Analysis on Photovoltaic Based Cost Effective Four Switch Three Phase Inverter Driven Water Pumping System

C. Saravanan [1], Dr. M. A. Panneerselvam [2],Dr. K. Srinivasan[3]
Assistant Professor[1], Professor[2],Professor[3]
Tagore Engineering College, Chennai.

Abstract

This paper presents the analysis of a Photo Voltaic (PV) based Four Switch Three-Phase Inverter (FSTPI) fed induction motor driven water pump. The cost effective FSTPI uses a SPWM technique for producing three phase voltage output and this output is used to drive 3 phase induction motor driving a pump load. Advantages of the FSTP inverter over the conventional six switch three phase inverter such as, reduced price because of reduction in the switches, low switching losses and less interface circuits to supply pulse signals for the switches, simpler control algorithms to generate pulses, damaging of the switches due to the lesser interaction between switches and less real-time computational burden. The Power quality improves by reducing the order of harmonics. The complete model is simulated in MATLAB/SIMULINK and validates the theoretical considerations.

Keywords- Four switch three-phase inverter (FSTPI), Induction motor drive, Photovoltaic array (PV), Pump load**.**

1. Introduction

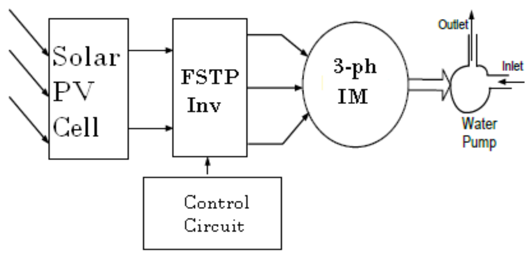
Solar photovoltaic (PV) system generates electricity and it has advantages as like pollution, noise and wear tear etc., Solar water pumping system is an rapid growth accepted means of obtaining water in remote areas where national grid connection is not viable [1]. There are numerous photovoltaic power systems ranging from 100 W to several megawatts [2]. PV cells are generated dc power, and further feed into the power controlling unit. Consecutively to maintain the frequency and Voltage level of inverter to be connected in the load. The Main cause in inverter is to eliminate harmonics, and this draw back has been concentrated by researcher over many years.

Traditionally, Six Switch Three Phase (SSTP) inverters have been widely utilized for variable-speed induction motor (IM) drives [4], [5]. These control algorithm and interface circuits to generate control algorithms and interface circuits to generate six PWM logic signals. Some efforts have been made on the application of Four Switches Three Phase (FSTP) inverter for uninterruptible power supply and variable-speed drives. Advantages of the FSTP inverter over the conventional SSTP inverter such as, low cost, number of switches, switching losses and number of interface circuits to supply logic signals for the switches, simpler control algorithms to generate logic signals, fewer chances of destroying the switches due to lesser interaction among switches and less real-time computational burden.

This four switch three-phase inverter connected to a three-phase induction motor. The use of induction motor gives many advantages as the comparison to DC motor. [5] In this paper, an analysis has been made on FSTPI supplying induction motor driven a water pump for irrigation purpose.

2. System Description

The Complete system is divided into three major parts a) Photovoltaic system, b) cost effective four switch three-phase inverter, c) Induction motor fed water pump drive system. The Various mechanism of system are described as,

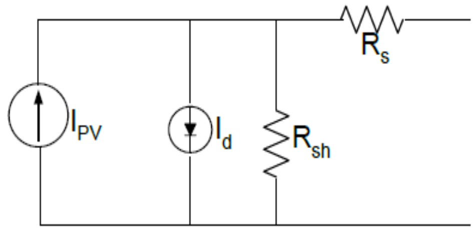


Φιγ.1. Σχηεματιχ διαγραμ οφ χομπλετε σψσ τεμ

The Schematic diagram of complete system is shown in fig-1. In it solar PV dc power output is feed to four switch three-phase inverter. The Pump load is driven by induction motor, which draws power from FSTPI.

