Techno-economic Study for Water Pumping by Solar Power Driven Three Phase Induction Motor

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Abstract— **The paper primarily focuses on water pump irrigation by operating the three phase induction motor, using photovoltaic supply. In many far away regions, mainly in villages, the main hindrance in agricultural production is the sole dependence on electricity. Up till now, solar application employed for DC motors throughout the world because of its simplicity and torque controlling techniques. In addition to it, regular maintenance of brushes and commutator is mandatory. Also it is not possible to replace all, already installed three phase induction motors with DC motors. A three phase induction motor with the help of inverter performs robustly. The primary goal of this paper is to study a DC-DC converter and DC-three phase inverter, to integrate three phase induction motor. The exploratory results satisfied the targets as it was effectively managed as a water pump with optimal efficiency and cost, using three phase induction motor.**

Index Terms— **Photovoltaic Source, Three Phase Inverter, DC-DC Converter, Three Phase Induction Motor, Solar Energy.**

I. INTRODUCTION

The present heavy reliance on conventional fuels likes fossil fuels; the solar energy ensures a source of electrical energy which is more economical, uninterrupted and efficient. The solar panels primarily provided by DC source, using three phase induction motor, are used to pump water. This pump is then used in industry, household purposes and irrigation for remote areas where conventional power is not available. Due to its low price robustness, reliability and efficient maintenance cost; many household, commercial and industrial applications have employed induction motors. A three phase induction motor is selected because of its higher initial torque than single phase induction motor. There are less severe effects of starting current in three phase motor than a single phase motor. As our main objective of this project is water pumping in remote areas where no electricity is present so we chose a three phase induction motor.

The inversion of low voltage DC source to high voltage AC source is used, in a two-step process. Initially, a converter is used to step up the DC voltage to a much higher voltage. In the next step, using Pulse Width Modulation (PWM), high voltage DC is transformed into an AC voltage. The implemented method is like: first transforming the DC source from solar panel to AC at low voltage level and after that stepping it up using a transformer. The stepped output AC voltage is rectified using bridge rectifier.

AC inverters are common devices nowadays. These devices are usually used for low voltage DC source; as battery of a motor vehicle and supply a 220V AC source at 50 Hz. As the market for such product is wide, many competitors have entered with so many implications. Low cost designs used a “modified sine wave” which resembles a square wave. This results in the substantial amount of noise being introduced into the circuits. This type of noise is highly undesirable to audio devices. To overcome this problem, a true sine wave should be generated from the DC source. Such devices are abundant in the markets but at a very high price. In order to become economical, a Pulse Width Modulation (PWM) is implemented with a pure sine wave. One condition in using PWM is employed with the supposition that the source voltage would be larger than the output voltage. That employs a requirement for DC-DC converter which would provide the inverter with a high voltage source. The converter is designed to boost 12V to 220V DC.

Inverters are employed to transform DC voltage into three phase AC voltage. In this project we are converting a 220V DC source to a three phase AC source which is then fed to three phase induction motor. Finally the load that will be used in our case is a three phase induction motor with a low power rating of 16 watt.

II. METHODOLOGY

A. Solar Energy

Solar energy is utilized in two ways:

- First; Solar Thermal Technologies; in which heat is generated to operate devices for cooling, drying, heating, power generation and water purification.
- Second; Solar Photovoltaic (SP) systems in which sunlight is converted into electrical energy for lighting, pumping, refrigeration and communications. It can also be employed for power generation on a large scale level.

i. Principle of Operation of PV Solar Cells:

A photovoltaic cell or a solar cell converts sunlight into electricity, directly at the very basic step of atomic level by releasing the electrons and absorbing the light energy. This is a property of a particular material which generates a low amount of electric current when came under the sunlight. An arrangement of solar cells converts the solar energy into a useful quantity of DC electrical energy. In this, the solar cell;

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which is the primary and fundamental element of a photovoltaic system is solely composed of semiconductor material and silicon as semiconductor. At the present time, three types of technologies are employed in the preparation of solar cells:

- Amorphous silicon,
- Monocrystalline silicon, and
- Polycrystalline silicon.

The efficiency of these materials is 7%, 15%, 13% respectively [1].

