

Performance Analysis of Photovoltaic Induction Motor Drive for Agriculture Purpose

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ABSTRACT

This paper presents water pumping system using renewable source (solar) without the use of chemical storage batteries. In this converter-inverter circuit is used to drive Induction motor. The Converter used here is Two Inductor boost converter (TIBC), which consists of a resonant tank, voltage doubler rectifier and a snubber circuit. TIBC is designed to drive the three phase induction motor from PV energy. TIBC converter is also known as current fed multi resonant converter having high voltage gain and low input current ripple. Converter switches are controlled through hysteresis controller and ZCS resonant topologies. Solar PV power fluctuates according to irradiation level of sunlight and hence tracking of maximum power at all time is mandatory. SPWM control with third harmonic injection is used to trigger the IGBT's in the inverter. The development is oriented to achieve a more efficient, reliable, maintenance free and cheaper solution than the standard ones, that uses DC motors or low voltage synchronous motors. The proposed method is verified with MATLAB/SIMULINK and the system simulation confirms the performance of the proposed system.

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1. INTRODUCTION

Lack of electricity is one of the main troubles in the development of rural India. India's grid system is considerably under developed, with major sections of its populace still surviving off-grid. Hence standalone system is most welcome and necessary in rural area of India. Moreover, environmental issues such as population and global warming effects are driving researchers towards the development of renewable energy sources including solar systems. One of the most beneficial applications of PV standalone systems is water pumping, particularly in rural areas that have a considerable amount of solar radiation and have no access to national grids. The presence of batteries allows motor pump system to operate at its rated power even in any conditions of solar radiations [1]. The system with batteries has low life span (average two years) which is very small compared to the useful life of 20 years of solar panel. So a converter inverter drive system is proposed for water pumping application without battery. Such systems are not new, which have been developed more than three decades, but most of the available converters in India are based on the intermediate energy storage systems ie, it is performed with the use of lead acid batteries [2].

The majority of previously proposed commercial systems use low voltage DC motors [3]. The drawback of such a system is, DC motors have less efficiency and require high maintenance due to the presence of commutators and brushes in it. Due to this reason DC motors cannot be used in isolated areas, where specialized persons are not available for its maintenance and operation. More sophisticated systems have already been developed with the use of low voltage synchronous motor. But such systems are too expensive [4]-[5]. So it can't be used in poor communities. In [6] PV is integrated with fuel cell for water

pumping. But the major problems are the cost of fuel cell and the available technology of fuel cell is at moderate level in India. The design of induction motor drive system without battery demands the solution for the operation of drive under variable power restrictions in [7]. Due to this, it demands the high efficient, low cost, robust, high life span DC-DC converter for induction motor based battery less water pumping system. A DC-DC converter is needed to boost the output voltage of PV panel. Many of the voltage fed converters have already been developed for the same [8]. Due to the presence of large input current ripple; these converters are forced to place the large filter capacitor at its input side. Basically it is electrolytic in nature, which has small life time; thus it affects the overall life span of the system before failure of the converter. The current fed converters offers more advantages than voltage fed converters. The current fed converters are derived from boost converter, so it consists of inductor at its input side. This inductor itself reduce large input current ripple, thus it eliminates the need of large electrolytic capacitors. The classical topologies of this kind are current fed push pull converter [9]-[10], the current fed full bridge [11]. These converters still have high voltage spike due to leakage inductance of the transformer. The resonant topologies are able to utilize the parasitic components such as leakage inductance and winding capacitance of transformer to achieve zero current switching (ZCS). The presence of voltage doubler circuit again reduces the needed transformer turns ratio. So a cheaper transformer can be used in the proposed converter. This paper is organized as following sections. In section 2 proposed system is described. In section 3 & 4 describes control strategy and design respectively. Simulation results are discussed in section 5.

2. PROPOSED SYSTEM

The entire system was designed to use a single PV module to meet the requirements ie low cost and higher efficiency. The maximum power developed by the panel is fed to induction motor drive through converter. The proposed system consists of two power stages. A DC-DC two inductor boost converter (TIBC) stage to boost the voltage of the panel and a three phase inverter to convert the DC output of TIBC to three phase AC voltage. The block diagram of the proposed converter is shown in Figure 1.

