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# Photo Voltaic (PV) fed Three Phase Induction Motor Drive for Rural Pumping Applications based on Single Stage Power Conversion

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***Abstract***

*This paper emphasizes on proposing a cost effective photovoltaic (PV) fed 3 phase Induction motor drive which serves for rural pumping applications. Generally in a standalone system, the solar panels generate direct current energy which is then stored in rechargeable batteries and the battery set up in turn will serve as a source for the inverter. But here in this proposed work a new single stage battery-less power conversion is employed by designing a maximum power point tracker (MPPT) embedded boost converter which revolutionizes the present tradition and makes the overall cost of the setup to go down considerably. The proposed work is realized as a prototype consisting PV array of 500watts, MPPT aided boost converter, three phase inverter and a three phase squirrel cage induction drive of 357 watts. An efficient and low cost micro controller dspic4011 is used as the platforms to code and implement the prominent perturb and observe MPPT technique. Sinusoidal pulse width modulation (SPWM) is the control technique employed for the three phase inverter. To validate the experimental results simulation of the whole set up is carried out in Matlab/Simulink environment. Simulation and hardware results reveal that the system is versatile.*

***Keywords:*** *Photo Voltaic (PV), Maximum power point tracking (MPPT), Perturb and Observe (P&O), Sinusoidal pulse width modulation (SPWM), Micro controller, Squirrel Cage Induction Motor (SCIM)*

## 1. Introduction

In a world of increasing energy demand, fossil fuels will eventually become depleted and renewable energy would then remain as the best alternative to satisfy world's hunger for energy. This alarming situation thereby has made people all over the globe concerned for depleting fossil fuels and this has resulted in increased inclination towards the alternate energy sources like the wind energy, solar energy, tidal and biomass etc [1-2]and amongst which solar and wind are on a high penetrations [3-4]. The fact that solar energy is renewable and also cleaner than any other energy produced from fossil fuels makes this resource of sustainable energy very important for the planet future. Developing countries like India, find it very difficult to realize the power produced by the renewable sources through the primary grids to load centers [5-7]. Primarily because it will affect the already existing setup and efficient synchronization would be required hereby. Therefore distributed power sources have dragged more attention over the years [8-10].

This particular work played utmost importance in designing a standalone PV system which can serve rural masses by employing irrigation facilities. There has been a lot of research around the world on employing PV systems as standalone power sources. Predominantly the researches paid their attention in PV powered water pumping system in desert well [11-12]. The fundamental research on PV for drives initiated in the late 90's

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where the model replaced the conventional motors by BLDC machines [13]. Since PV source is an inconsistent source, there arises a need for proper and efficient designing of arrays and in that regard many researchers have worked on sizing the arrays for task-specific loads like pumping, irrigation, etc [14-15]. The output power characteristics of PV are nonlinear in nature with respect to ambient temperature (T), sun's irradiation (G) therefore a technique called maximum power tracking technique is mandatory (MPPT) research adopted. When the research on PV fed induction drive for pumping was at its threshold, researchers tried to match the performance of Induction motor with Photo Voltaic system to achieve maximum power output [16]. There has been a spurt of research articles on PV systems feeding power to AC drives but most of the articles emphasized on two stage power conversion which involves a battery interface between the inverter and PV system.

But in this particular work a single stage power conversion technique is proposed which paves way for the removal of battery set up which in turn reduces the system cost considerably as well as maintains the performance of the system.

The article is organized in the following manner. Section 2 describes about the proposed system and where as in Section 3 the simulation and experimental results are analyzed in detail. The conclusions of the article are given in Section 4.

