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Solar Powered Induction Motor Pump

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Abstract: *Often it is necessary to pump water for irrigation purposes in remote areas where grid supply is not available. A PV based system can be used for such purposes. The output voltage of PV system is usually low. It has to be boosted to higher value for use in standard inverter driven induction motor by minimizing losses in converter. The converter can achieve high voltage gain using LC parallel resonant tank.. This converter has the characteristics like ZVS of semiconductor switches and high boost ratio. Moreover, the equivalent voltage stress of the semiconductor devices is lower than other resonant step up converters. The output of the converter is fed to an inverter which converts DC to AC. The harmonics are eliminated by using a LC filter. The output is used to drive an induction motor pump set. The speed of the motor is kept constant by v/f control method. Maximum Power Point Tracking (MPPT) techniques are used in PV systems to maximize the PV array output. In this work the simulation details in MATLAB platform of a converter-inverter combination to drive an induction motor pump set is presented.*

Keywords: *Maximum power point tracking, Voltage stress, Zero voltage switching, voltage gain, Resonant Converter.*

I. Introduction

There are still many remote areas where electricity is not available for water pumping. In such places the main source of water is from distant rivers or rain. So the conventional method of supplying water cannot be implemented because of unavailability of electrical energy. The use of photovoltaic sources for water supply is one of the efficient method. Photovoltaic is being employed around the whole world in most recent years. It is widely used in many applications in remote areas. The PV water pumping system generally consists of PV array, converter, inverter, filter, motor and a pump. These systems are more suitable in remote areas where electricity is not easily accessible. The pumped water can be used for many applications like domestic use, water for irrigation and to supply the water to villages. The main benefits of the water pumps powered by photovoltaic systems are low maintenance, ease of installation, reliability. The majority of commercial systems use low-voltage DC motors, thus avoiding a booster stage between the PV module and the motor But DC motors have higher maintenance costs and lower efficiency compared to induction motors. So voltage from a PV source will not be sufficient for operating an induction motor of required power. In order to step up the voltage level, a converter which is more efficient than conventional step up converter should be provided. In this work, a Parallel Loaded Resonant DC-DC converter is used to obtain a high step-up voltage. A three phase induction motor is used in the work for pumping. Induction motor enables a wide range of controlling easiness compared to other motors. It is available in many power ratings and is less costly compared to dc motors. The induction motor is driven by an inverter. The pump converts the mechanical energy into hydraulic energy hence the AC pumping system is powered by PV cell. The major issue regarding harnessing of solar energy is the variation in insolation and temperature. Hence we require an effective Maximum Power Point Tracking (MPPT) algorithm to harness maximum efficiency throughout the working. There are various methods to extract the maximum energy from the PV source. Incremental conductance, P \& O, Hill climbing are some of the commercially available MPPT algorithms. Here the Perturb and Observe method is utilized.

II. Proposed System

The block diagram of the proposed system is shown in Fig 1. The main blocks in the block diagram are solar panel, DC-DC converter, inverter, filter, induction motor coupled to a centrifugal pump. The solar panel extracts the solar energy and gives a dc voltage at its output. The low voltage dc has to be stepped up using a boost converter, here a parallel resonant converter (PLR) is used for boosting. The stepped up dc voltage is given to a single phase inverter which converts the dc voltage to corresponding ac voltage. The ac voltage out from the inverter contains harmonics. So as to avoid these harmonics a filter is placed as an intermediate between the inverter and the induction motor. The motor is coupled to drive a pump.

