# Standalone Photovoltaic Water Pumping System using IMD

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**Abstract -** *A simple and efficient water pumping system using induction motor drive(IMD), comprises of two stages of conversions. The initial stage extracts the maximum power from a PV array by controlling the duty ratio of a boost converter. The motor speed is controlled to maintain the dc bus voltage. This regulation helps in the reduction of motor losses by reducing motor currents at higher voltage for the same power injection. An incremental conductance based maximum power point tracking (MPPT) control technique is utilized to control the duty ratio. A scalar controlled voltage source inverter serves the purpose of operating an IMD. The scalar control eliminates the need of a speed sensor or encoder. Consequently, the requirement of motor current sensor is also eliminated. Moreover, the dynamics are improved by an additional speed feed forward term in the control scheme. The control scheme makes the system inherently immune to the variation in the pump constant.*

***Key Words***: —Induction motor drives, boost converter, inverter, maximum power point tracking (MPPT), photovoltaic(PV) cells, V/f control, water pumping

## 1. INTRODUCTION

Power demand is increasing day by day and are one of the major concerns in the power sector, because of the unavailability of enough resources to meet the power demand using the conventional energy sources. Demand has increased for renewable sources of energy to be utilized along with conventional sources to meet the energy demand. Renewable sources like wind energy and solar energy are the prime energy sources which are being utilized in this regard. The continuous use of fossil fuels has caused the fossil fuel deposit to be reduced and has severely affected the environment conditions, depleting the biosphere and leading to global warming. Solar energy is abundantly available energy resource that has made it possible to harvest it and utilize it properly. Solar energy can be a standalone generating unit or can be a grid connected generating unit depending on the availability of a grid nearby. The standalone generating unit can be used to power rural areas where the availability of grids is very low. Another advantage of using solar energy is the portable operation whenever and wherever necessary. Earlier solar photovoltaic(PV) energy converters have been inefficient, with efficiency also was 5–6 %, and highly expensive. However, with the advancement in technological research, the efficiency of a PV unit, at present, has reached 15–16 % and also the prices have been reducing gradually. However, the technology is in developing phase and many challenges need to be addressed, such as intermittency, high initial cost, and low efficiency. The solar water pumps are gaining more popularity in rural areas, where the electricity is unavailable. Moreover, solar PV fed water pump are favored for irrigation, water treatment plant, and agricultural purposes. For a country like India, where 70 % of the population depends upon agriculture, irrigation is vital for good yield. There are a large number of water pumping system in the world running with electricity or with nonrenewable energy sources. The solar PV based water pumping systems are more convenient compared to diesel based water pumping systems considering the factors such as cost and pollution.

In PV pumping (PVP) systems, an induction motor drive(IMD) shows better performance compared to other commercial motors because of its rugged construction. The evolution is intended to develop a productive, maintenance-free, reliable, and cheap PV water pumping system. However, new permanent magnet motors such as brushless dc motors and permanent magnet sine fed motors are used for pumping, but these are still overshadowed by an induction motor because of availability constraints and cost. Moreover, the manufacturing of the induction motor is in a mature stage giving an edge to its use in developing countries for solar water pumping application. With the emergence of out performing solid state switches, high-speed processors, and efficient motor control algorithms, IMD-based water pumping systems have taken a step ahead to conventional water pumping systems such as diesel powered and other sources. Moreover, PV array fed IMD has performed ruggedly in the field of pumping system by utilizing a voltage source inverter (VSI). The proposed work deals with a three-phase IMD for solar water pumping, which meets the requirement of life without electricity in remote locations. The block diagram of the proposed system is depicted in Figure 1.