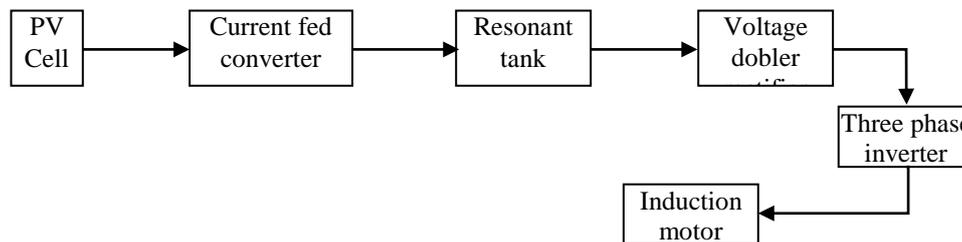


Figure 1. Block Diagram of Proposed System

The inverter is based on classical topology and it uses sine PWM (SPWM) strategy with third harmonic injection [12]. Third Harmonic injection improves the output voltage level compared to ordinary SPWM and it cancels all third harmonic and its multiples. The current fed converter used in the proposed system is shown in Figure 2. This converter consists of two inductors at its input side, hence it is known as two inductor boost converter. The classical TIBC require minimum operating load to maintain its output voltage. ie TIBC can't be operated in no load or low load condition. In such condition TIBC input inductors are charged even if there is no load current. So the energy transferred to the capacitor can't transfer completely to load which results increase in output voltage. In the proposed system motor is variable load, so it will demand low power at low speed or at transients (start up & stop). To solve such condition Hysteresis controller with snubber is used. The main features of this converter are that small number of components, simple circuit, easy transformer flux balance [13]-[14], common ground gate driving for both input switches.

One important feature is that the input current is distributed equally through the two inductors, thus its current ripple amplitude is halved at twice the switching frequency. The presence of snubber circuit makes the converter as a non isolated converter, which has no undesirable effect on PV motor drive. The TIBC is operated on the basis of overlapped fixed duty cycle. During one switching period two resonant processes are occurring 1). When both input switches are turned on, then the leakage inductance L_r is also participated in the resonance with C_r and L_m 2) when at least one switch is opened, then L_m and C_r participated in the resonance.

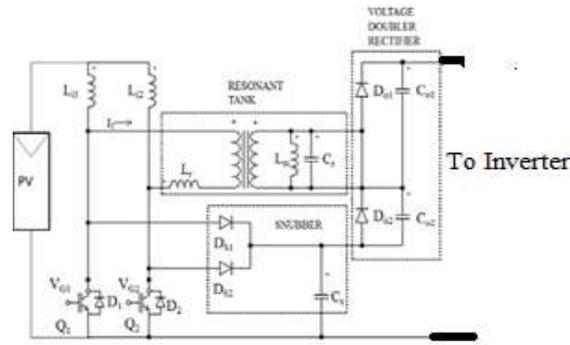


Figure. 2 Modified TIBC

The hysteresis controller is active only when the output voltage of the converter higher than threshold value. With the help of added snubber the primary switches are turned off because there is still a path for the current in input inductors and the energy stored in the inductor directly transferred to the snubber capacitors. Due to turn off of the switch output voltage starts to decrease and switches will again turn on with fixed duty cycle when output voltage reaches lower threshold.

The Figure 3 shown is the inverter circuit. The output of the TIBC Converter given to inverter fed induction motor. Inverter is operated on the basis of sine pulse width modulation (SPWM) with third harmonic injection. SPWM with third harmonic injection cancels third harmonics and its multiples.

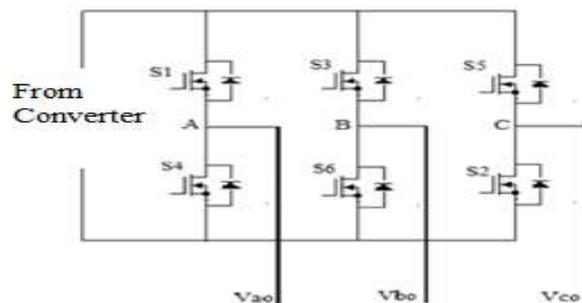


Figure 3. Inverter Circuit

3. CONTROL OF THE SYSTEM

The entire control of the system consists of three main aspects.