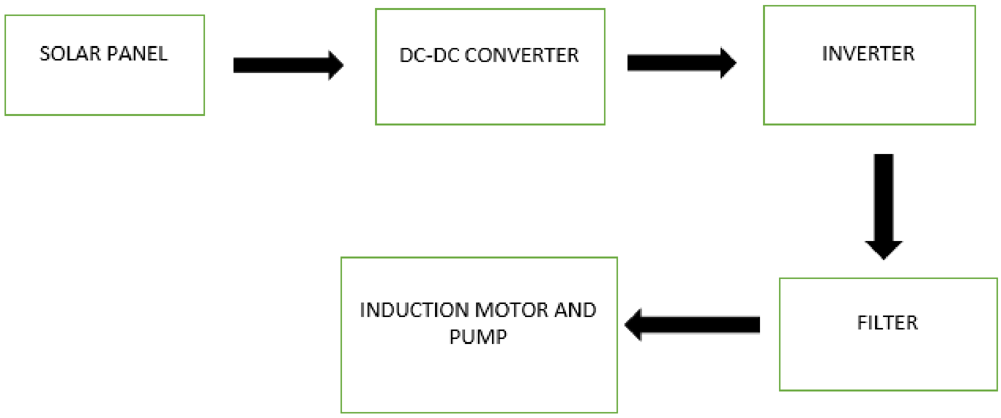

Fig 1: Block Diagram of the proposed system.

Resonant converters have been found to be a feasible option for high power converter. They allow high frequency operation which results in the magnetic component size reduction without decreasing the converter efficiency. Increasing the switching frequency of the power converters can help to reduce the size and volume of the passive components, such as the inductors, transformers, and capacitors, so that the power density can be increased. However, as the switching frequency increases, the switching losses also increase. The soft switching technique is one of the effective solutions to reduce the switching loss at high switching frequency. With Zero-Voltage Switching (ZVS), the converters exhibit lower switching loss and are widely used in many applications. In this system, a step up resonant converter which can realize soft switching technique and low voltage stresses for semiconductor is included in DC/DC conversion stage. The output of the converter is fed to an inverter which is SPWM based. V/f control is the most popular and has found widespread use in industrial and domestic applications because of its ease of implementation and this method can be used for a wide range of speed control.

III. Proposed Converter & Operation Principle

The proposed resonant converter is as shown in Figure 2. The converter is composed of a full-bridge switch network, which is made up by Q_1 through Q_4 a LC parallel resonant tank, a voltage doubler rectifier and two input blocking diodes, D_{b1} and D_{b2}. For the proposed converter Q_2 and Q_3 are tuned on and off simultaneously, Q_1 and Q_4 are turned on and off simultaneously. In order to simplify the analysis of the converter, the following assumptions are made:

1) All switches, diodes, inductor and capacitor are ideal components.

2) Output filter capacitors C_1 and C_2 are equal and large enough so that the output voltage V_o is considered constant in a switching period Ts.

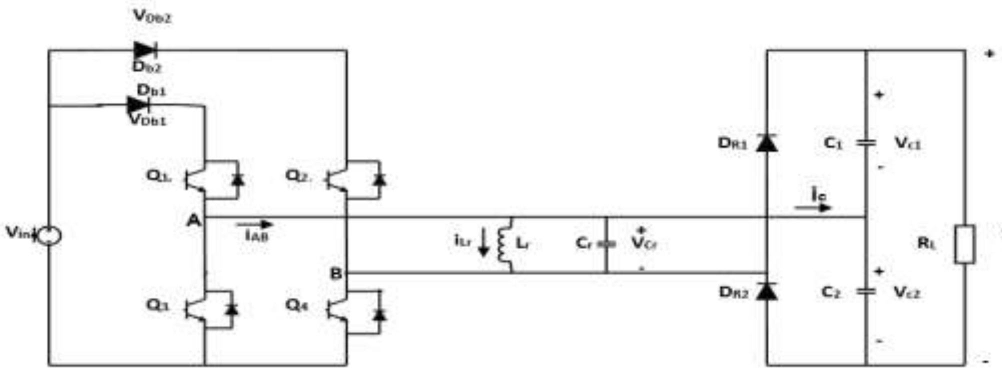

Fig 2: Circuit diagram of the converter

There are five modes of operation which is discussed in detail in the following sections.

