CHAPTER – 5

PHOTOVOLTAIC POWERED INDUCTION MOTOR DRIVE

5.1 INTRODUCTION

Solar energy is the most low cost, competition free, universal source of energy as sun shines throughout. This energy can be converted into useful electrical energy using photovoltaic technology. The steady state reduction of price per peak watt and simplicity with which the installed power can be increased by adding panels are attractive features of PV technology. Among the many applications of PV energy, pumping is the most promising. In a PV pump storage system, solar energy is stored, when sunlight is available as potential energy in water reservoir and consumed according to demand. There are advantages in avoiding the use of large banks of lead acid batteries, which are heavy and expensive and have one fifth of the lifetime of a PV panel. A number of experimental DC motor driven PV pumps are already in use in several parts of the world, but they suffer from maintenance problems due to the presence of the commutator and brushes. Hence a pumping system based on an induction motor can be an attractive proposal where reliability and maintenance-free operations with less cost are important. The effective operation of Induction motor is based on the choice of suitable converter-inverter system that is fed to Induction Motor. Converters like Buck, Boost and Buck-Boost converters are popularly used for photovoltaic systems. But these converters are limited to low power applications. For PV applications like pumping these converters could do a good job as pumping is carried out at high power. Thus a new push pull converter which is two switch topology can do justice by giving a high power throughout. The Induction Motors are the AC motors and hence from converter, an inverter system is also required to obtain an AC voltage. This inverter is chosen based on its advantages and it is fed to induction motor.

Photovoltaic technology is one of the most promising for distributed low-power electrical generation. The steady reduction of price per peak watt over recent years and the simplicity with which the installed power can be increased by adding panels are some of its attractive features. Among the many applications of photovoltaic energy, pumping is one of the most promising. In a photovoltaic pump-storage system, solar energy is stored, when
sunlight is available, as potential energy in a water reservoir and then consumed according to demand. There are advantages in avoiding the use of large banks of lead-acid batteries, which are heavy and expensive and have one-fifth of the lifetime of a photovoltaic panel. It is important, however, that the absence of batteries does not compromise the efficiency of the end-to-end power conversion chain, from panels to mechanical pump. Photovoltaic panels require specific control techniques to ensure operation at their maximum power point (MPP). Impedance matching issues mean that photovoltaic arrays may operate more or less efficiently, depending on their series/parallel configuration.

5.1.1 PHOTOVOLTAIC TECHNOLOGY

Converting the sun’s radiation directly into electricity is done by solar cells. These cells are made of semiconducting materials similar to those used in computer chips. When sunlight is absorbed by these materials, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity. This process of converting light (photons) to electricity (voltage) is called the photovoltaic effect. Photovoltaics (PV) are thus the field of technology and research related to the application of solar cells that convert sunlight directly into electricity.

Solar cells, which were originally developed for space applications in the 1950s, are used in consumer products such as calculators or watches, mounted on roofs of houses or assembled into large power stations. Today, the majority of photovoltaic modules are used for grid-connected power generation, but a smaller market for off-grid power is growing in remote areas and undeveloping countries.

Given the enormous potential of solar energy, photovoltaics may well become a major source of clean electricity in the future. However, for this to happen, the electricity generation costs for PV systems need to be reduced and the efficiency of converting sunlight into electricity needs to increase.

5.2 PHOTOVOLTAIC SYSTEM

A photovoltaic system (or PV system) is a system which uses one or more solar panels to convert sunlight into electricity. It consists of multiple components, including the
photovoltaic modules, mechanical and electrical connections and mountings and means of regulating and modifying the electrical output.

5.2.1 PHOTOVOLTAIC ARRAYS

Due to the low voltage of an individual solar cell typically 0.5V, several cells are wired in series in the manufacture of a "laminate". The laminate is assembled into a protective weatherproof enclosure, thus making a photovoltaic module or solar panel. These solar panels are linked together to form photovoltaic Arrays as shown in Figure 5.1.

