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Analysis on Photovoltaic Assisted Three Phase five level Unipolar PWM Inverter for Induction Motor Driven Water Pumping System

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Abstract

This paper presents the analysis of a photovoltaic bases three-phase five level voltage source inverter (VSI) supplying induction motor driven water pump. The VSI uses a unipolar PWM technique for producing three phase 5 level voltage output and this output is used to drive three-phase induction motor driving a pump load. Multilevel inverters are used for generating AC voltage from several levels of DC voltages and enhance the performance of the system. The proposed system is used to reduce the filtering requirements and reduce the amplitude of all harmonics at the output of the inverter. The Power quality improves by reducing the harmonics level. The complete simulation model is simulated in MATLAB/SIMULINK and validates the theoretical considerations.

Keywords

Five level inverter, Induction motor drive, Photovoltaic array, Pump load, Unipolar PWM Converter.

1. Introduction

Nowadays solar power is the quintessential energy source and receiving considerable attention from the researchers. Solar photovoltaic (PV) system generates electricity with advantages such as no pollution, no noise and many more. Solar PV is well suited to remote or arid regions. Solar water pumping system is fast becoming an 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 to the power conditioning system. In order to suit the frequency and voltage level requirement of the load, a suitable switching power inverter is used.

The Major problem in power inverter is to eliminate harmonics and this aspect has been received attention of researcher for many years. It is found that multilevel inverters gives satisfactory performance in high power industrial applications [3][4]. Because multi level inverter output waveform increase in steps that's why it produced lower dv/dt stress in load side [5][6] also multi level inverter gives staircase waveforms synthesized a nearly sinusoidal voltage waveform with low harmonic distortion, thus reducing filter requirements. While the multilevel inverter requires more switches, capacitors and diodes than conventional two-level inverters, but here the advantage of multilevel inverter is that it offers the possibility of lower switching frequency, which leads to higher efficiency and lower electromagnetic interference (EMI) [7]. The Applications of multi level inverter covers wide area in industrial as well as in heavy industries, such as pumps, compressors, crushers, extruders, fans, marine propulsion, grinding mills, mine hoists, rolling mills, conveyors, blast furnace blowers, mixers, reactive power compensation, high-voltage direct-current (HVDC) transmission, hydro-pumped storage, gas turbine starters, wind energy conversion, railway traction etc. [3].

This five level inverter connected to a 3-Ø induction motor. The Use of induction motor gives several advantages as comparison to DC motor. The Induction motor offers several advantages of being inexpensive, more robust etc. than other counterparts [1]. In this paper, the attempt has been made on analysis of multi-level inverter 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) Three phase five level voltage source inverter (VSI) topology, c) Induction motor drive water pump. The Various components of system are described as,

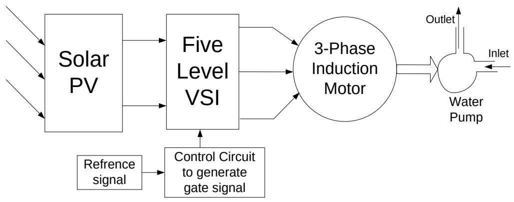

Fig-1: Schematic diagram of complete system

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

I. 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:

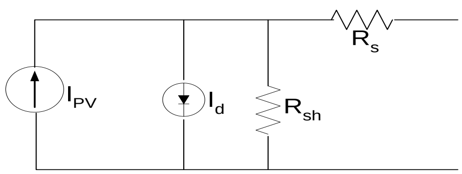

Fig-2: Equivalent circuit of solar PV

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.[10]

The equation governing the behavior of photovoltaic cell is expressed as,

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

Where, I_{PV}= 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

For simplicity PV is replaced by a dc battery in this paper.

II. Five-level inverter topology

In multilevel inverter, a unipolar technique is proposed for generating five voltage levels and is shown in Fig-3. In this unipolar technique each inverter phase requires four IGBTs. The line-to-neutral voltage with this power circuit has 5-levels in voltage. The load for each phase in connected through two filter inductor, here La1 and La2 for phase 'a'. Each IGBT carries half of the load current [11].