MODE 1 [to < t < t_1]

The circuit diagram showing Mode 1 is shown in Fig 3. During this mode Q_1 and Q_4 are turned on resulting in the positive input voltage V_{in} across the LC parallel resonant tank, i.e., $VL_r = VC_r = V_{in}$. The converter operates similar to a conventional Boost converter and the resonant inductor L_r acts as the Boost inductor with the current through it linearly increasing from I_0. C_1 and C_2 powers the load. At t_1, iL_r reaches I_1.

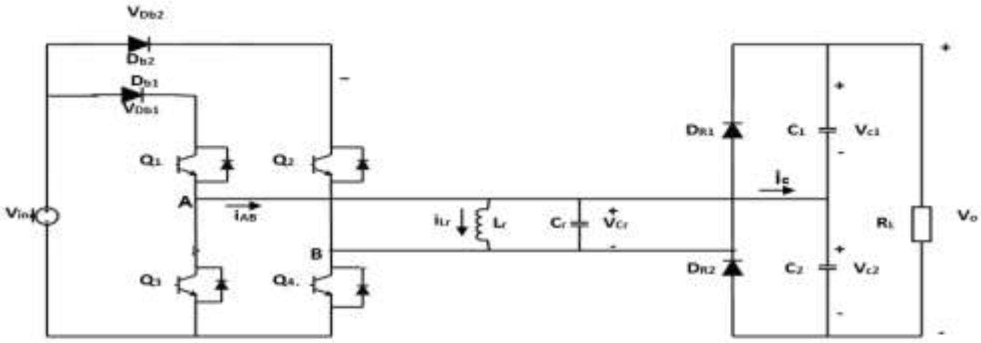

Fig 3: Mode 1 operation

MODE 2 [$t_1 < t < t_3$]

The circuit diagram representing Mode 2 operation is shown in Fig 4. During this mode Q_1 and Q_4 are turned off and after that L_r resonates with C_r, VC_r decreases from V_{in} and iL_r increases from I_1 in resonant form. C_r is much larger than parasitic capacitances the voltage across Q_1 and Q_4 increases resulting in turn off at zero voltage in this mode. At t_1, $VC_r = - V_{in}$, the voltages across Q_1 and Q_4 reach V_{in}, the voltages across Q_2 and Q_3 fall to zero and the two switches can be turned on under zero-voltage condition. Q_2 and Q_3 could be turned on after t_2, there are no currents flowing through them. This mode runs until VC_r increases to $-V_0/2$ and iL_r reduces to I_2.

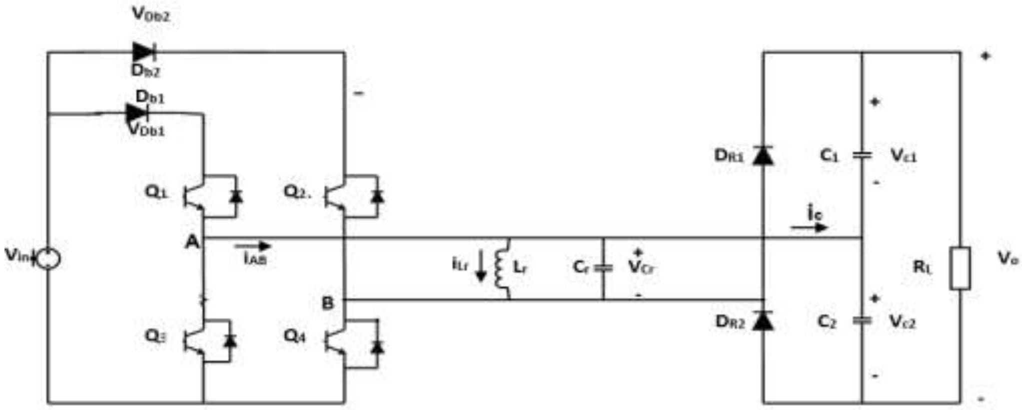

Fig 4 : Mode 2 operation

MODE 3 [$t_3 < t < t_4$]

The circuit diagram showing Mode 3 is as shown in Fig 5. At t_3 , $VC_r = -V_0/2$, D_{R1} conducts naturally, C_1 is charged by iL_r through D_{R1}, V_{Cr} remains unchanged and iL_r decreases linearly. At t_4, iL_r becomes zero.