2.1. Photovoltaic system

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



Φιγ.2. Εθυιϖαλεντ χιρχυιτ οφ σολαρ Πς

As shown in the fig-2, I_{PV} stands for PV short-circuits current, I_d is a diode current, R_s means the series resistance of photovoltaic cells, R_{sh} represents the photovoltaic battery parallel resistance, the internal value is less than 1 Ω.[2]

The performance of photovoltaic cell is expressed as in below equation,(1)

$$I = I_{pv} - I_o\left[\exp\left(\frac{q(V+IR_S)}{KTa}\right)-1\right]-\left[\frac{V+IR_S}{R_{Sh}}\right] \quad \text{----(1)}$$

Where,
I_{PV}= Photo-generated current (A)
I= Cell output current (A)
I_0=Diode Saturation Current (A)
V=Cell Output Voltage (V)
Rs=Series Resistor (Ω)
e= Electron Charge 1.6×10-19 (coul)
K=Boltzman Constant *(j/K)*
T=cell temperature

For ease the dc battery is used instead of PV in this paper.

2.2. Four Switch Three Phase Inverter topology

In the analysis, the inverter switches are considered as ideal power switches and it is assumed that the conduction state of the power switches is associated with binary variables S_{01} to S_{04}[4]. Therefore, a binary "1" will indicate a closed state, while "0" will indicate the open state. Pairs S_{01} to S_{03} and S_{02} to S_{04} are complementary and as a sequence:

$$S_{03} = 1 - S_{01} \quad (2)$$
$$S_{04} = 1 - S_{02} \quad (3)$$

Also, it will be assumed that a stiff voltage is available across the two dc-link capacitors and:

$$V_{C1} = V_{C2} = \bar{E}/2 \quad (4)$$

where, Ē corresponds to a stiff dc-bus voltage, i.e., the actual value of the dc-bus voltage is equal to Ē. The phase voltage equations of the motor can be written as a function of the switching logic of the switches and the dc-link voltage and given by [5]:

$$V_a = V_{dc}(4S_a-2S_b-1)/3 \quad (5)$$
$$V_b = V_{dc}(-2S_a+4S_b-1)/3 \quad (6)$$
$$V_c = V_{dc}(-2S_a-2S_b+2)/3 \quad (7)$$

Where:

V_a, V_b, V_c= Inverter output voltages

V_{dc} =Be the voltage across the dc-link capacitors

S_a, S_b =The switching functions for each phase leg

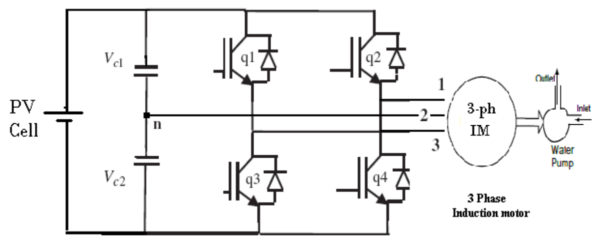
In matrix form, the above equations can be written as:

$$\begin{pmatrix} V_a \\ V_b \\ V_c \end{pmatrix} = \frac{V_{dc}}{3}\begin{pmatrix} 4 & -2 \\ -2 & 4 \\ -2 & -2 \end{pmatrix}\begin{pmatrix} S_a \\ S_b \end{pmatrix} + \begin{pmatrix} -1 \\ -1 \\ 2 \end{pmatrix} \quad (8)$$

For a balanced capacitor voltage, the four switching combinations lead to four voltage reactors. Table 1 shows the different modes of operation and the corresponding output voltage vector of the inverter.

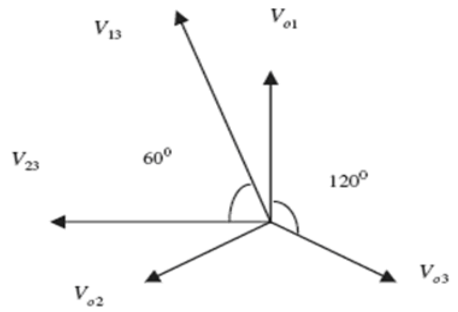
Ταβλε 1: Μοδεσ οφ οπερατιον οφ φουρ σωιτ χηεσ

