ORIGINAL RESEARCH PAPER | Engineering | Volume : 6 | Issue : 9 | September 2016 | ISSN - 2249-555X | IF : 3.919 | IC Value : 74.50

Design and Simulation of Solar Powered B-4 Inverter for Induction Motor

KEYWORDS: PV module, B-4 inverter, Induction motor, PSIM software.

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ABSTRACT *In this paper solar powered B-4 inverter for induction motor is presented. The speed of an induction motor is controlled by three phase inverter normally have six switches. Instead of using six switches the performance of induction motor is realized by four switch three phase inverter (FSTPI). This reduces the switching losses, cost of the system and complexity of generating six PWM pulses. The inverter is supplied by solar power. A simulation model of the drive system is developed in PSIM and analyzed in order to verify the effectiveness of the approach.*

INTRODUCTION

Induction motors are widely used in many industrial applications that too squirrel cage in nature due to its simple construction, low cost, robust in design and satisfactory efficiency. These motors essentially run at constant speed from zero to full load. So it's fairly not easy to control its speed. The speed control of induction motor is done at the price of reduce in efficiency and low power factor. In recent years the industries are focusing on the low cost ac drives to meet the need for reducing the cost. Also in rural electric systems and in remote areas, the cost of bringing three phase power is often high due to high cost of three phase extension. Moreover the rate structure of three phase service is higher when compared to single phase service. Progress in the field of power electronics and microelectronics enables the application of induction motors for high-performance drives, where traditionally only DC motors were applied. The four switch inverter is supplied by solar power which is abundant and environmental friendly. The simulation of the proposed model is carried out by PSIM (Powersim) software.

FSTPI TOPOLOGY

The block diagram of the system is shown in Fig 1.It consists of a solar PV array, Boost converter, 3 phase four switch Inverter, 3-phase Induction Motor and control circuits. From the solar PV array the unregulated dc voltage is obtained and converted into regulated higher voltage by using a boost converter. A voltage source B4 inverter is used to convert the dc voltage to the controlled ac voltage. The output of B4 inverter is fed to 3- phase induction motor. The control circuit consists of PWM generator and drive circuit. It is used to generate the controlled PWM pulses at different duty ratio for B4 inverter to drive the Induction Motor at different speeds.

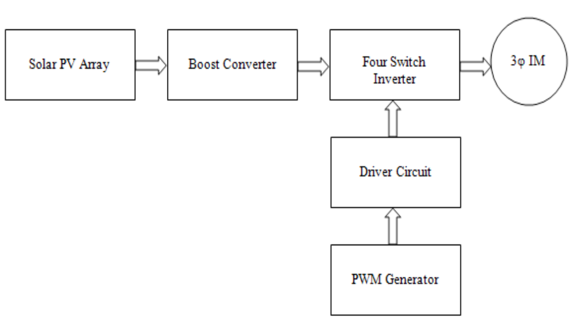

Figure 1: Block diagram of FSTPI

The power circuit of the IM fed from 4 switch 3 phase voltage-source inverter is shown in Fig.2. It has four switches S1, S2, S3 and S4. The two phases 'a' and 'b' are connected through two legs of the inverter, while the third phase 'c' is connected to the center point of the DC link capacitors, C1 and C2. The capacitance value of C1 and C2 are equal.

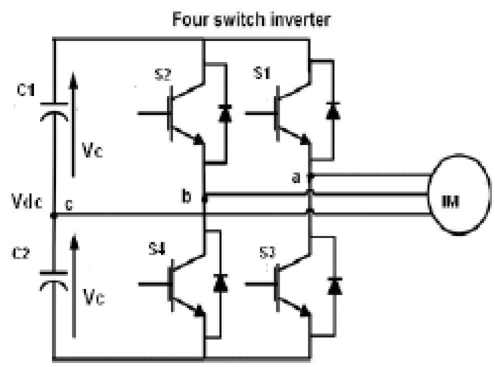

Figure 2: Circuit diagram of FSTPI

DESIGN OF THE SYSTEM

The complete system involves the design of solar PV array, boost converter and Inverter which are discussed in the following sections.