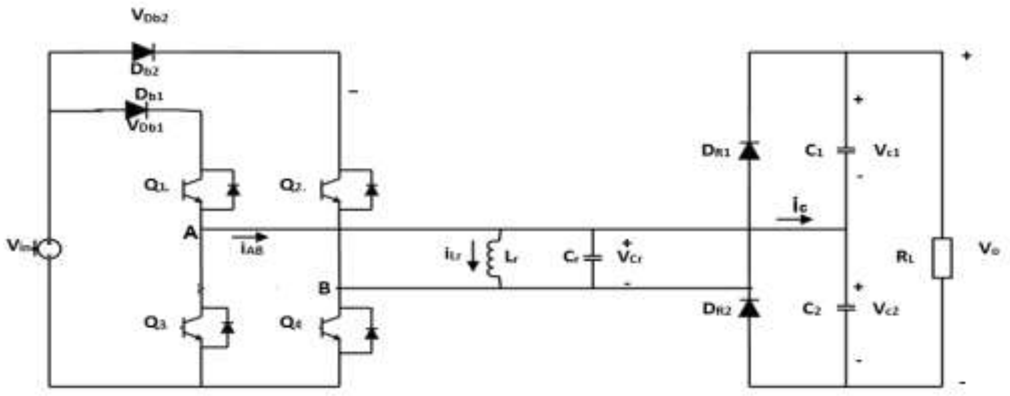

Fig 5: Mode 3 operation

MODE 4 [$t_4 < t < t_5$]

The circuit diagram showing Mode 4 is as shown in Fig 6. At t_4, iL_r decreases to zero and the current flowing through DR_1 also decreases to zero, and DR_1 is turned off with zero-current-switching (ZCS), therefore, there is no reverse recovery. After t4 , Lr resonates with Cr , VC_r increases from - V_0 /2 in positive direction, iL_r increases from zero in negative direction. At t_5 , $VC_r = -V_{in}$, $iL_r = -I_3$.

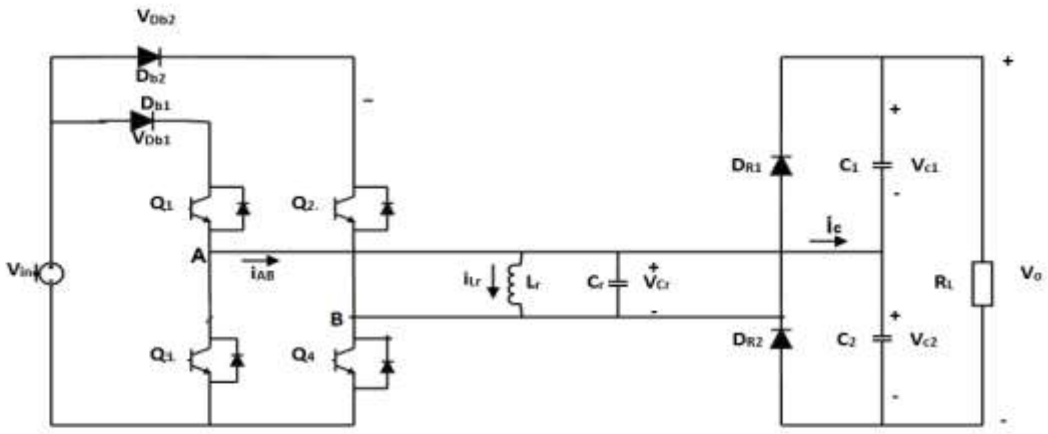

Fig 6 : Mode 4 operation

MODE 5 [$t_5 < t < t_6$]

The circuit diagram showing Mode 5 is as shown in Fig 7. If Q_2 and Q_3 are turned on before t_5 , then after t_5 L_r is charged by V_{in} through Q_2 and Q_3, iL_r increases in negative direction. If Q_2 and Q_3 are not turned on before t_5, L_r will resonate with C_r. Q_2 and Q_3 must be turned on before t_5 to reduce the switching losses. The operating modes during [t_6, t_{10}] are similar to modes 2, 3, and 4 respectively.