![Figure 5.1 PV array](image)

5.2.2 SERIES CONNECTION OF PV PANELS

The panels are connected in series as shown in Figure 5.2. The current through the cell is constant and the voltage across the cell adds up and the I-V characteristics are shown in Figure

![Figure 5.2 Series connection of PV panels](image)
5.2.3 PARALLEL CONNECTION OF PV PANELS

The panels are connected in parallel as shown in Figure 5.4. The voltage through the cell is constant and the current across the cell adds up. The I-V characteristics are shown in Figure 5.5. In order to obtain a high current in PV cell, the parallel connections are required.
5.2.4 WORKING PRINCEPLE OF PV CELL

When photons of light strike the material, however, some normally non-mobile electrons in the material absorb the photons, and become mobile by virtue of their increased energy. This creates new holes too - which are just the vacancies created by the newly created mobile electrons. Because of the "built in" electric field, the new mobile electrons in the n-material cannot cross over into the p-material. In fact, if they are created near or in the junction where the electric field exists, they are pushed by the field towards the upper surface of the n-material. If a wire is connected from the n-material to the p-material, however, they can flow through the wire, and deliver their energy to a load.

On the other hand, the holes created in the n-material, which are positively charged, are pushed over into the p-material. In fact, what is really happening here is that an electron from the p-material, which was also made mobile by the adsorption of a photon, is pushed by the electric field across the junction and into the n-material to fill the newly created hole. This completes the circuit as the electrons flows in all the ways around the circuit, dropping the energy they acquired from photons at a load as shown in Figure5.6.
5.2.5 EQUIVALENT OF PV CELL

The equivalent circuit describes the static behavior of the solar cell. It has a current source, P-N junction diode, a shunt resistor (Rsh) and a series resistor (Rse). The practical and an ideal solar cell is shown in Figure 5.7.

![Figure 5.7: PV equivalent circuit](image)

5.2.6 ADVANTAGES OF PV SOURCE

The following are the outstanding advantages

- There are no need for fuel as the, Inexhaustible sunlight is used as the source of electrical energy.
- Clean energy since there is no emission of environmental pollutants, such as NOx and CO2.
- No need for troublesome operations because the system operation is automatic.
- Simple system configuration, easy maintenance.

5.2.7 BLOCK DIAGRAM OF PHOTOVOLTAIC PUMPING SYSTEM

Among the many applications of photovoltaic energy, pumping is one of the most promising. In PV pump storage system, solar energy is stored, when sunlight is available as potential energy in a water reservoir and is consumed according to the demand. There are advantages in avoiding the use of large banks of lead acid batteries, which are heavy and expensive and have one fifth of the lifetime of PV panel.
A typical configuration of a battery less photovoltaic pumping system comprises of 1) PV panels 2) DC/DC converter 3) DC/AC converter 4) an induction motor and 5) centrifugal pump as shown in Figure 5.8. The design of an effective PV pumping system without the use of a battery bank represents a significant challenge. It is necessary to deal with the effect of the stochastic nature of solar installation on the entire energy conversion chain, including the nonlinear characteristics of PV pumping, the voltage boost converter, and the electromechanical power conversion device. In general terms, it is necessary to obtain the best performance from each system component over a wide input power range. Currently, solar water pumps are used in the western United States as well as in many other countries or regions with abundant sunlight. Solar pumps have proven to be a cost effective and dependable method for providing water in situations where water resources are spread over long distances, power lines are few or non-existent, and fuel and maintenance costs are considerable.

Figure 5.8 Photovoltaic pumping systems

5.2.8 COMPARISON TO OTHER PUMPING SYSTEMS

There are other options for pumping water in remote areas and for other applications. Their advantages and disadvantages are listed in Table 5.1.
Table 5.1 Comparison of PV and other Pumping system

<table>
<thead>
<tr>
<th>Pump Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar</td>
<td>• Low maintenance</td>
<td>• Potentially high initial cost</td>
</tr>
<tr>
<td></td>
<td>• No fuel costs or spills</td>
<td>• Lower output in cloudy weather</td>
</tr>
<tr>
<td></td>
<td>• Easy to install</td>
<td>• Must have good sun exposure between 9AM to 3PM</td>
</tr>
<tr>
<td></td>
<td>• Simple and reliable</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Unattended operation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• System can be made to be mobile</td>
<td></td>
</tr>
<tr>
<td>Diesel or Gas</td>
<td>• Moderate capital costs</td>
<td>• Needs maintenance and replacement</td>
</tr>
<tr>
<td></td>
<td>• Can be portable</td>
<td>• Maintenance often inadequate reducing life</td>
</tr>
<tr>
<td></td>
<td>• Extensive experience available</td>
<td>• Fuel often expensive and supply intermittent</td>
</tr>
<tr>
<td></td>
<td>• Easy to install</td>
<td>• Noise, dirt and fume problem</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Site visits necessary</td>
</tr>
<tr>
<td>Windmill</td>
<td>• Potentially long-lasting</td>
<td>• High maintenance and costly repair</td>
</tr>
<tr>
<td></td>
<td>• Works well in windy site</td>
<td>• Difficult to find parts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Seasonal disadvantageous</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Need special tool for installation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• No wind No power</td>
</tr>
</tbody>
</table>