Design of Solar PV array

Photovoltaic (PV) power systems convert sunlight directly into electricity. PV model is described as a simple circuit consisting of a current source which is connected in parallel with a diode as shown in Figure 3.

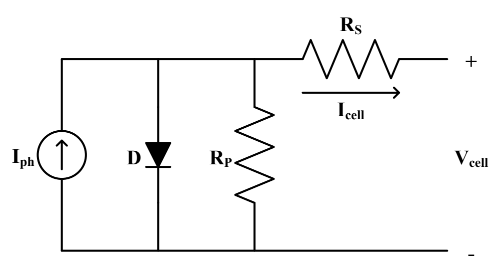

Figure 3: Equivalent circuit of PV cell

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PV's output power is depends on irradiation of sunlight and temperature received by PV cell's surface. PV has various types and models. Each PV module has different characteristics and efficiency. The I-V characteristics of the equivalent solar cell circuit can be determined by following equations. The current through diode is given by,

$I_D = I_O$ [exp (q (V + I R_S)/nKT)) – 1]

While, the solar cell output current,

$I = I_{SC} - I_D - I_R$

Now,

$I = I_{SC} - I_O$ [exp (q (V + I R_S)/nKT)) – 1] – (V + IR_S)/ R_P (1)

Where,

I -Solar cell current (A)
I_{SC}- Light generated current (A) [Short circuit value assuming no series/ shunt Resistance]
I_O - Diode saturation current (A)
q -Electron charge (1.6×10-19 C)
T -Cell temperature in Kelvin (K)
K - Boltzmann constant (1.38×10-23 J/K)
V - Solar cell output voltage (V)
Rs- Solar cell series resistance (Ω)
Rp - Solar cell shunt (parallel) resistance (Ω)

n: is known as the "ideality factor" ("*n*" is sometimes denoted as "*A*") and takes the value between one and two.

TABLE-1
SOLAR PV ARRAY DETAILS

Description	Quantity
Number of cells	72
Light Intensity	1000 W/m^2
Reference Temperature	25° C
Short circuit current	3.8 A
Shunt resistance	1000Ω

Boost Converter Design
DC-DC converter has an important role in the PV system. In this paper the boost converter topology shown in Figure 4 is used. It consists of a single MOSFET or IGBT switch, an inductor, a diode and a capacitor.

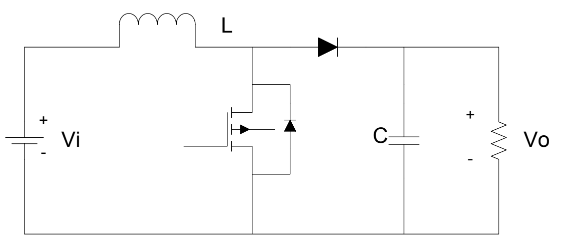

Figure 4: Boost Converter.

In order to design a good boost converter the calculation of proper values of components are very important. The following parameters are required to design a boost converter.

Input power (P): 120 W
Input voltage (V_{in}): 34 V
Output voltage (V_{out}): 50 V
Switching frequency (f): 20 kHz

a. Calculation of duty cycle (D):

$$D = 1 - \frac{V_{in}}{V_{out}} = 1 - \frac{34}{50} = 0.32 = 32\% \quad (2)$$

b. Calculation of load resistance (R):

$$I_{out} = \frac{P}{V_{out}} = \frac{200}{50} = 4A, \quad R = \frac{V}{I} = \frac{50}{4} = 12.5\Omega \quad (3)$$

c. Calculation of inductor's current (I_L):

$$\Delta I_L = 0.2 \times I_{in} = 0.2 \times I_{out} \times \frac{V_{out}}{V_{in}} = 0.2 \times 4 \times \frac{50}{34} = 0.11A \quad (4)$$

d. Calculation of inductor (L):

$$L = \frac{V_{in} \times (V_{out} - V_{in})}{\Delta I_L \times f \times V_{out}} = \frac{34 \times (50-34)}{0.11 \times 20000 \times 50} = 5.44\,mH \quad (5)$$

e. Calculation of capacitor (C_{min}):

$$C_{min} = \frac{V_{out} \times D}{\Delta V_{out} / V_r \times f \times R} = \frac{50 \times 0.32}{0.1 \times 20000 \times 12.5} = 640uF$$