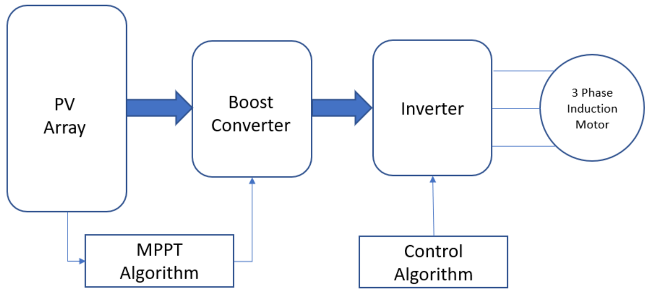


**Fig -1**: Basic Block Diagram

## 2. METHODOLOGY.

### 2.1 Boost Converter

Boost converter steps up the input voltage magnitude to a required output voltage magnitude without the use of a transformer as shown in Figure 2. The main components of a boost converter are an inductor, a diode and a high frequency switch. These in a co-ordinated manner supply power to the load at a voltage greater than the input voltage magnitude. The control strategy lies in the manipulation of the duty cycle of the switch which causes the voltage change ratio.

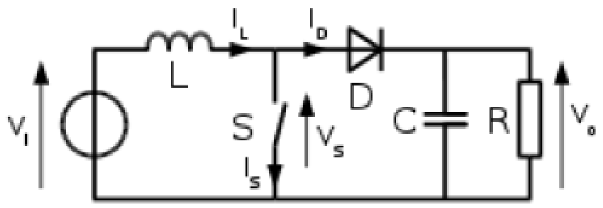

**Fig -2**: Boost Converter

There are two modes of operation of a boost converter. Those are based on the closing and opening of the switch. The first mode is when the switch is closed; this is known as the charging mode of operation. The second mode is when the switch is open; this is known as the discharging mode of operation. The charging mode of operation is shown in Figure 3; the switch is closed and the inductor is charged by the source through the switch. The charging current is exponential in nature but for simplicity is assumed to be linearly varying. The diode restricts the flow of current from the source to the load and the demand of the load is met by the discharging of the capacitor

The discharging mode of operation is shown in Figure 4, the switch is open and the diode is forward biased. The inductor now discharges and together with the source charges the capacitor and meets the load demands. The load current variation is very small and in many cases is assumed constant throughout the operation Figure 5 shows the theoretical waveform of the dc-dc boost converter.

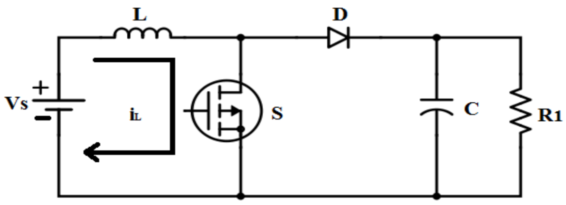

**Fig -3**: Operating Circuit of Charging Mode.

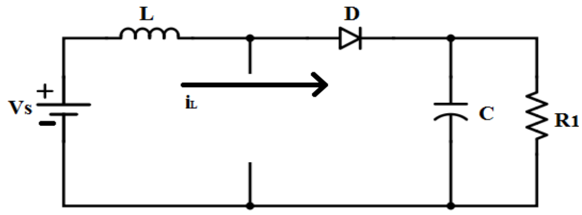

**Fig -4**: Operating Circuit of Discharging Mode.

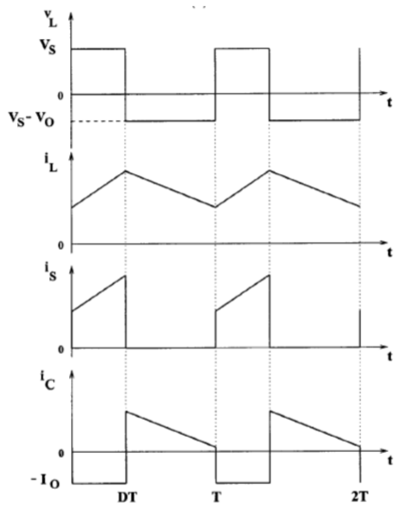

**Fig -5**: Theoretical wave form

### 2.2 Inverter

A simple V/f (voltage/frequency) control approach is uti⍰lized for water pumping application is shown in Figure 6. The V/f approach is simple, easy to implement, and cost effective. Inverters are used to supply power to a centrifugal pump with the sample-averaged zero-sequence elimination pulse width modulation technique. Apart from V/f control, direct torque control (DTC) and vector control techniques are complicated and they require extra current sensors for implementation. In V/f control, only PV array current, voltage, and dc bus voltage are sensed. The proposed system tracks the maximum power point by altering the modulation frequency so that the IMD is able to extract the maximum power from the solar PV array at sustained torque for different solar irradiation levels.