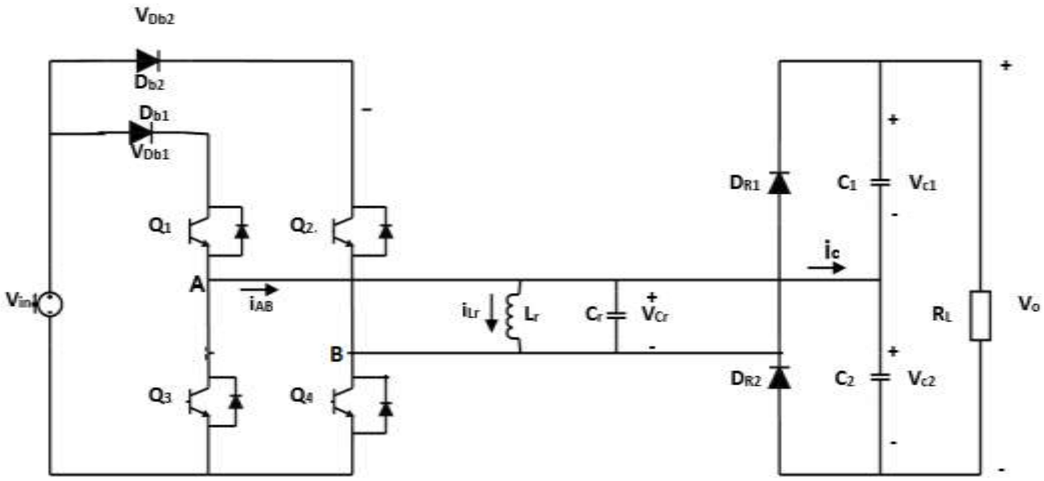

Fig 7: Mode 5 operation

The waveform representing the modes of operation is shown in Figure 8.