There are more than 10,000 solar powered water pumps in use in the world today. They are widely used on farms and outback stations in Australia to supply water to livestock. In developing countries they are used extensively to pump water from wells and rivers to villages for domestic consumption and irrigation of crops. A typical PV-powered pumping system consists of a PV array that powers an electric motor, which drives a pump. The water is often pumped from the ground or stream into a storage tank that provides a gravity feed. No energy storage is needed for these systems. PV powered pumping systems are widely
available from agricultural equipment suppliers and they are a cost-effective alternative to agricultural wind turbines for remote area water supply.

Photovoltaic pumping systems are used to pump water for livestock, plants or humans. Since the need for water is more on hot sunny days the technology is an obvious choice for this application. Pumping water using PV technology is simple, reliable, and requires almost no maintenance. Agricultural watering needs are usually more during sunnier periods when more water can be pumped with a solar system. PV powered pumping systems are excellent for small to medium scale pumping and there are thousands of agricultural PV water pumping systems in the field today throughout the world. PV powered water pumping systems are similar to any other pumping system, only the power source is solar energy. PV pumping systems have, as a minimum, a PV array, a motor, and a pump. PV water pumping arrays are fixed, mounted or sometimes placed on passive trackers (which use no motors) to increase pumping time and volume. AC and DC motors with centrifugal or displacement pumps are used with PV pumping systems. Assessment of the economic viability of PV pumping systems by IEA in comparison to diesel pumping systems indicate that, although the high investment cost of PV pumping systems is a major factor to slowed expansion of the market. But still the life cycle cost of PV is often less than diesel or petrol-powered pumps which are a challenging factor

**5.2.9 INTRODUCTION TO PUSH PULL CONVERTER**

Push-Pull type DC - DC converter is suitable to boost up the voltage from low to high voltage. This converter may be used in conjunction with a high frequency transformer to boost the output voltage with the advantage of providing isolation between the input and output stage. In this project a simple two switch push pull converter topology is used, which will step up a 12V DC voltage supply to the required output voltage. A 12V supply is used as the input supply. The high frequency transformer is known as the push pull transformer. This push pull transformer is usually the preferred choice in high power switching transformer applications exceeding one kilowatt. Power ratings for push pull transformer can vary from a fraction of a Watt to Kilowatt.
5.2.10 CIRCUIT DESCRIPTION OF PUSH PULL CONVERTER

The circuit diagram of the step up dc/dc converter is shown in Figure 5.9

![Circuit Diagram](image)

**Figure 5.9 Push-Pull converter**

With reference to the figure 5.11, when Q1 switch is on, current flows through the ‘upper’ half of ‘n’ primary and the magnetic field in ‘n’ expands. The expanding magnetic field in ‘n’ induces a voltage across ‘n’ secondary, the polarity is such that D1D2 is forward biased and D3D4 is reverse biased. D1D2 conducts and charges the output capacitor C.

When Q1 turns off, the magnetic field in ‘n’ collapses, and after a period of dead time, Q2 conducts, current flows through the ‘lower’ half of ‘n’ primary and the magnetic field in ‘n’ expands. Now the direction of the magnetic flux is opposite to that produced when Q1 is conducted. The expanding magnetic field induces a voltage across n’s secondary, the polarity is such that D3D4 is forward biased and D1D2 is reverse biased. D3D4 conducts and charges the output capacitor C. After a period of dead time, Q1 conducts and the cycle repeats.