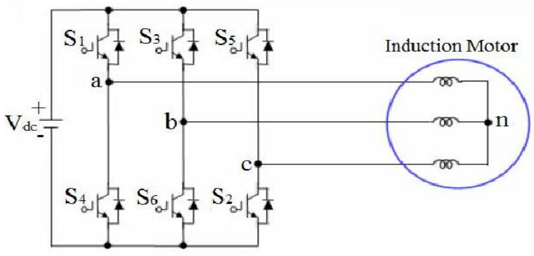


**Fig -6**: Voltage Source Inverter.

## 3. DESIGN OF COMPONENTS

### 3.1 Boost Converter

Let $V_{in}$ = 180V, $V_{out}$ = 240V, $P_{out}$ = 500W and $F_s$ =20KHz. Assume $\eta$ = 90 %, $\delta I$ = 30% of input current, $\delta V$ =10% of output voltage. Then,

$$D = \frac{V_{out} - V_{in}}{V_{out}} \quad (1)$$

$$L = \frac{V_{s\,min} * D}{F_s * \delta V} \quad (2)$$

$$C = \frac{I_{o\,max} * D}{F_s * \delta I} \quad (3)$$

On solving this, we will get the value of inductance and capacitance as L= 4mH and C= 1000 µF.

### 3.2 Design of Pump Constant

For the selected water pump, the proportionality constant $K_{pump}$ is given as

$$K_{pump} = \frac{T_L}{\omega_r^2} \quad (4)$$

where $T_L$ is the load toque of water pump, which is equal to the torque offered by an induction motor under steady-state operation and $\omega_r$ is the rotational speed of the rotor in rad/s

## 4. CONTROL SCHEME FOR THE PROPOSED SYSTEM

The proposed topology is a two-stage power conversion system for a solar PV array fed water pumping. It embodies scalar control for IMD operation and the INC method for maximum power extraction from the PV array. The simplicity and ease of implementation of scalar control overshadow precise but computation intensive control algorithms such as vector control. Moreover, in the later algorithms, the position sensorless operation is it self an exhaustive task. The voltage and current of PV array are sensed and fed to the INC algorithm. Based on the change in voltage, current, and power, this algorithm decides the duty ratio of the boost converter. The boost converter output voltage is maintained at a constant value using a proportional integral (PI) controller. Since the pump characteristics are centrifugal in nature, the power absorbed and the speed of the pump have a direct relation, as mentioned in (4). A speed feed forward term is calculated from the available PV power from which the PI controller output is subtracted. This is helpful in reducing the burden on the PI controller and improving the dynamic performance of the system. The V/f control algorithm generates the switching logic for VSI using sinusoidal pulse width modulation(PWM). If dc link voltage is higher than the reference value, the PI controller increases the reference speed given to V/f control and vice versa. The sum of two quantities gives a resultant speed reference f for IMD, which is fed to the V/f control Algorithm.

### 4.1 Scalar (V/f) Control of Induction Motor.

The scalar control of an induction motor is the most common and simplest control so far. Usually, induction motors are designed for 50-Hz input voltage. For operation at a lower speed, the voltage has to be reduced. The frequency control along with voltage magnitude control is also desired for con�stant flux operation. The voltage should be proportional to the frequency such that flux magnitude is maintained constant as s = V /ω. An IM is usually fed from a three-phase PWM VSI. Only an input parameter is the reference speed. Neglecting the small slip speed, the speed of the motor is approximately equal to the reference speed. The speed reference is integrated to generate θ, which is used to obtain three sinusoidal voltage references, which are compared with high-frequency triangular wave to generate the switching pulses for VSI. Three phase reference voltages are