Fig. 1: ATypical Solar Panel

The solar cells transform solar energy directly into electricity. The phenomenon (commonly called photoelectric effect used to initiate an electromotive force when the surface of a cell comes under light) occurs in that type of material which has the property of capturing the photons and emitting the electrons. The particular principle governing the behavior of photovoltaic cell, consisting on p-n junction, is explained by a semiconductor material sensitive to the sunlight. By becoming vulnerable to the sunlight, photons create some electron-hole pairs proportional to the incident radiation with the higher energy, than the band-gap energy of the semiconductor. A conventional solar cell composed of two types of slightly different layers of silicon having contact with each other. As the sunlight fall on the top layer, the movement of electrons across the junction took place between the layers, creating an electric current.

The upper layer of silicon of a solar cell is usually very slim. This layer comprised of some atoms of an element, such as phosphorus, as a deliberate impurity which has more electrons than silicon. This type of impurity due to other atoms, are usually known as donors as they release or donate the extra electrons into the silicon layer as free electrons. The lower layer in the solar cell is usually thicker as compared to the top layer of the solar cell. It consists of few atoms, as an impurity, in the element like boron which has fewer or lesser electrons than silicon atoms. This type of impurity of atoms, are called as acceptors, in comparison to the silicon atoms. These atoms accept electrons because they have holes. The two layers came closer at the junction; the donors next to the junction release the electrons that eventually migrate to the adjacent acceptors across the junction. This electron movement creates the electric current from a solar cell that could flow through the circuit having contact between the two layers [2].

Since, the load is 16W only, so to be on the safe edge in case of power we bought a solar panel of 30W only. It can give maximum of 21v when full radiation is available. The PV cell's electrical behavior is basically that of a diode. The transformation is without noise, fuel, mechanical action and also having nonpolluting behavior.

The generated voltage could vary from 0.3V to 0.7V because of its disposal and the used material, the temperature and the ageing of the cell. To increase the output voltage, solar cells are connected in series in this setup. Likewise, higher current will be yielded in the cells in parallel arrangement.

ii. Attributes of PV Solar Cells:

The nonlinear Current-Voltage and Power-Voltage attributes of the solar cells which depicts how the solar cells will react to all possible loads under particular temperature and solar radiation conditions, is shown in Fig 2.

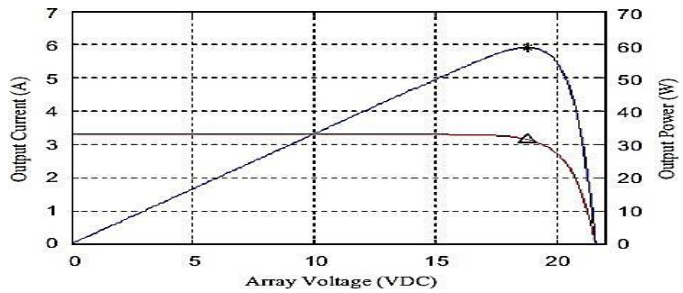

Fig. 2: Power Voltage and Current-Voltage Characteristics of Solar Cell

The current-voltage attributes of a module are achieved in a simple way:

- Multiply the current by number of cells in parallel; Np, and
- The voltage of cells and number of cells in series; Ns.

The basic and primary factors and elements concerning solar cells are fill factor, short circuit current, open circuit voltage and efficiency of solar cells.

iii. Open Circuit Voltage (Voc):

Voc is the voltage across the cell when there is no load in connection of infinite resistance. Ultimately there will be no current passing through the cell. The value will decrease with the increase in the temperature and changes minutely with the light radiation. It can be calculated when the current in the circuit equals to zero.

$$V \text{ (when } I=0) = V_{oc} \tag{1}$$

iv. Short Circuit Current (Isc):

Isc is the current, matches the conditions of short circuit when the solar cell impedance is low or almost zero thus it is the maximum current value that the cell can provide in this condition. It is the property of the illuminated surface, temperature and solar radiation spectrum. The current increases linearly with the intensity of light of the cell. This current is obtained when the voltage of the circuit becomes zero.

$$I \text{ (when } V=0) = I_{sc} \tag{2}$$

v. Fill Factor (FF):

FF stands for the calculation of solar cell quality. The value is measured by comparing the theoretical power (Pt) to the maximum power that can be delivered by the cell (P max) by multiplying open-circuit voltage by the short circuit current. It is defined by the term FF. To understand these concepts some equations are here:

$$P\ max = Vm\ .\ Im \tag{3}$$

Where:
Voltage (V) and Current (I) corresponds to the maximum power.