## 2. Proposed System

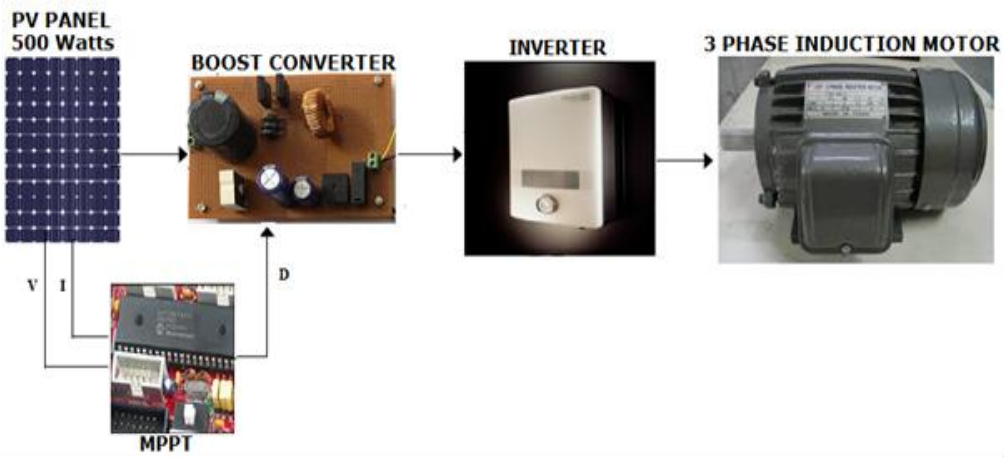


**Figure 1. Block Diagram of Proposed System**

The functional block diagram of the proposed system is depicted in Figure 1. The system embodies PV array, MPPT aided DC-DC (boost) converter, voltage source inverter and an induction motor.

### 2.1. PV Modeling and Characteristics

Solar cells are connected in series and parallel to get the desired output as a single solar cell could only contribute a meek voltage of 0.5 to 0.7 volt. Such designed unit is called a PV panel and these panels are in turn arranged series and parallel to form PV array. A photovoltaic cell has its equivalent circuit shown in Figure 2.

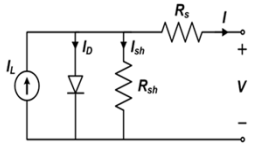


**Figure 2. PV Panel Equivalent Circuit**

 

Mathematical Model of a PV system

$$I = I_{pv} - I_d - \frac{V + IRs}{Rsh} \quad (1)$$

By substituting the value for $I_d$

$$I = I_{pv} - I_o \exp \frac{q(V + IR_S)}{kT_C i} - 1 - \frac{(V + IRs)}{R_{Sh}} \quad (2)$$

The model includes the temperature dependence of photo-current, $I_{pv}$ and saturation current of the diode, $I_o$. Using the equations [1-2], a mathematically modelled PV system is created in Matlab/Simulink environment. The inference from the mathematical model is the output PV characteristics are nonlinear in nature and also its peak power varies with respect to sun's radiation and temperature. Figure 3 represent the output characteristics of a PV model.

**Table 1. Electrical Parameters of 250W Panel**

| PARAMETERS | VALUES |
|---|---|
| Maximum Power (Pmax) | 250W |
| Voltage at Max. Power (Vmp) | 30.06 V |
| Current at Max. Power (Imp) | 8.32 A |
| Open Circuit Voltage(Voc) | 36.78 V |
| Short Circuit Current(Isc) | 8.75 A |

### 2.2. Perturb and Observe MPPT Technique

Maximum Power Point Tracking is electronic tracking-usually digital controller which makes the panel to operate at a voltage at which maximum available power at that instant is extracted. Since the power production of PV system changes with respect to ambient temperature and irradiation, a MPPT set up in a PV system is indispensable .There are lots of MPPT algorithms available among that the most prominent is used perturb and observe method due to its simple structure and efficiency [17]. A Flow Chart of the perturb and observe algorithm is shown in Figure 3