S_{01}	S_{02}	V_a	V_b	V_c
0	0	$-U_c/6$	$-U_c/6$	$-U_c/3$
1	0	$U_c/2$	$-U_c/2$	0
0	1	$U_c/6$	$U_c/6$	$-U_c/3$
1	1	$-U_c/2$	$U_c/2$	0

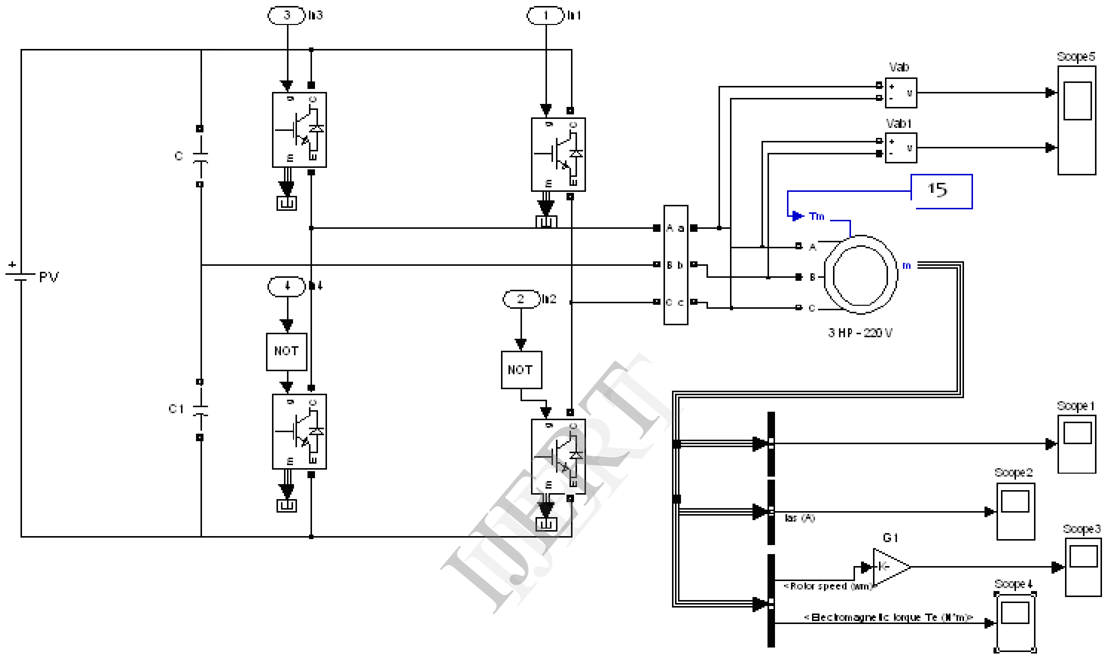


Φιγ.3. Ποωερ χιρχυιτ οφ φουρ σωιτχη ινϖερτερ

However, the basic problem with four switch three phase inverter lies in the control of the third phase for maintaining balanced output in all the three phases of the inverter. Existing modulation schemes are employed for controlling q_1-q_4 switches, such that the fundamental frequency component of the reduced switch three phase inverter output voltages has a 60^0 phase difference. Thus, the fundamental components of the three phase voltages are a balanced set with 120^0 phase difference as shown in Figure 4.

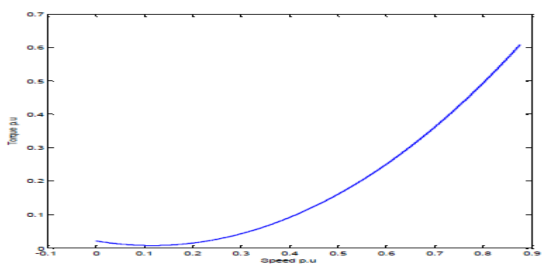


Φιγ.4. 120^0 πηασε σηιφτ τηρεε πηασε ϖο λταγεσ



Φιγ.6. Χομπλετε Σιμυλινκ Μοδελλινγ

In this paper three phase induction motor is driving a water pump system. The starting torque required by a water pump is shown Fig-5. In order to overcome the static friction torque, 10% of full-load torque is allowed at standstill as there is no gland friction. When the pump fails to meet the line of torque, then torque taken by water pump is proportional to square of speed. The speed-torque characteristic of pump load is expressed in Eq. (7), where quantities are expressed in p.u.