$V_a = m * \sin(\theta)$ (5)

$V_b = m * \sin(\theta - 120)$ (6)

$V_c = m * \sin(\theta - 240)$ (7)

### 4.2INC Method for MPPT.

The solar PV array has nonlinear bell-shaped $P_{PV}$ versus $V_{PV}$ characteristics, the operating point depends on the impedance of the load connected to the array terminals. A dc– dc converter is used to track the point of operation on the PV curve. There have been many algorithms in the literature for tracking of maximum power point. Most basic of all is the perturb and observe algorithm, which involves step change in the reference voltage or duty ratio to the dc–dc converter and monitoring of the power output. It faces several issues when radiation changes. The

INC method works much better in dynamic changes in solar insolation. This is due to a fact that the mechanical time constant of the motor is much higher than the electrical time constant of the whole system. This work uses an INC algorithm, which is based on the monitoring of slope of the $P_{PV}$ –$V_{PV}$ curve.

$P_{PV} = V_{PV} * I_{PV}$ (8)

$$\frac{dP_{PV}}{dI_{PV}} = I_{PV} + V_{PV}\frac{dI_{PV}}{dV_{PV}} \quad (9)$$

$$\frac{dP_{PV}}{dI_{PV}} = -\frac{I_{PV}}{V_{PV}} \quad (10)$$

The duty ratio of the boost converter is adjusted in accordance with the algorithm, as shown in Figure 7.On the right side of MPP, slope is negative, which suggests that $\frac{dI_{PV}}{dV_{PV}} <= \frac{I_{PV}}{V_{PV}}$ and on the left side, slope is positive, i.e., $\frac{dI_{PV}}{dV_{PV}} >= \frac{I_{PV}}{V_{PV}}$ . At MPP, slope is zero, $\frac{dI_{PV}}{dV_{PV}} = \frac{I_{PV}}{V_{PV}}$.The duty ratio of the boost converter is adjusted in accordance with the algorithm.

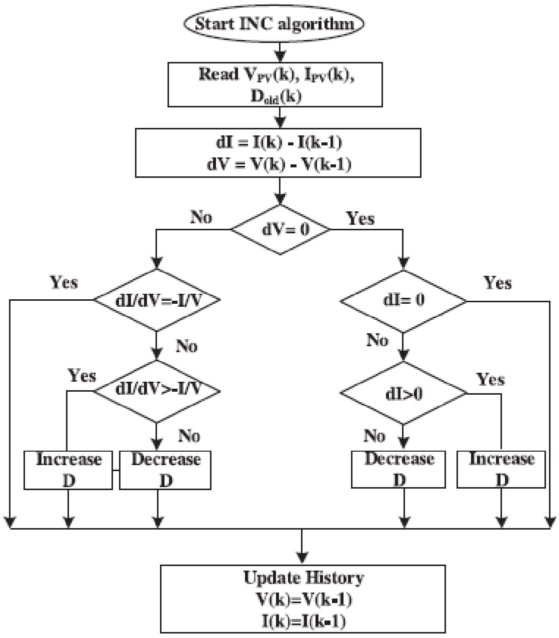


**Fig -7**:Flowchart for the INC algorithm for MPPT.

## 5. SIMULATION RESULTS AND ANALYSIS

The dc-dc boost converter and voltage source inverter are simulated in MATLAB/SIMULINK by choosing the parame�ters from the design values and the Simulink model of boost converter is shown in Figure 8. And the simulink model for voltage sourse inverter is shown in Figure 13.

### 5.1 Converter section.

The simulation results of the boost converter with PV array is shown in the following figures. It can be seen that the input voltage $V_{dc}$ is 120 V and the output voltage $V_o$ is 240 V. This verifies the boosting operation. The switching frequency is chosen to be 20 kHz and the duty ratio varies in accordance with the MPPT algorithm. The switching pulse varies in accordance with the irradiance and temperature hence the duty ratio of the converter also varies. Hence the duty ratio varies in accordance with the maximum power point.Figure11 shows the switching pulse obtained for the converter. The inductor current is triangular in shape and it varies around 3A to 4A and is shown in Figure 12 .Figure 9 shows input voltage for the boost converter which is obtained from the PV array with user-defined parameters. Figure 10 shows the output voltage of boost converter by the boosting operation.