- During the normal operating condition, fixed duty cycle switching scheme is used to control the input switches.
- Hysteresis control is used during no load and start up of the system. Since motor is a variable load so it will demand low power at some operating points. (low speed and start up/stop transients). So in such condition hysteresis controller along with fixed duty cycle is used.
- MPPT algorithm along with PI controller and V/F controller is used to set the speed of the motor and thus achieving the energy balance of the system at MPP voltage.

3.1. Fixed Duty Cycle Control

Two inductor boost converter is a multi resonant converter. ie two resonant process are occur in one switching period. In order to occur resonance, definite time intervals in the switching period are necessary. The converter may no longer operate at ZCS condition, by altering the fixed Duty cycle or switching period for controlling the output of the converter. The operation of fixed Duty cycle is to make the converter to works with constant voltage gain K_V .

$$\frac{V_o}{V_{in}} = K_V \frac{1}{1-D} \left(2 \frac{N_s}{N_p} + 1 \right) \quad (1)$$

Where $\frac{N_S}{N_P}$ is the turns ratio of the transformer.

3.2. Hysteresis Controller

The proposed system uses modified TIBC. Classical TIBC doesn't consist of hysteresis controller and snubber circuit. The classical TIBC can't operate in the no load or low load conditions. This modified TIBC with snubber uses hysteresis controller for overcome the low load conditions.

3.3. MPPT Controller

Photovoltaic system has nonlinear current vs voltage and power vs voltage characteristics, continuously varied with irradiation and temperature. So maximum power point tracking is used to track the maximum power under different irradiation condition. In this system perturb and observe method is used because of its simple implementation and fast dynamic response [15-16]. This MPPT method is based on the shape of the power vs voltage curve of the panel.

3.4. V/F Controller (Inverter Drive Control)

One important thing is that, there should be a minimum DC voltage on the inverter DC bus necessary to drive the motor at a specified power level. To satisfy this condition, the v/f controller was used to maintain approximately constant motor flux. This controller generates nominal torque at any speed below its rated value. The overview of the control system is shown in Figure 4.

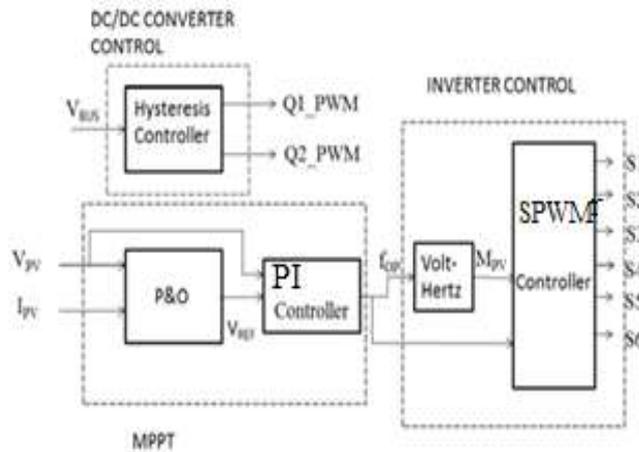


Figure 4. Control of the system

Based on the measured voltage and current, the MPPT algorithm along with PI controller estimates the operating frequency. The motor is drives at this frequency. A v/f controller calculates the modulation index for the switching pattern. The switching is done by SPWM with third harmonic injection. The main feature of third harmonic injected sine PWM strategy is that better utilization of DC bus supply.