Φιγ.5.Τηε ωατερ πυμπ σπεεδ–τορθυε χηαραχτεριστιχσ

$$T=1.04073\omega2-0.24422\omega+0.022 \qquad (9)$$

The Complete simulation model based on Matlab/Simulink is shown in fig-6, which contains three major sections. First one is inverter section, second section is induction

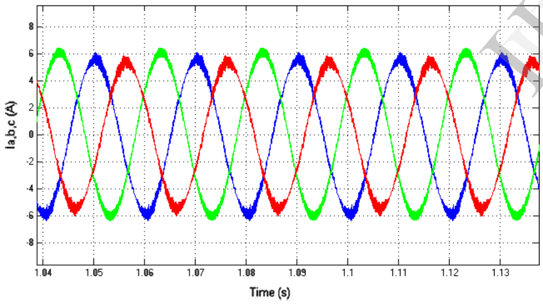
major sections. First one is inverter section, second section is induction motor, and third one is pump load. A three phase squirrel cage 220V, 60Hz induction motor is used. The induction motor is run by PV based cost effective FSTPI and it is used for driving a water pump load.

3. Results and Discussion

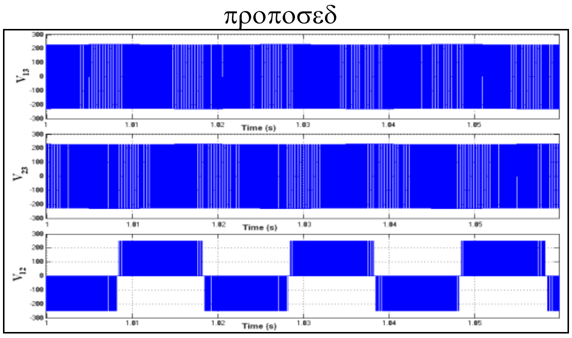
The Performance analysis of the system is studied using various system quantities such as voltage generated, torque, rotor current, stator current, Speed, water pump power V/s speed curve, THD analysis Following investigations are carried out on the system to verify the system model.

3.1. Analysis of four switch three phase inverter output for induction motor-pump load system

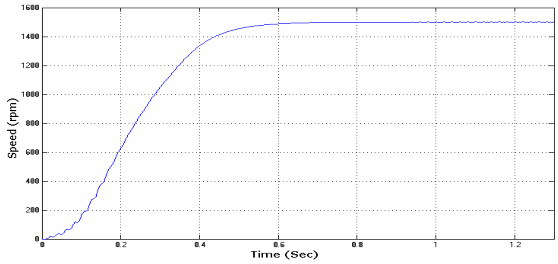
Transients in stator and rotor currents are there for short span of time that is, it settles quickly as shown in Figures 12- 15. The starting current is high but within the steady state value. Steady state value of stator current is equal to 10.6 Ampere. Steady state value of rotor current is equal to 10.10 Ampere. The result of speed estimation is shown in Figure 14. It can be observed that speed reaches at steady state value that is 1535 rpm within 0.5 seconds when motor is subjected to constant load of 11.9 N-m. So when the motor is fed by FSTP inverter then its speed increases and settling time decreases and it is due to voltage after inverter circuit which boosted by FSTP inverter. The electromagnetic torque waveform of the induction motor is shown in Figure 15. It is also observed that the cost effective four switch inverter performance is much closer to that of the conventional inverter from Figures 8 and 9 respectively. The efficiency of induction motor for this system is nearly about 80%.