Assumed: $\Delta V_{out} / V_r = 0.1V$

Inverter Design
The power circuit is the three-phase four switch inverter. The maximum obtainable peak value of the line voltages equals V_{dc} . In the analysis, the inverter switches are considered as ideal switches. The output voltages are defined by the gating signals of the two leg switches and by the two dc link voltages, V_{dc} .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 V_{dc}.

$$V_a = \frac{V_{dc}}{3}[4S_a - 2S_b - 1]$$

$$V_b = \frac{V_{dc}}{3}[4S_b - 2S_a - 1]$$

$$V_c = \frac{V_{dc}}{3}[-2S_a - 2S_b + 1]$$

Where,

S_a, S_b is the switching function for each phase leg. The above equation can be written in matrix form

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{V_{dc}}{3}\begin{bmatrix} 4 & -2 \\ -2 & 4 \\ -2 & -2 \end{bmatrix}\begin{bmatrix} S_a \\ S_b \end{bmatrix} + \frac{V_{dc}}{3}\begin{bmatrix} -1 \\ -1 \\ 2 \end{bmatrix}$$

The following table shows the switching states and output voltages in each phase.

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TABLE-2
SWITCHING SEQUENCE AND OUTPUT VOLTAGES

Switching states		Output Voltages		
S1	S2	V_a	V_b	V_c
0	0	$-V_{dc}/3$	$-V_{dc}/3$	$-2V_{dc}/3$
0	1	$-V_{dc}$	$-V_{dc}$	0
1	0	$-V_{dc}$	$-V_{dc}$	0
1	1	$V_{dc}/3$	$V_{dc}/3$	$-2V_{dc}/3$

SIMULATION

The computer simulation of the B4 inverter is developed using PSIM software. From the simulation model it is easy to understand that the motor control and power electronics simulation can be carried out uncomplicated using PSIM. Following are the specifications of the induction motor in PSIM environment.

Stator resistance - 0.294Ω
Stator inductance - 1.39mH
Rotor resistance - 0.156Ω
Rotor inductance - 0.74mH
Number of poles - 4
Magnetizing inductance - 41mH

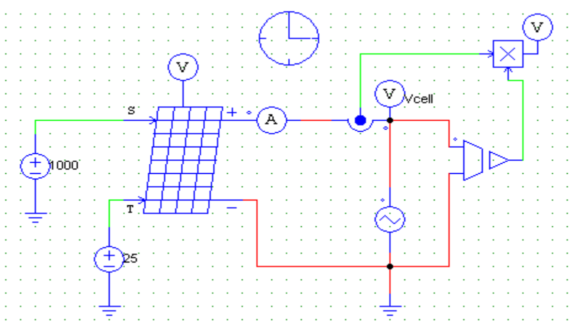

Figure 5: Simulation model of Solar cell.

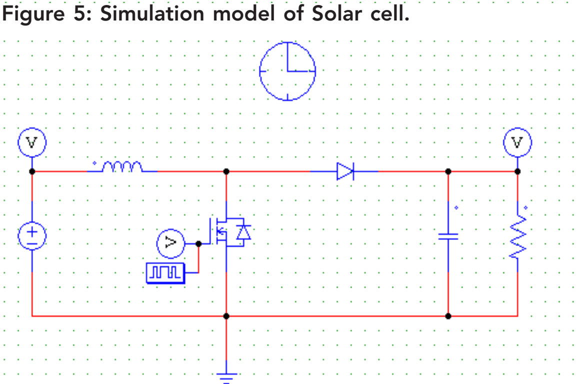

Figure 6: Simulation model of Boost Converter.