4. SYSTEM DESIGN

The Figure 5 below shows the simplified circuit of the converter. The circuit equations are as follows

$$i_{rec}(t) = i_{CS}(t) - i_{LP}(t) \tag{2}$$

$$i_{CS} = \frac{i_{in}}{2} \tag{3}$$

$$V_{rec} = V_o/2 \tag{4}$$

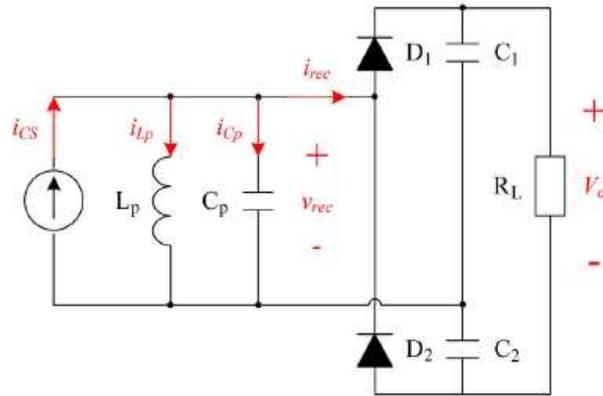


Figure 5. Simplified circuit (Ref-23)

4.1. ZCS Condition of Primary Switches

When both switches are turned on simultaneously, L_r is also participated in the resonance with L_m & C_r . The resonant frequency in this interval

$$F_{rp} = \frac{1}{2\pi \sqrt{\frac{L_m L_r}{L_m + L_r} * C_r}} \quad (5)$$

But $L_m \gg L_r$, so effect of L_m can be neglected. F_{rp} becomes

$$F_{rp} = \frac{1}{2\pi \sqrt{L_r * C_r}} \quad (6)$$

Or F_{rp} can be written as

$$F_{rp} = \frac{F_{sw}}{2D+1} \quad (7)$$

Where F_{sw} is the switching frequency. Energy of capacitor transferred to L_r (when both switches are turned off) so L_r should satisfy the following condition.

$$\frac{1}{2} C_r V_{Cr}^2 \geq L_r (I_{in}/2)^2 \quad (8)$$

From this design criteria for L_r is $L_r \leq 2 C_r V_{Cr}^2 / (I_{in}^2)$. The maximum value of L_r (L_r -max) is set by equation (8). To minimize the influence of the load on the resonant process on the primary current commutation interval, the switching frequency (F_{sw}) should be higher than the resonant frequency (F_{rs}) of L_m and C_r by a value of at least 1.1. Thus

$$F_{rs} = \frac{1}{2\pi \sqrt{L_m * C_r}} \leq \frac{F_{sw}}{1.1} \quad (9)$$

With the soft commutation of i_{pri} , the ZCS operation of Q1 & Q2 can be achieved by properly controlling their overlapped conduction time ΔT_{ov} .

$$\Delta T_{ov} = \frac{D-0.5}{F_{sw}} \quad (10)$$

4.2. Input Inductor Design

In the converter, the input current i_{in} rises up during the overlap time and declines during the off time of any primary switches. Hence, i_{in} has the input ripple current of two times the switching frequency and the peak-to-peak amplitude of

$$\Delta i_{in} = 2 \frac{V_{in}}{L} \Delta T_{OV} \quad (11)$$

The ripple is taken as 5%. Where L_{in1} & L_{in2} are assumed to have the same value. The average current flowing through each input inductor I_{Li1} is equal to half of the input current ($I_{in}/2$). The designed parameters are shown in Table 1.

Table 1. Parameters of the Converter

Components	Value
Input inductors Li1 & Li2	100 μ H
Leakage Inductance Lr	1.3 μ H
Magnetizing inductance Lm	3083 μ H
Snubber capacitor Cs1	4.5 μ F
Output Capacitor	1.5 μ F
Transformer	N2/N1=2.3
Resonant capacitor	5.8 nF

5. SIMULATION RESULTS AND DISCUSSIONS

The proposed system was simulated on MATLAB/SIMULINK Figure 6 shows the simulation set up of entire system. The 26 V from the PV array using MPPT algorithm is as input and produces 350V output. The control of the primary switches was simulated using a fixed duty cycle and a Hysteresis controller with its upper limit and lower limits are 360 and 340 V respectively