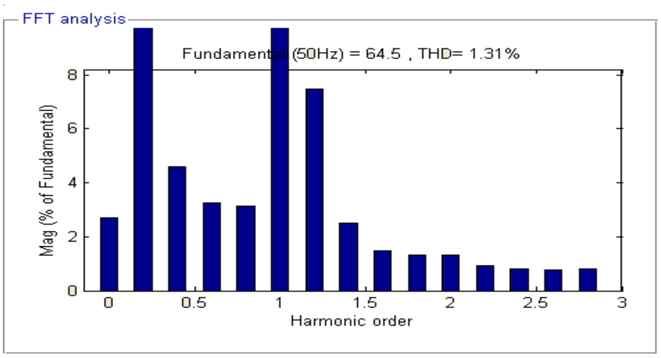
Φιγ.7. Τηρεε πηασε στατορ χυρρεντσ ιν τηε προποσεδ



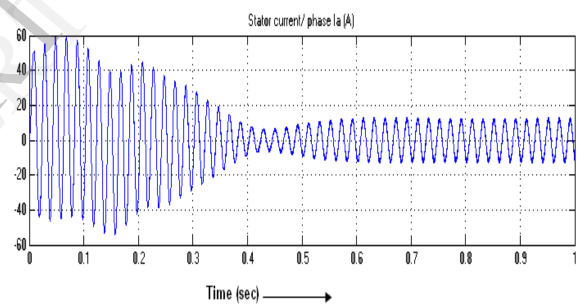
Φιγ.8.Λινε ϖολταγε ωαϖεφορμ οφ φουρ σωιτχη τηρεε πηασε ινϖερτερ



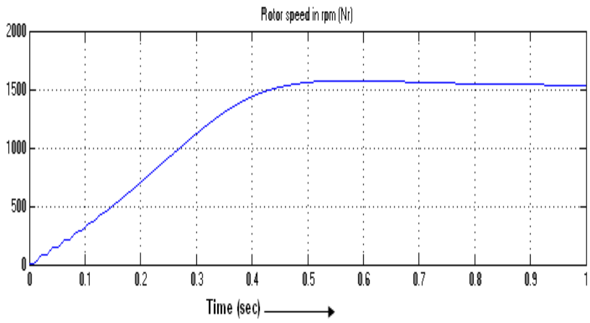
Φιγ.9. Ρεσπονσε χυρϖε φορ σπεεδ



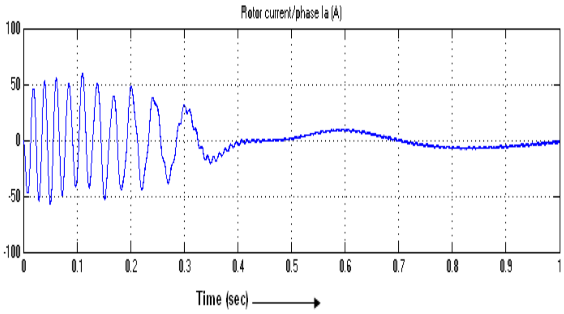
Φιγ.10. Ηαρμονιχ σπεχτρα οφ πηασε χυρρεντ (ι_α)



Φιγ.11Στατορ χυρρεντ/πηασε ι_α φορ φυλλ λοαδ χονδιτιον



Φιγ.12. Ροτορ σπεεδ Νρ φορ φυλλ λοαδ χονδιτι ον



Φιγ.13 Ελεχτρομαγνετιχ τορθυε Τε φορ φυλλ λ οαδ χονδιτιον

3.2. Power quality analysis

The FFT analysis of line-line voltage V_{ab} has been carried out for one cycle after study state is shown in fig-11. The performance of the four switch three phase inverter fed induction motor drive is compared with the six switches three phase inverter fed drive on the basis of THD of stator current and speed response under identical operating conditions. The total harmonic distortion of the four switch three phase inverter was found to be 1.31 % as against the standard value of 5% which proves the effectiveness of the proposed topology.

4. Conclusion

In this paper, the analysis on four switch three phase inverter fed induction motor-pump load system is studied. The proposed cost effective four switch three phase inverter produce low harmonic distortion and power quality is enhanced. The proposed FSTPI also has less complex control circuit in comparison to the traditional three phase inverter topology. The complete system is designed in MATLAB/ SIMULINK. The system performance is found to be satisfactory for induction motor-pump load system which thereby validating the system model.

5. References

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