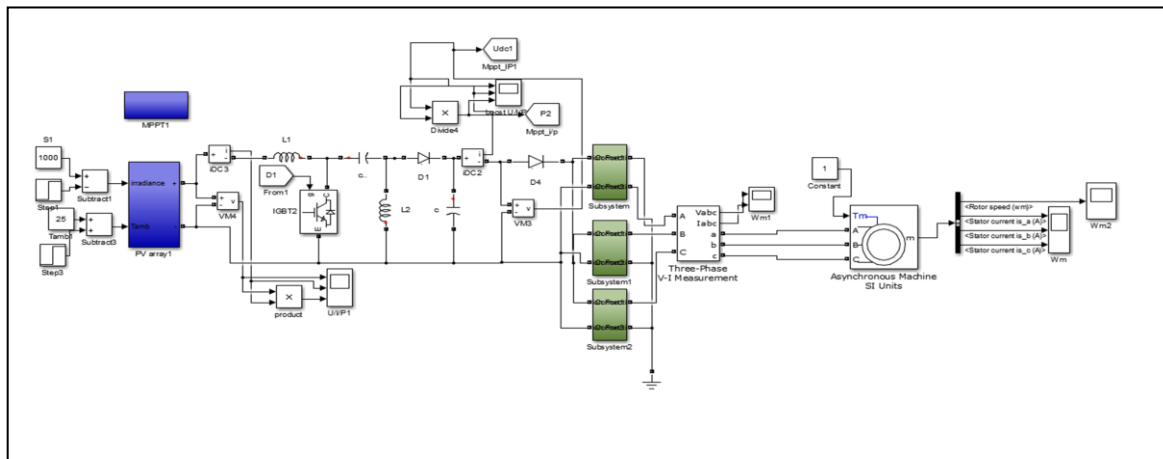


Figure (5a) PV system connected to multilevel inverter fed induction motor

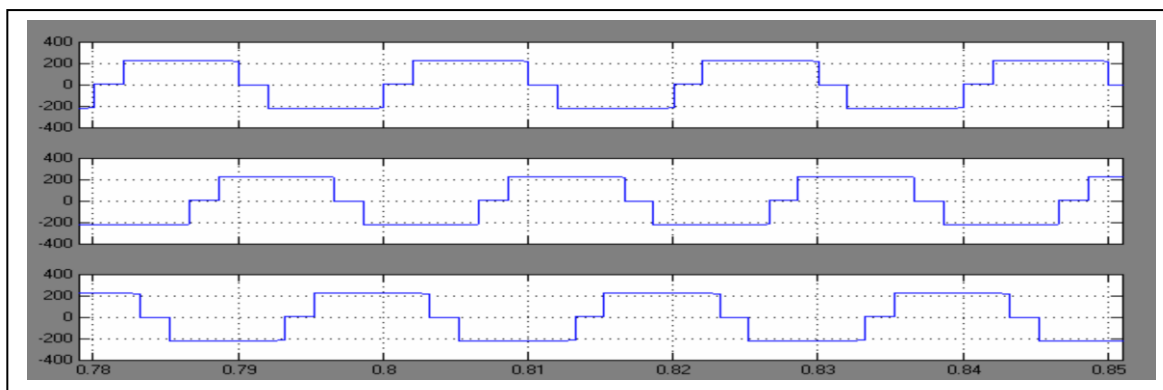


Figure (5b) the waveforms of phase voltages with time in seconds

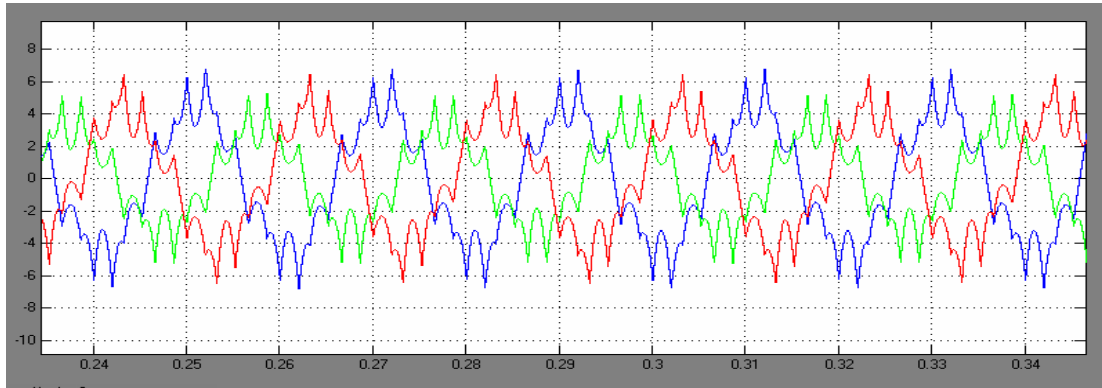


Figure (5c) the waveforms of stator current with time in seconds

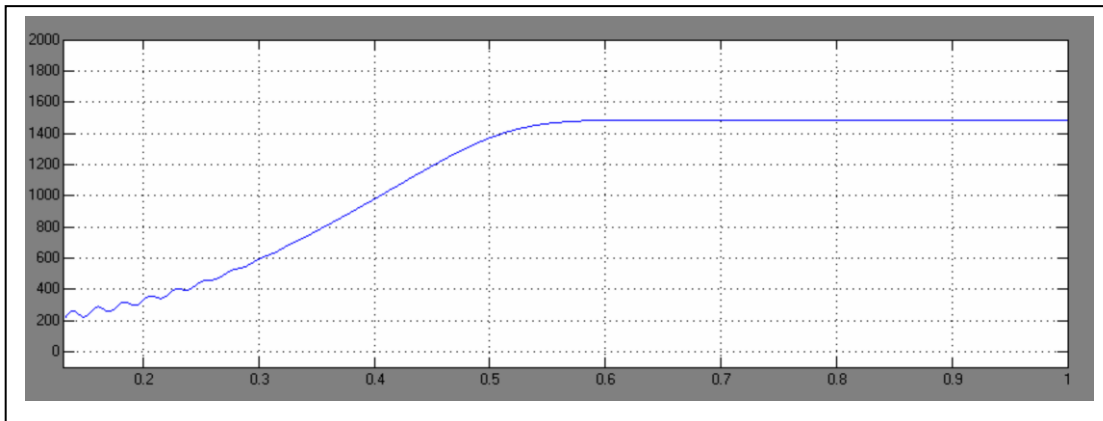


Figure (5d) the rotor speed in r.p.m with time in seconds

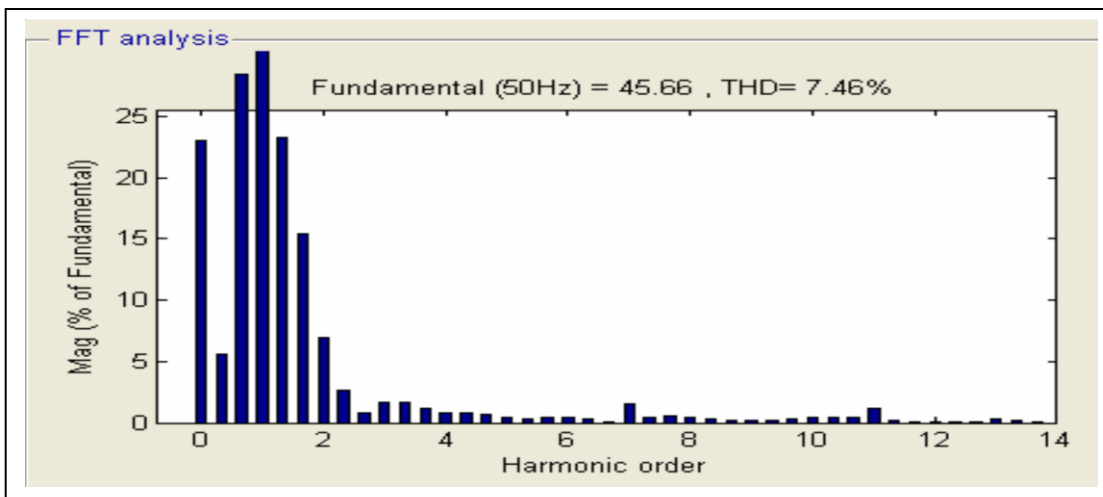


Figure (5e) the FFT analysis of the current

5. Conclusion

The simulation of the PV source with two types of inverters fed a three-phase induction motor is presented. The algorithm of P&O MPPT is used with PV source to get the maximum power point operation. The results of voltage, current, speed and spectrum of a three phase induction motor are presented, multilevel inverter results are compared with the VSI system results. The results show the multilevel inverter total harmonic distortion is scientifically less than that of VSI system. Then, the

heating due to harmonics distortion of multilevel inverter is less as compared with VSI system heating. The results show that Multilevel inverter system is better than VSI fed drive system due to the reduced value of THD. So multilevel inverters can be used in industrial areas where the variable speed drives desired to produce output less harmonic content.

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