$$FF = {}^{Pmax}\!/_{Voc\ .\ Isc} = {}^{\eta\ .\ Ac\ .\ G}\!/_{Voc\ .\ Isc} \tag{4}$$

It is actually representing the difference between ideal cell; a cell for which series resistance Rs = 0 and parallel resistance Rp = ∞ and the actual cell.
The Fill Factor declines as the temperature of the cell increases. Usually Fill Factor ranges from 0.5 to 0.82 and as closer it is to 1, the cell is as closer to the ideal cell.

vi. Efficiency (η):

Efficiency 'η' is the fundamental and vital attribute of the solar cell i.e., it is the power conversion efficiency. The efficiency is defined as the ratio between the powers of the incident light i.e., P inc and the maximum power supplied by the cell P max. It is defined by the following equations:

$$P\ inc. = G.\ Ac \tag{5}$$

Where:
G = Incident radiation flux (W/m^2)
Ac = Area of collector (m^2)

$$\eta = {}^{Pmax}\!/_{Pinc}\ \text{x}\ 100 \tag{6}$$

The efficiency can be improved by increasing the fill factor, open circuit voltage, short circuit current.

B. DC-DC Converter

The main objective of convertor in our circuit is to step up the output voltage of solar panel from 12V DC to 220V DC. For this purpose we have to design and perform techno-economic study of a DC-DC converter. Many techniques are employed for devising and studying DC-DC converter. In this paper, almost all of them are not considered as the output, as it was not isolated from the input or they did not function or operate in required power range. The design must meet certain demands like output should be 220V; it must be highly efficient as it is half of overall project; and the output power must be greater than 16W as our load is of 16W for this project. There are three topologies that were seriously considered for this project and paper. These are:

i. Half Bridge Topology:

The half bridge converter has 85% efficiency at 500 W of power. It has a fifty percent duty cycle. A center-taped transformer separates the input from the output. It is mostly used in high power systems.

ii. Full Bridge Topology:

The full bridge converter has 85% efficiency at 1000 W of the power. It has a fifty percent duty cycle. A center-taped transformer separates the input from the output. It is used in high power systems usually. It resembles with that of half bridge converter.

iii. Push Pull Topology:

The push pull converter has 85% efficiency at 350 W of the power. It has a fifty percent duty cycle. A center-taped transformer separates the input from the output. It is often used in high power systems. It resembles with that of half bridge converter [3].
At first we worked on push pull technique using a simple center-taped transformer. We used high speed and high power Metal Oxide Semiconducting Field Effect Transistors (MOSFETs) for this circuit, in our case it is IRFP460 [4]. We generated pulses with 50% duty cycle using an IC TL494. When these pulses were given to the primary winding of center-taped transformer it worked for low voltage up till 8 to 10v but for 12v or high it gets saturated and suddenly current drops to zero and output voltage also becomes zero. So we have changed our strategy for the convertor circuit but it is an advice, for someone who wants to works with push pull topology that he/she must use ferrite core transformer not simple one as it gets saturated when high frequency pulses are applied across it. For what this project needs, the topology chosen has to convert a 12V DC into 12V AC using single phase inverter and then step up by using a transformer which is rectified using an Integrated Circuit (IC#D3SB-08) to produce 220V DC at the output. The switching scheme is implemented by a microcontroller (89C51) which allows to ON two transistors at a time, S1 with S4 and S2 with S3, [5] as shown below in Fig 3.

S1	S2	S3	S4	Va	Vb	Vab
OFF	ON	OFF	OFF	- Vs/2	- Vs/2	- Vs
ON	OFF	ON	ON	Vs/2	- Vs/2	Vs
OFF	ON	ON	ON	- Vs/2	- Vs/2	0
ON	OFF	OFF	OFF	Vs/2	Vs/2	0

Fig. 3: Switch Scheme of MOSFET's

Also the output of the switching scheme displayed on the oscilloscope is shown in the Fig 4.