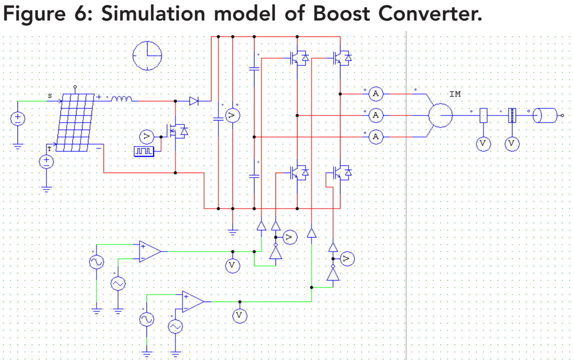

Figure 7: Simulation model of the system.

RESULTS

The following results were obtained during the simulation. It shows the performance of induction motor is well suited while running through B-4 inverter.

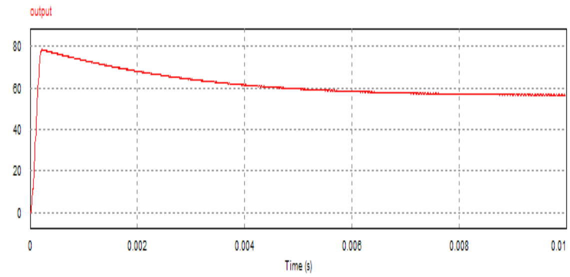

Figure 8: Output of Boost converter.

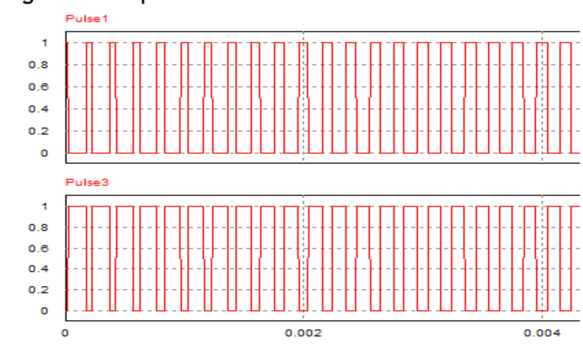

Figure 9: Switching pulses for inverter.

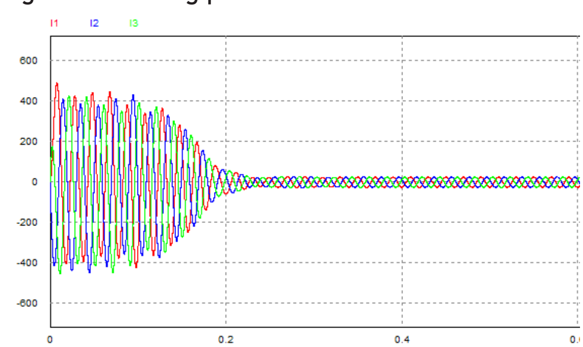

Figure 10: Stator phase currents.

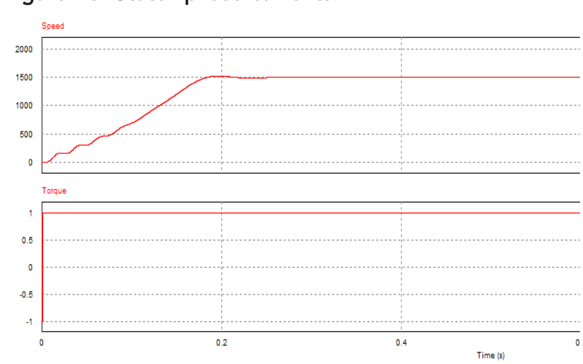

Figure 11: Speed and torque.

CONCLUSIONS

Solar powered B-4 inverter is simulated in this paper. This system provides variable voltage and frequency. Based on the inverter output, the operation of induction motor is controlled. Input to the system is solar energy; hence per-

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formance of the system is better in terms of efficiency. The result obtained shows the satisfactory operation of the motor.

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