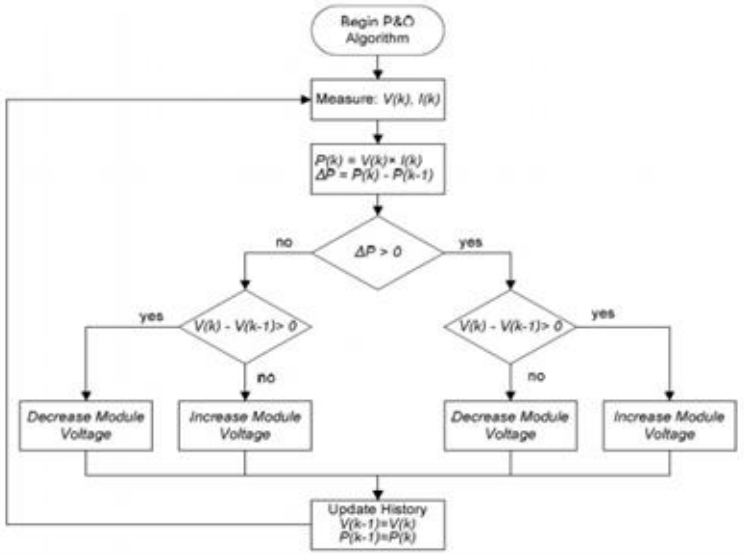


**Figure 3. Flow Chart of P&O Algorithm**

### 2.3. Boost Converter

A boost converter (step-up converter) is a DC-to-DC power converter with an output voltage greater than its input voltage. It is a class of switched-mode power supply (SMPS) containing at least two semiconductors (a diode and a transistor) and at least one energy storage element, a capacitor, inductor, or the two in combination. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple.

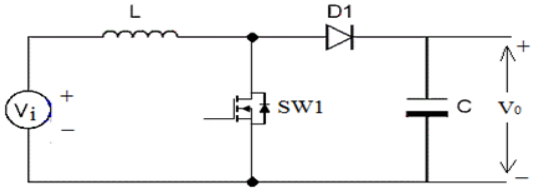


**Figure 4. Boost Converter**

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current by creating and destroying a magnetic field. In a boost converter, the output voltage is always higher than the input voltage. A schematic of a boost power stage is shown in Figure 4. Let the switch be on for a time period $T_{on}$ and off for period $T_{off}$. In the on period the switch closes and the inductor charges to a certain value. During the off period switch opens and the inductor discharges across the load. The equations corresponding to this are given below

$$\Delta I_{L_{on}} = \frac{1}{L}\int_0^{DT} V_i dt = \frac{DT}{L}V_i \tag{3}$$

$$\Delta I_{L_{off}} = \int_{DT}^{T} \frac{(V_i - V_o)}{L} dt = \frac{(V_i - V_o)(1-D)}{L} T \tag{4}$$

$$V_i - V_o = L\frac{dI_L}{dt} \tag{5}$$

$$\Delta I_{L_{on}} + \Delta I_{L_{off}} = 0 \tag{6}$$

$$\Delta I_{L_{on}} + \Delta I_{L_{off}} = \frac{V_i DT}{L} + \frac{(V_i - V_o)(1-D)}{L} T = 0 \tag{7}$$

$$\frac{V_o}{V_i} = \frac{1}{(1-D)} \tag{8}$$

### 2.4. Voltage Source Inverter

An inverter is a device that converts DC power into AC power at desired output voltage and frequency. The inverter's role is to be the interface between two energy sources: the DC network on one side and the AC utility grid on the other. In addition to the conversion and feed-in function, the inverter is also responsible for system control and performance optimization. The SPWM is a major control scheme in inverter here, due to its features like low THD in output voltage, low switching losses and higher output voltage for the same dc-bus voltage. This PWM technique involves generation of a digital waveform, for which the duty cycle can be modulated in such a way so that the average voltage waveform corresponds to a pure sine wave. A VSI setup is shown in Figure 5.