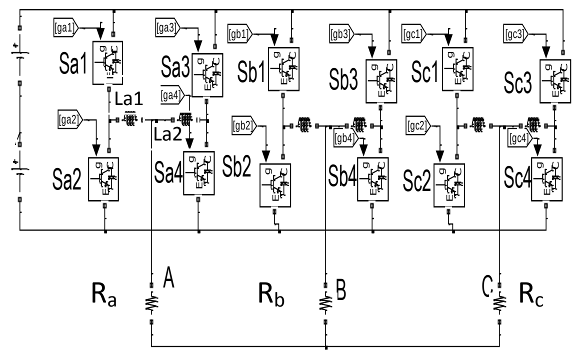

Fig-3: Five level unipolar topology

The modulation scheme for phase 'a' is shown in fig-4 and fig-5[11]. The High frequency triangular carrier waves are compared with the reference signal and in turn generate the PWM pulses. In this method reference signal is in the form of sine wave. When the reference signal is greater or equal to the triangular carrier wave than switch Sa1 is ON and Sa2 is OFF. The modulation switching scheme for switch Sa1 & Sa2 are shown in fig-4 and modulation scheme for switch Sa3 and Sa4 are shown in fig-5. When reference signal is greater than or equal to triangular carrier wave switch Sa3 is ON otherwise switch Sa4 is ON. Here reference signal frequency is 60Hz.

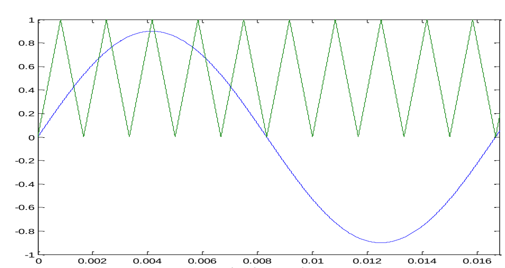

Fig-4: Modulation scheme for switch Sa1 & Sa2

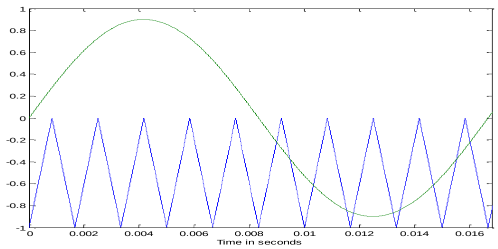

Fig-5: Modulation scheme for switch Sa3 & Sa4

III. Induction motor driven water pump

In this paper three phase induction motor is driving a water pump system. The starting torque required by a water pump is shown Fig-6. 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 [12][13]. The speed-torque characteristic of pump load is expressed in Eq. (2), where quantities are expressed in p.u. [14]

$$T=1.04073\omega^2-0.24422\omega+0.022 \qquad (2)$$

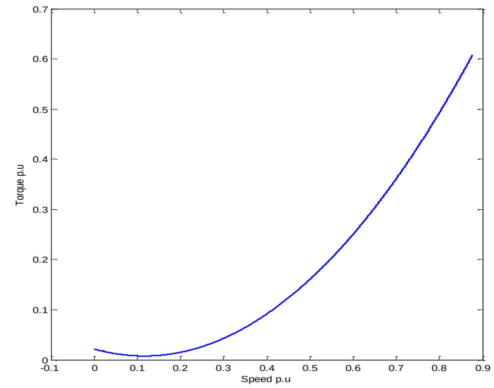

Fig-6: The water pump speed-torque characteristics

3. Simulink model of complete system

The Complete simulation model based on Matlab/Simulink is shown in fig-7, which contains three 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, whose parameters are given in Table A1 of appendix. The induction motor is run by three phase five level VSI and it is used for driving a water pump load.