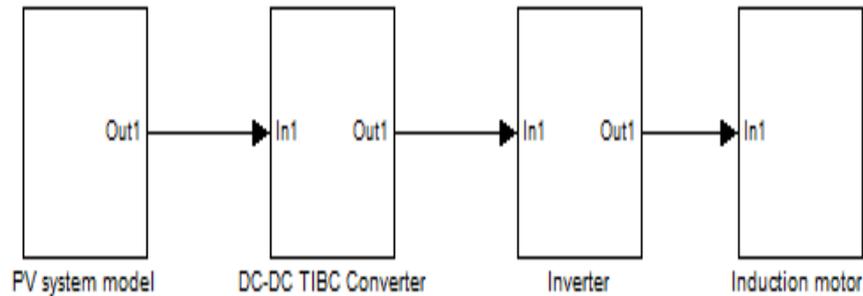


Figure 6. Simulation set up

From Figure 7b) average input current is 11.8 A. This current is distributed through two inductors and its average value is 5.4 A. shown in Figure 7c). The ZCS condition of input switch Q_1 are shown in Figure 7d). It is shown that both turn on & turn off occurs at almost ZCS. So it reduces switching losses during turn on & off. Figure 7e) shown that the diode also satisfy the ZCS condition. The operation under ZCS condition allows the use of fast recovery diodes instead of expensive silicon carbide ones, thus reducing the cost of the system. It is observed that each one of the inductors has a current ripple at the converter switching frequency and out of phase with each other; however, both currents are supplied by the PV module, and when they are analyzed together (I_{PV}), a reduction in the ripple amplitude to half of the original ones is seen. In order to analyze the performance of the system, the Induction Motor Drive has simulated on the MATLAB/SIMULINK with following specifications.

Switching frequency of inverter is taken as 2 KHz. Motor specification: 5 HP, 4 pole, 1800 rpm, flux= (1/60). The simulation results for different values of PV current corresponding to irradiation is shown in Table 2. Initially speed of the motor is very small (due to inertia it can't run at maximum speed), it take some time to reach steady state. At time $t=30$ sec, a small increase in speed due to change in solar irradiation. The solar radiation is made to change at $t=30$ s. The Figure 8a) shows the speed of the induction motor corresponding to PV current 3A & 4A.