 

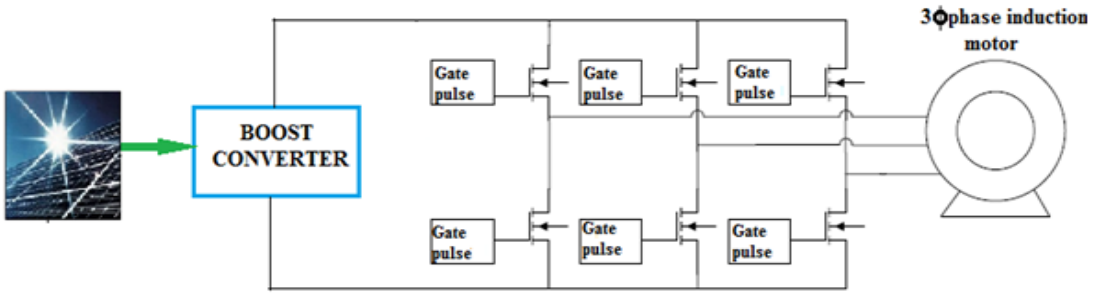


**Figure 5. VSI Setup**

**Table 2. Electrical Parameters of Three Phase Induction Motor**

| PARAMETERS | VALUES |
|---|---|
| Real Power | 0.37kW/5HP |
| Rated Current | 1.4A |
| Voltage | 415V |
| Speed | 1330 rpm |
| Frequency | 50Hz |

### 2.5. Induction Motor Drive

AC motors are widely used motors in all applications these days due to low cost, robustness, reliability and low maintenance. While pumping water for irrigation purposes the load draws a lot of current and hence it is advisable to have Solar panels which deliver a power almost 2 to 3 times the rating of the motor. This work suggests extracting maximum power from the panel by using the MPPT technique and yielding the best out of the panel for our purpose of pumping water. In addition, these systems need very limited maintenance, since they operate without storage batteries and they do not pollute the environment.

## 3. Results and Discussion

In this section simulation and experimental results are discussed in detail.

### 3.1. Simulation Results

The PV panel (refer with Table 1) which is taken for consideration is mathematically modeled in a simulation environment and it's V-I & P-V shown in Figure 6.