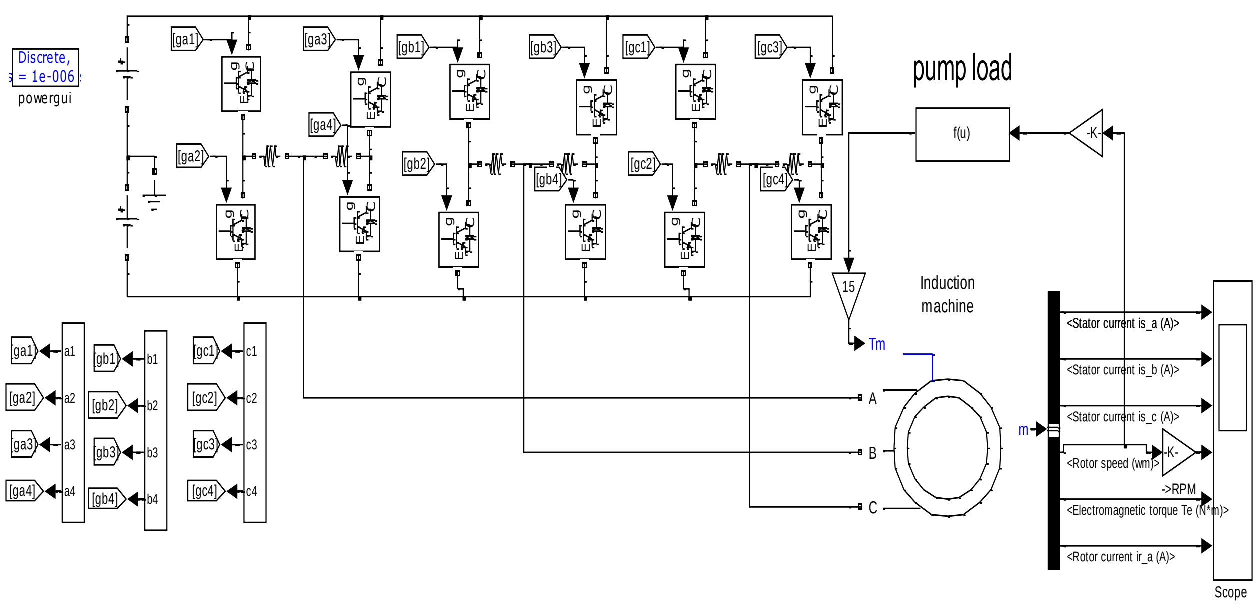

Fig-7: Complete simulation model

4. 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.

I. Analysis of five level inverter output for resistive load with and without filter

For resistive load each phase is having a resistance of 5Ω. The output waveform of three-phase five-level, 60Hz, VSI phase to phase voltage is shown in fig-8 , phase to neutral voltage for phase 'a' in fig-9, and, phase to neutral voltage for three phase is shown in fig-10 for load without filter inductor. After using small filter inductance; L_{a1}, L_{a2} for phase 'a', each one having value of 1.5mH, output waveform is shown in fig-11.

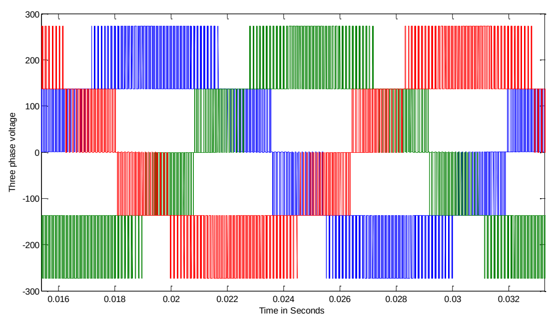

Fig-8: Three phase, phase to phase output waveform the of five level inverter without filter

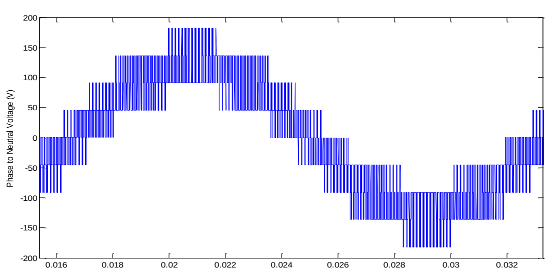

Fig-9: Phase to neutral voltage for phase 'a'

Normally leveling in multi-pulse converters are counted based on phase voltage. Here five steps as $+V_{dc}$,$+ V_{dc}/2$,0, $-V_{dc}/2$, $-V_{dc.}$ in phase to phase voltage are derived from dc side voltage [11].