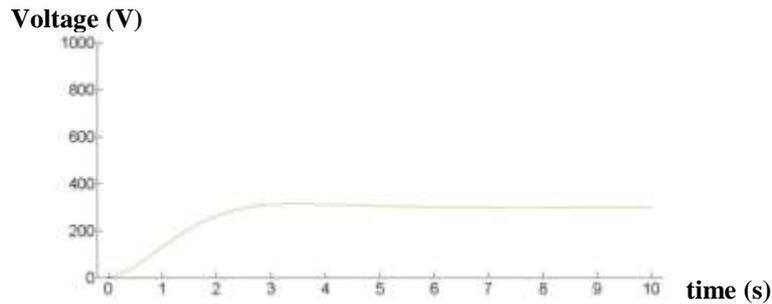


Figure 7a. Output voltage of the converter

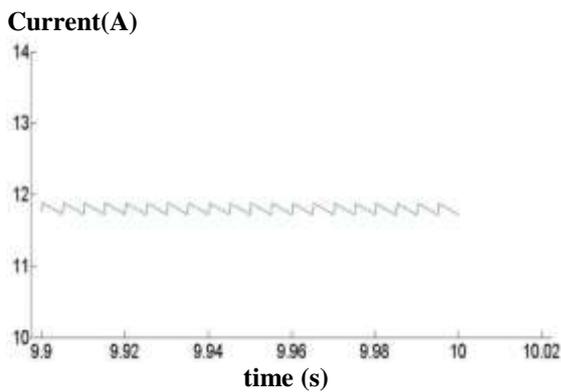
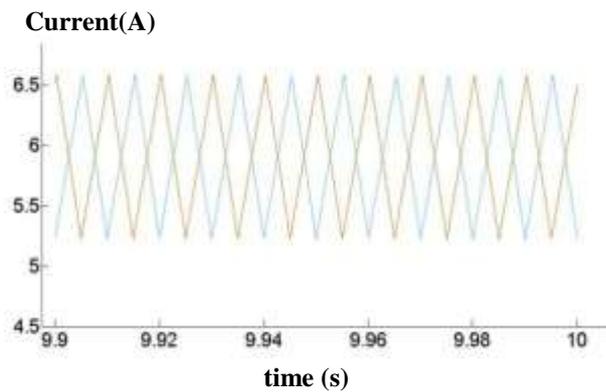
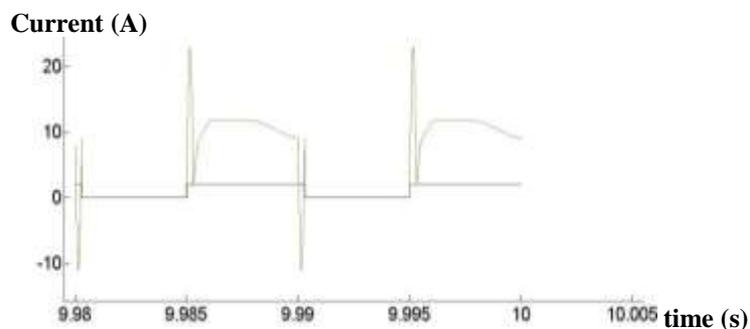


Figure 7b. Total input current

Figure 7c. Inductor's input current I_{Li1} and I_{Li2} Figure 7d. ZCS condition on the input switch Q_1

Upto 30 Sec, its speed is 1460 rpm because the output of PI controller (after processing the MPP voltage and PV voltage) is 49 Hz. After that the speed changes to 1600 rpm corresponding to the frequency 54 Hz. This is because solar irradiation is made to change at 30 Sec, Mpp voltage is determined by using the hill climbing algorithm. The Figure 8b shows the estimated frequency corresponding to the speed of induction motor ie output of PI controller. Centrifugal pump is like fan load. So load torque $T = Kw^2$.it is shown in Figure 8c.The inverter is controlled by using the SPWM with third harmonic injection. Figure 8d shows the modulating wave with third harmonic injection. The PV power under various irradiation level is shown in Figure 8e. Photovoltaic power is changes from 1410 W to 1840 W at 30 second. Figure 8f shows the output power of the motor. Up to 30 s, output power of induction motor drive is 1350W. The power is changes to 1760W at 30 s, due to change in solar irradiation. The efficiency of the system at each values of solar irradiation is shown in Table 2.