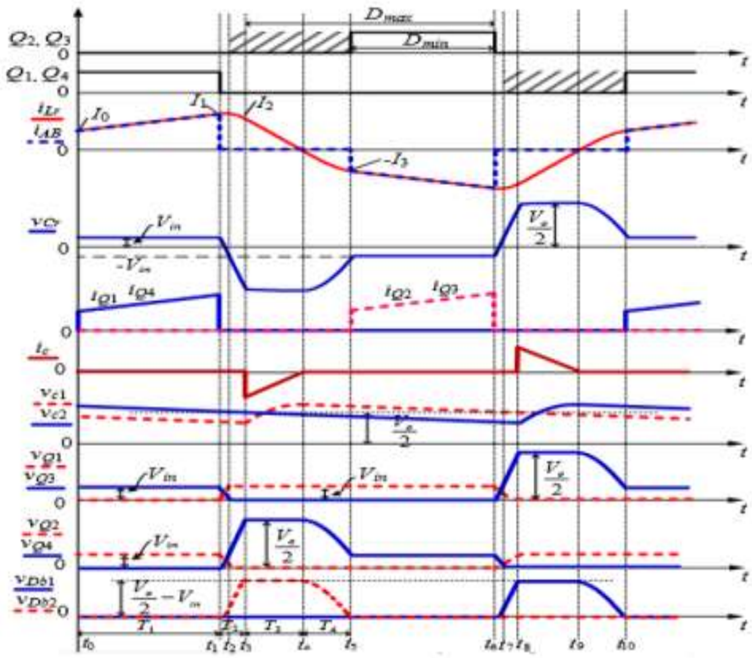

Fig 8: Waveforms of the proposed converter

II.2 Maximum power point tracking

The conversion efficiency of photovoltaic panels is not very high and this can drop further during variable solar irradiation, panel temperature and load conditions. Therefore the load cannot be directly coupled to the PV array and if this is done it may lead to an over-sized expensive system. It is important to operate the PV-cells of the array at the maximum power point (MPP), or as near to it as possible by using an electronic load-matching circuit,since this gives an improvement in the available power in comparison with direct load connection. The output current and power of a PV array depends on the terminal voltage. Moreover, the available output power of PV array fluctuates with change in ambient temperature and solar irradiation. Thus the operating point of most dc motor and pump systems over varying solar radiation levels would be far from the MPP of the PV array. It is a challenge to track the exact MPP with varying source and load conditions due to the non-linear voltage-current characteristic of the PV array. To accomplish this, electronic maximum power-point tracker (MPPT) systems are used. An MPPT system consists of a switch mode power converter inserted between the PV source and the load, and the duty ratio of the converter is controlled by a control algorithm to enable tracking of the MPP. There are different MPPT algorithms, some of them are. Incremental Conductance, Hill Climbing Method and Perturb and Observe etc. The flowchart of p & o algorithm is shown in Fig 9.

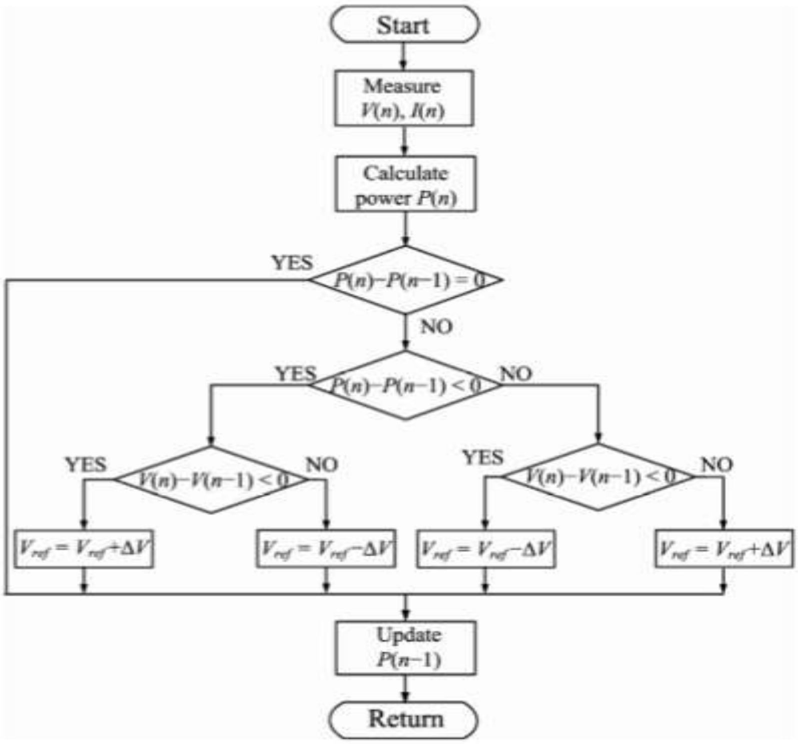

Fig 9: Flowchart of p & o algorithm

IV. Indentations And Equations

Design of converter

P_o= 372.5 W ………………………….. (1)

V_o=400V ………………………….. (2)

V_{in}= 20V …………………………… (3)

$R_L = \frac{V_0^2}{Po}$ …………………... (4)

$R_e = \frac{\pi^2}{8} R_L$ …………………... (5)

$f_s = 4$ kHz …………………… (6)

$\omega_s = 2\pi f_s$ …………………… (7)

$\omega_0 = \frac{\omega_s}{1.2}$ …………………… (8)

$f_0 = \frac{\omega_0}{2\pi}$ ……………………..(9)

$X_c = \frac{1}{\omega_0 * C_r}$, C_r = **1.5μF** …………………… (10)

$V_o = \frac{4V_s}{\pi^2 [1-(\frac{X_L}{X_C})^2+(\frac{X_L}{R_e})^2]^{\frac{1}{2}}}$ ……………………..(11)