For phase to neutral voltage the five levels counted as: 0,+V/4,+V/2,+3V/4,+V as shown in fig-9 and fig-10 [11].

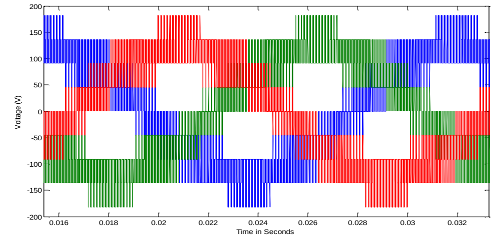

Fig-10: Three phase, phase to neutral voltage

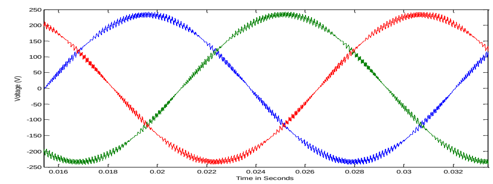

Fig-11: Three phase output waveform the of five level inverter with filter

II. Analysis of five level inverter output for induction motor-pump load system

When this 3-Ø five-level VSI is connected to 3-Ø induction motor for induction motor- pump load drive system, the output line to line voltage for three phase waveform is shown in fig-12. Fig-13 represents electromagnetic torque of induction motor with permanently connected pump load. The induction motor experienced a very high starting torque of around 47 Nm and attains steady state after some time. In steady sate, induction motor torque is around 10 Nm. Fig-14 represent's rotor current profile for phase 'a'. During starting condition the rotor current is very high and nearly about four times of steady state value. Fig-15 represents phase 'a' stator current. The speed V/s time curve are shown in fig-16 in it speed in RPM. At steady state the speed of induction motor is 1672 RPM. Water pump power V/s speed curve is also shown in fig-17. The efficiency of induction motor for this system is nearly about 80%