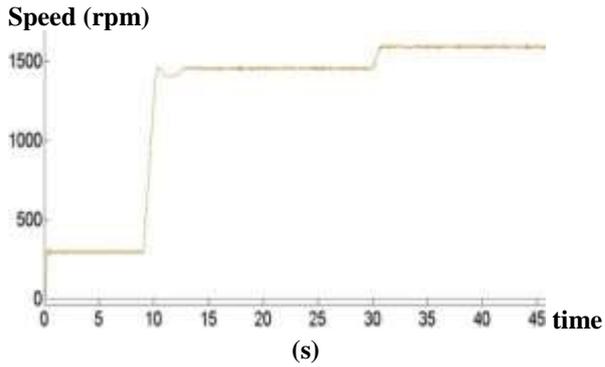


Figure 8a. Speed of the induction motor

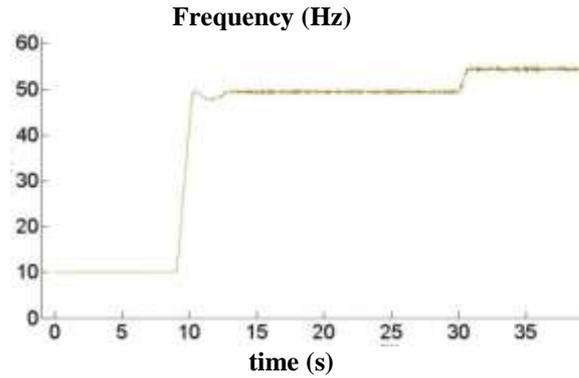


Figure 8b. Output of the PI controller

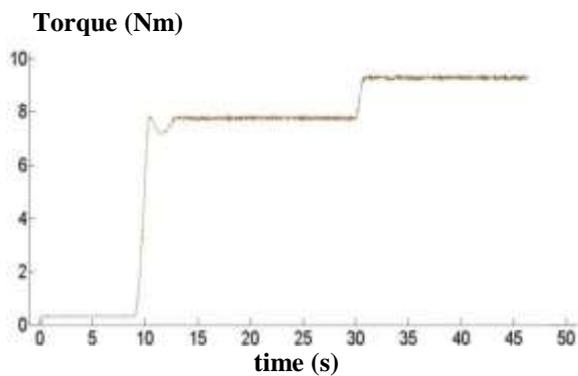


Figure 8c. Load torque

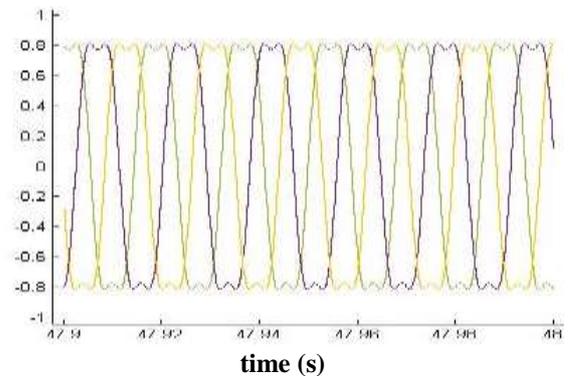


Figure 8d. Third harmonic injected modulating wave

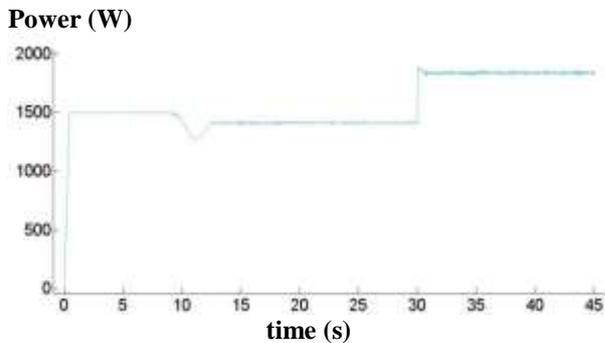


Figure 8e. Input power of the system (solar)

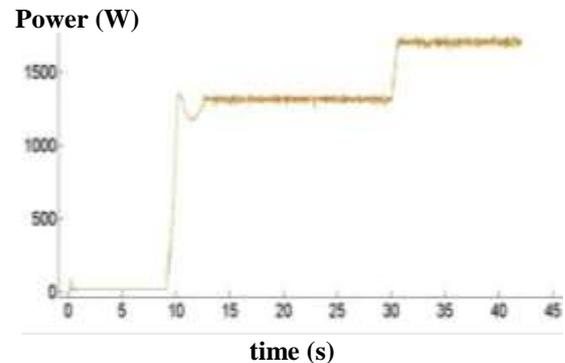


Figure 8f. Output power of the motor

6. CONCLUSION

In this proposed system, a converter inverter drive system for water pumping using a photovoltaic array is analyzed. The converter was designed to drive a three phase induction motor directly from PV energy, and was conceived to be a commercially viable solution having low cost, high efficiency, and robustness. The TIBC converter used here has low input current ripple, low cost and high step-up characteristics. The multi resonant tank provides high voltage gain and absorbs the parasitic parameters of the transformer. By employing the voltage doubler at the load side, the turns ratio of transformer could be halved. With this TIBC system, the input voltage of 26 Volts is boosted to 350 volts. The output of the converter system is given to the inverter system and motor is controlled under v/f strategy. Here SPWM with third harmonic injection control is used. MPPT control is provided to operate the PV cell at maximum power.

The proposed converter provides the best solution for the application of water pumping from the solar PV without storage battery. Use of the TIBC converter reduces the component size and hence cost is also reduced. TIBC converter provides high voltage gain and will also reduce the input current ripple. Distributed conductivity of current proposed in this method gradually reduces the copper loss.

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