From the above equation we obtain X_L

$X_L = L\omega_O$

From the above equation, the value of L_r can be obtained

V. Figures And Tables

The simulation parameters for the converter, panel and induction motor are given in the following table.1

Table 1 : Simulation parameters

Converter	
Parameters	**Values**
Input voltage	20V
Output voltage	400V
Resonant inductor	124 □H
Resonant capacitor	1.5 □ F
Filter capacitor	22 □ F
Solar Panel	
Solar panel	Isoltech ISTH-215-P
Number of parallel strings	4
Maximum power	213.15 W
Open circuit voltage	36.3 V
Short circuit current	7.84A
Voltage at maximum power	29 V
Motor	
Squirrel cage motor	0.5 hp , 400V, 50hz

The overall simulation diagram of the proposed system is shown in Fig 10.

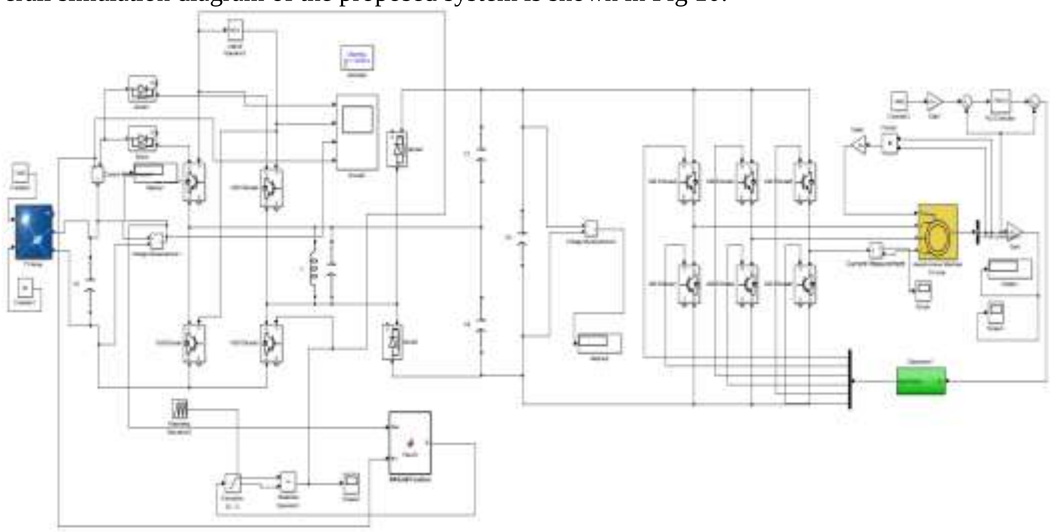

Fig 10 Simulation diagram of the proposed system

The simulation results of the system is shown in Fig 11, 12, 13 .