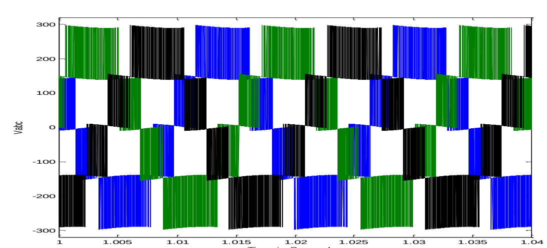

Fig-12: Three phase line to line voltage waveform at induction pump load

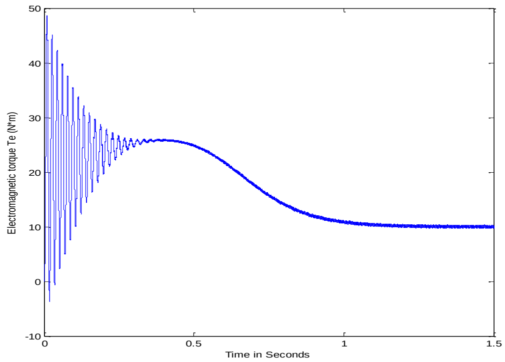

Fig-13: Induction motor electromagnetic torque

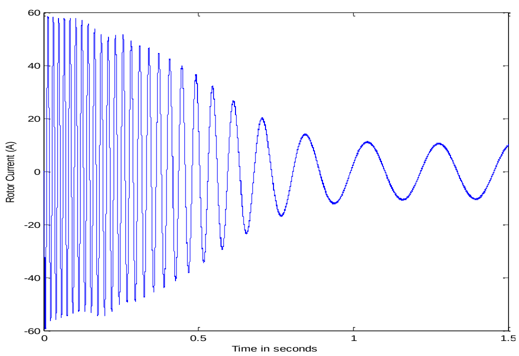

Fig-14: Induction motor phase "a" rotor current waveform

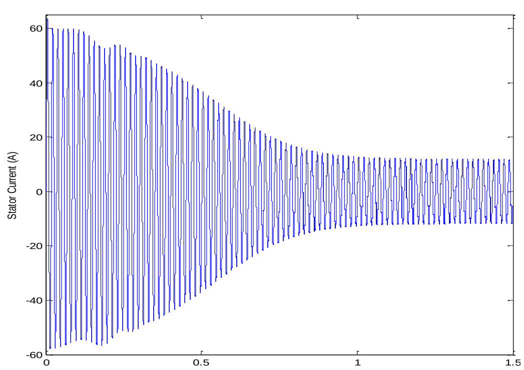

Fig-15: Induction motor phase "a" stator current waveform

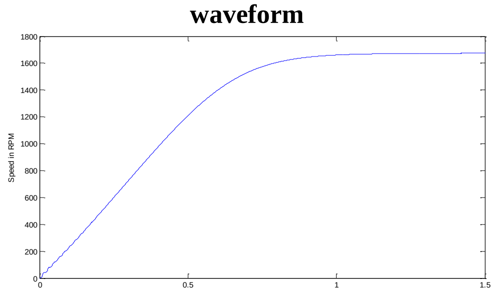

Fig-16: Speed V/s time curve

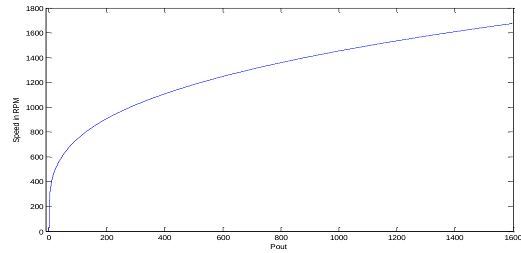

Fig-17: water pump power V/s speed curve

III. Power quality analysis

The FFT analysis of line-line voltage V_{ab} has been carried out for one cycle after study state without filter inductance and with filter inductance and are shown in fig-18. In case of without filter the THD is 39.27% and after using small filter inductance the THD reduced to 2.80%.

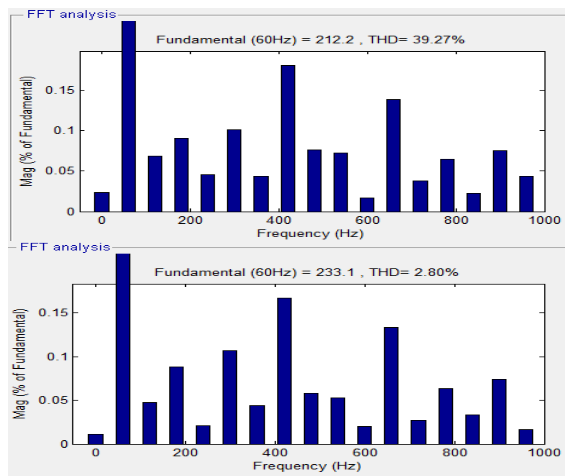

Fig-18: FFT analysis of THD without filter 39.27% and 2.80% with filter

The Harmonic analysis of without filter inductance in phase voltage V_{ab} as:

Third harmonics present in it 0.09%, fourth harmonic present 0.05%, fifth harmonic present 0.10%, sixth harmonic present 0.04%, seventh harmonic present 0.18%, eighth harmonic present 0.08%, ninth harmonic present 0.07%, eleventh harmonic present 0.14% thirteenth harmonic present 0.06%.

5. Conclusion

In this paper, the analysis on multilevel inverter fed induction motor-pump load system is studied. The proposed five-level PWM inverter produce low harmonic distortion and by using small filter inductance the THD is reduce and power quality is enhanced. The proposed five-level inverter also has less complex control circuit in comparison to the traditional five-level 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.

6. Appendix

Table A 1: Induction motor specifications and parameters

S.No.	Parameter	Values
1	Rotor type	Squirrel-cage
2	Nominal Power	2238
3	Frequency	60Hz
4	Vrms	220
5	Stator Resistance	0.435Ω
6	Stator Inductance	0.002H
7	Rotor Resistance	0.816Ω
8	Rotor Inductance	0.002H
9	Mutual Inductance	69.31×10^{-3}H
10	Inertia	0.089 kg.m^2
11	Friction factor	0.005 N.m.s
12	Pole Pairs	2

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