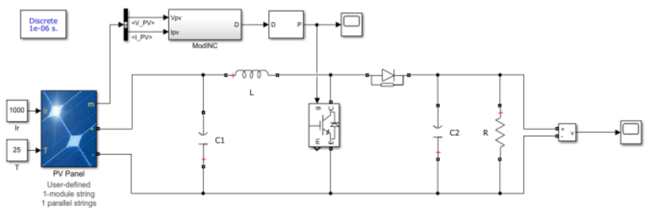

**Fig -8**: Simulation diagram of boost converter

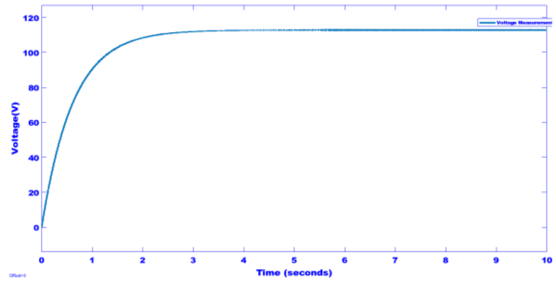


**Fig -9**: Input of boost conveter

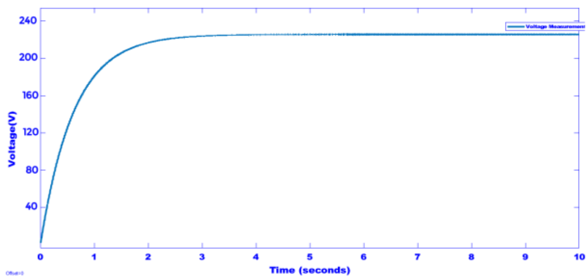


**Fig -10**: Output of boost converter

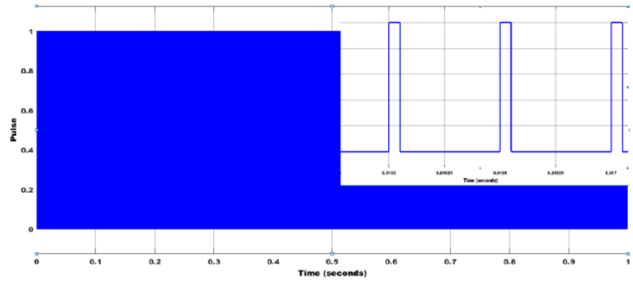


**Fig -11**: Switching pulse for converter

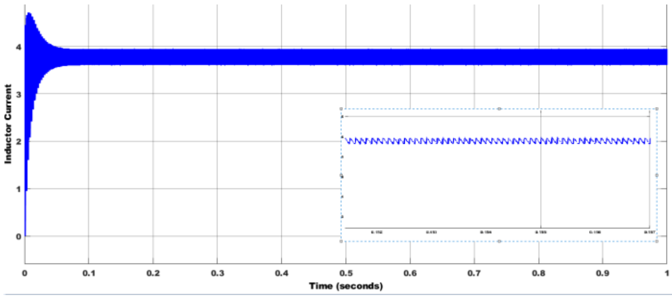


**Fig -12**: Inductor Current

**5.2. Inverter section.**

The simulation results of the V /f control of the three phase induction motor is shown in Figure 13. It can be seen that the speed is 1500rpm. It is clear from the Figure 12 the output speed remains constant. It is achieved by the help of V /f control.