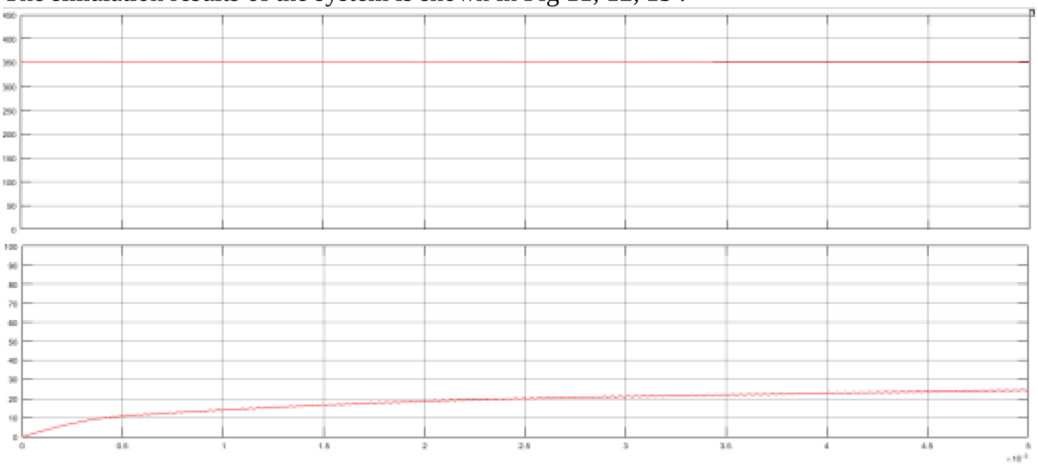

Fig 11: Output waveform of converter and panel

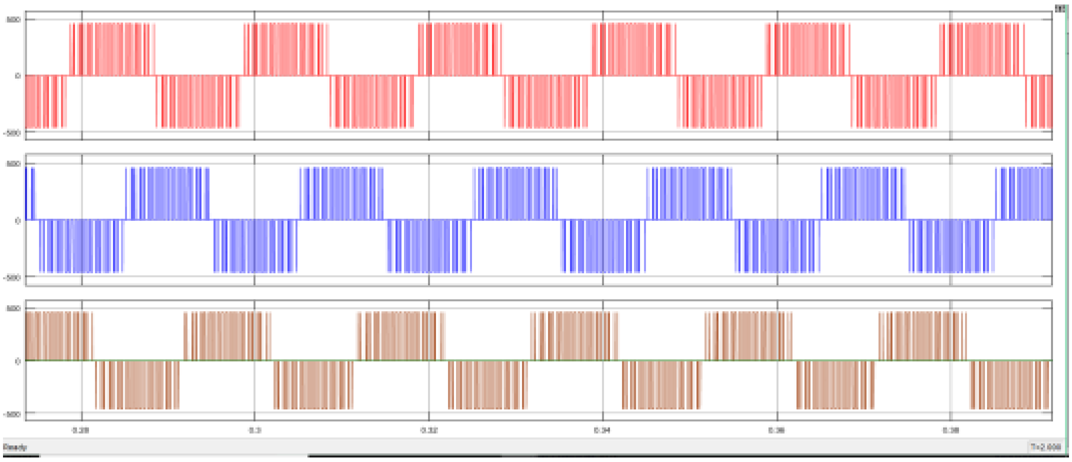

Fig 12 : Line Voltages of three phase inverter

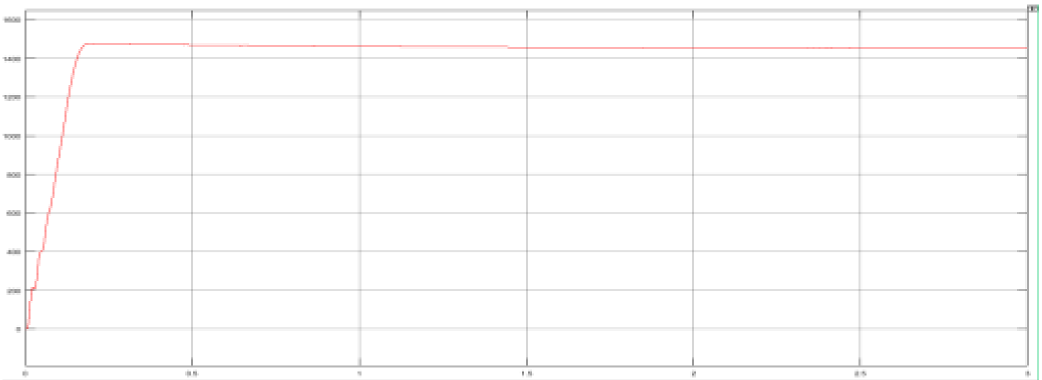

Fig 13 : Speed curve of induction motor

VI. Conclusion

A standalone water pumping system which can be implemented in isolated areas are presented. The system makes use of solar energy with a proper MPPT control to work with maximum efficiency. A resonant converter is designed to drive a three phase induction motor directly from a PV source. A converter which can achieve high step up voltage gain and which is suitable for high power applications is implemented. The converter can be operated with variable switching frequency. The use of induction motor instead of other motors have many advantages as induction motors requires less maintenance, cheap etc. as compared to other motors. The complete water pumping system is simulated using MATLAB software.

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