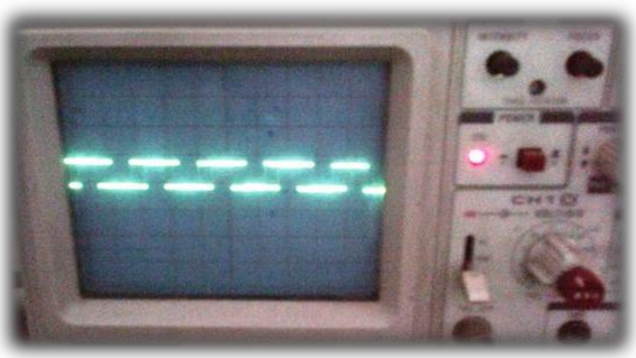

Fig. 4: Waveform of Switching Scheme

The filter capacitor is also used at the output to eliminate ripples and harmonics [6]. The capacitor used in this case is 0.1uf 500V. The approximate DC output voltage obtained is 160V.

C. DC 3- Phase Inverter

Since the load is a three phase induction motor so there is a need to convert this high voltage DC into three phase AC.

The first task accomplished was an initial design for the output waveforms for the IRFP460.

The objective of this part is to devise, study and develop a three phase inverter which will be used to invert the input DC voltage of 110V into 110V AC voltage. While designing and developing an inverter, a simulation and hardware is constructed step by step in sequence. For the purpose of simulation, PROTEUS software will be used. The design is implemented by using microcontroller 89C51. We have classified the structure of three phase inverter in such a way that microcontroller is generally used. Microcontroller is energized by 5V DC from supply and oscillator. Six output signals, three high side and three low sides will be generated by microcontroller. These six signal are driven by three drivers (IR2110) giving an output of three signal which will be bidirectional. A three phase MOSFET inverter scheme is being used to get the desired three phase output. A combination of the diode and resistor is also used between the drivers and MOSFETs for the protection of back current produced by MOSFETs.

III. CONCLUSIONS AND FUTURE WORKS

After the various iterations of the circuits and the minor bug fixes, the circuit started working as required. The controls are working perfectly and giving a manual change in frequency and speed control correctly. The implemented hardware circuit is shown in Fig 5 [7].

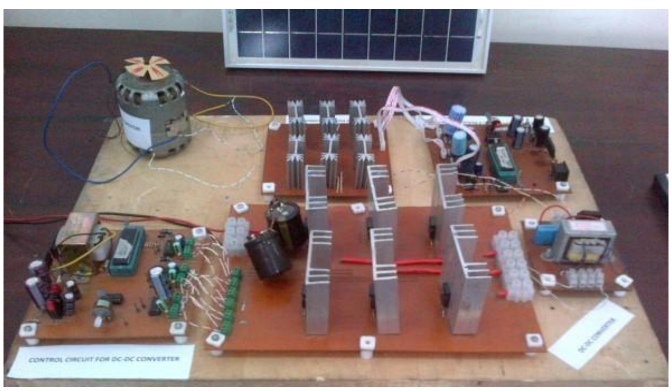

Fig. 5: Complete Hardware of Project

The overall design is giving an output DC voltage of 160V instead of 220V due to losses inside the circuit. The capability is that a three phase induction motor is operated and driven with reasonable speed.

A question arises here that since an induction motor requires active power as well as reactive power for its operation while solar panel gives only active power then how can a solar panel run an induction motor? Actually the reactive power is provided by the capacitor connected at the output of inverter. This capacitor removes unwanted noise signals as well as provides reactive power to induction motor for its operation.

There is still more work that can be done in this project. The primary recommendation would be to use a ferrite core transformer in DC to DC converter portion because the iron core transformer gets saturated and results in losses [8].

The other improvement will be a feedback system in which a microcontroller provide a view of the output across the load so that according to certain parameters in the programming, the signals controlling the system could be adjusted.

Another improvement can be the design of modified sine wave instead of square wave so that inductive loads such as motor can be driven smoothly [9].

The project can be further taken for improvement. The speed control can be done with a closed loop path automatically using V/F control such that as the voltage increases or decreases from solar panels, the frequency is changed so that the speed remains constant. An improvement can be made in overall system i.e., losses can be minimized. However the system efficiency can be achieved by implementing a Maximum Power Point Tracker (MPPT). Sufficient field data is required in order to compare this system with DC counterparts [10].

This paper will enable farmers to switch to renewable energy for irrigation instead of conventional utility. A lot was performed and learned in terms of researching existing products, finding the accurate results, schematics and PCB layout skills, debugging and circuit re-wire skills.

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