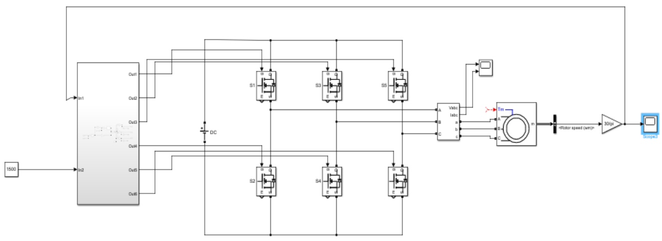

**Fig -13.**Simulation diagram of inverter.

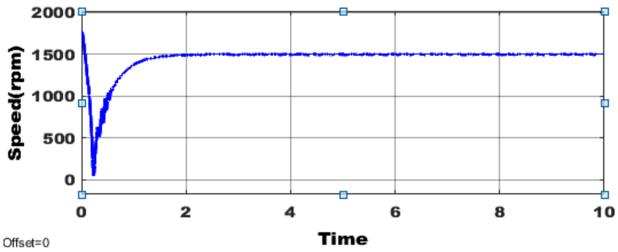


**Fig -14.**. Output speed of induction motor

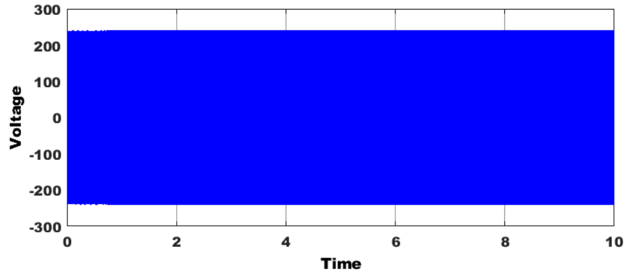


**Fig -15**: Output voltage of induction motor.

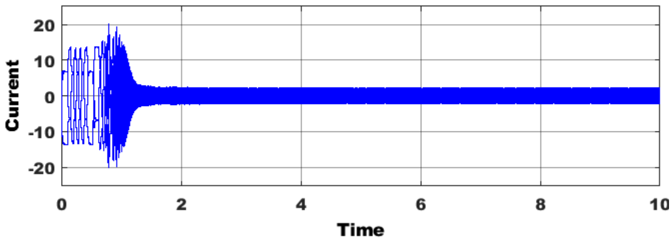


**Fig -16**: Output current of induction motor.

**6. HARDWARE IMPLEMENTATION AND RESULT**

A prototype of a standalone photovoltaic water pumping system for IMD with an input voltage of 120V for Boost mode is implemented. The experimental setup is shown in Figure17. It consists of control circuit, driver circuit and power circuit converter and inverter. Control circuit is composed of PIC microcontroller and its power supply. The control pulses for MOSFETs are generated using PIC microcontroller. The pulses from microcontroller is amplified by driver circuit which is composed of TLP250. It also provides isolation between control and power circuits. Power circuit for the inverter and converter sections are separately designed and fabricated. The speed of the induction motor is varied in accordance with the change in input voltage and the dclink voltage is found to be 238V and it is shown in Figure18.

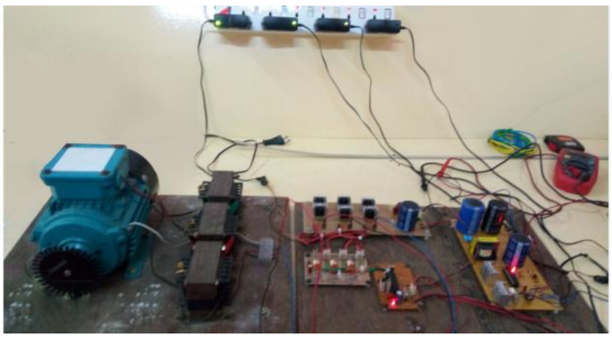

**Fig -17.**Experimental Setup

**Fig -18.DC Link Voltage**

## 7. CONCLUSION

A standalone PV water pumping system with a reduced sensor has been proposed. The reference speed generation for the V/f control scheme has been proposed based on the available power by regulating the active power at dc bus. The DC Link Voltage is found to be 238V, measured using a digital multimeter. The PWM frequency and pump affinity law have been used to control the speed of an induction motor drive. Its feasibility of operation has been verified through simulation and from the experimental setup. The output speed of the induction motor changes in accordance with the change in input to the converter, have been experimentally verified and found to be satisfactory.

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