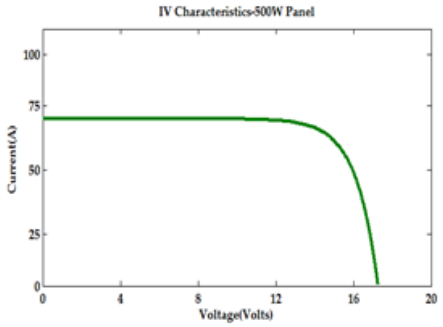


**Figure 6. V-I Curve**

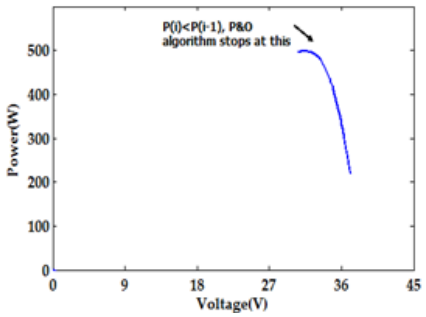


**Figure 7. P&O MPPT**

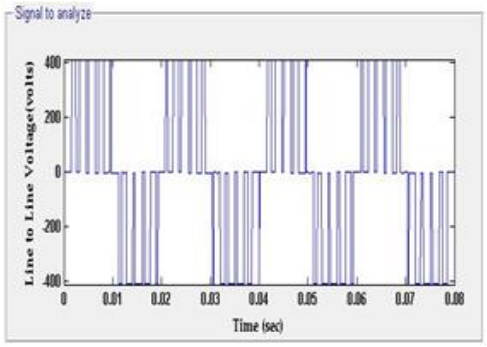


**Figure 8. VSI Output**

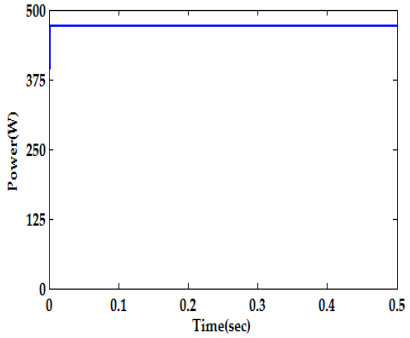


**Figure 9. Power vs Time**

Figure 7 shows the P& O MPPT output wave form and it can be observed from the figure the power is perturbed till maximum power is detected and the peak power oscillates near the peak power point. The tracked peak power vs time plot is shown Figure 9. The VSI output for single phase is shown in Figure 8.The MPPT control as well the PWM control of VSI is effectively implemented by using a digital signal controller dsPIC30F4011.The controller is so effective and easy to handle as it is capable of releasing six PWM outputs. The pulse, usually generated by comparing a triangular and a sine wave, is directly generated by this IC thereby simplifying the hardware setup.

### 3.2. Hardware Results

To validate the suggested proposed work, intensive investigations are done on a prototype set up. The whole prototype set up is shown Figure 10.

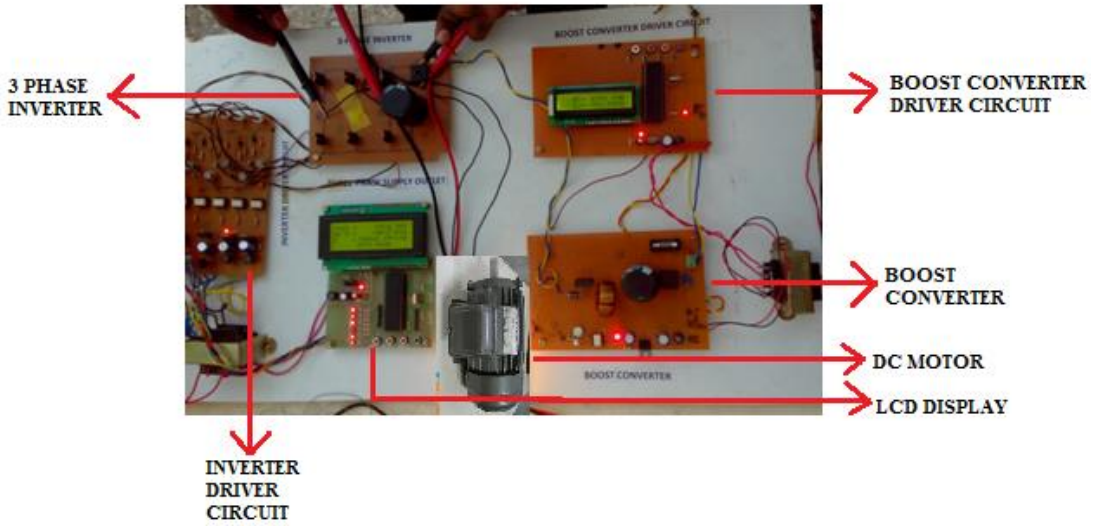


**Figure 10. Hardware Prototype**

## 4. Conclusion

This paper has proposed a three phase Induction motor drive fed by PV array for rural applications. The design considerations of the photovoltaic array complying with three phase inverter fed induction motor drive were investigated. The key advantage of our system is that in order to reduce the stultifying complexity and installation cost, a single stage conversion embedded boost converter based perturb and observe MPPT is proposed. Considering the financial constraints of farmers who largely depend on agriculture for their living and on who's punitive work relies the whole country's stomach, this setup is

highly cost effective and a sheer gift since it works devoid of a battery, which is supposed to be the most expensive component when it comes to PV applications. Taking into account the most reliable and simpler control scheme, a voltage source inverter is used to drive the induction motor. The developed prototype operates satisfactorily with varying insolation and temperature. Since the system is bestowed with simplicity, improved performance, high efficiency and low cost, the PV fed induction motor drive will become ideal set up for pumping and other irrigational applications in remote places.

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