There are two important considerations with the push pull converter:

- Both transistors must not conduct together, as this would effectively short circuit the supply, which means that the conduction time of each transistor must not exceed half of the total period for one complete cycle, otherwise conduction will overlap.
- The magnetic behavior of the circuit must be uniform, otherwise the transformer may saturate, and this would cause destruction of Q1 and Q2. This requires that the individual
conduction times of Q1 and Q2 be exactly equal and the two halves of the centre-tapped transformer primary be magnetically identical.

5.2.11 SELECTION OF MOTOR DRIVE SYSTEM

The selection criteria of electrical motors depend on the cost and compatibility at which the motors work. In this project the induction motor is chosen, as the AC motors are more advantageous than DC motors. The comparison of electrical motors and drawbacks with DC motors a listed in the Table 5.2. The most common and simple industrial motor is the three phase AC induction motor. The various aspects at which the three phase AC induction motor was selected is also listed.

**Table 5.2 Comparison of DC and AC drive system**

<table>
<thead>
<tr>
<th>DC MOTORS</th>
<th>AC MOTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>- The commutator and brushes makes the motor bulky, costly and heavy.</td>
<td>- Not bulky and heavy.</td>
</tr>
<tr>
<td>- Costly</td>
<td>- Expensive</td>
</tr>
<tr>
<td>- It requires frequent maintenance.</td>
<td>- Less maintenance</td>
</tr>
<tr>
<td>- Requires battery or inverter.</td>
<td>- They can be used in all locations, as the supply is AC.</td>
</tr>
</tbody>
</table>

**Simple Design**

The design of the AC motor is simple because, it has simply a series of three windings in the exterior (stator) section with a simple rotating section (rotor). The changing field caused by 50 or 60 Hertz AC line voltage causes the rotor to rotate around the axis of the motor.

The speed of the AC motor depends only on three variables:
The fixed number of winding sets (known as poles) built into the motor, which determines the motor’s base speed.

- The frequency of the AC line voltage. Variable speed drives change this frequency to change the speed of the motor.
- The amount of torque loading on the motor, which causes slip.

**Low Cost**

The AC motor has the advantage of being the lowest cost motor for applications. This is due to the simple design of the motor. For this reason, AC motors are overwhelmingly preferred for fixed speed applications in industrial applications and for commercial and domestic applications where AC line power can be easily attached. Over 90% of all motors are AC induction motors. They are found in air conditioners, washers, dryers, industrial machinery, fans, blowers, vacuum cleaners, and many, many other applications.

**Reliable Operation**

The simple design of the AC motor results in extremely reliable, low maintenance operation. Unlike the DC motor, there are no brushes to replace. If run in the appropriate environment for its enclosure, the AC motor needs new bearings after several years of operation. If the application is well designed, an AC motor may not need new bearings for more than a decade.

**5.2.12 SIMULINK MODEL OF PUSH PULL CONVERTER**

The push-pull converter has a push-pull inverter with transformer and Diode Bridge. Hence the push-pull inverter is simulated first and then the diode bridge is coupled to push-pull inverter.

**Simulation of Push-Pull Inverter**

The simulink model of push-pull inverter is shown in Figure 5.10. The MOSFETs, 1 and 2 do the inverting operation. MOSFETs are used as switches due to its high frequency operation and because of their fast switching speed; the switching losses can be small. Their
on-state resistance has a positive temperature coefficient, so MOSFETs are easily paralleled. This causes the device conducting the higher current to heat up and thus forces it to equitably share the current with the other MOSFETS in parallel. The three winding high frequency transformer ensures for the boost in voltage. This model converts the 12V DC to the required level of AC voltage.

**Figure 5.10 Simulink Model of push pull inverter**

**Output of Push-Pull Inverter**

The output voltage waveform of push-pull inverter is shown in Figure 5.11. It is inferred that an input of 12V DC is boosted to 230V AC.
The simulink model of push-pull converter is shown in Figure 5.12. A diode bridge rectifier is coupled to push-pull inverter with high frequency transformer set up to obtain the required DC level voltage from 12V DC input.
Figure 5.12 Simulink Model of push pull converter

Output of Push-Pull Converter

The output voltage waveform of push-pull converter is shown in Figure 5.13. It is observed that the 230V AC obtained at the output of high frequency transformer is rectified using diode bridge rectifier to approximately 400V DC.

Figure 5.13 Output Voltage Waveform of push-pull converter
Power measurement for Push-pull converter

The converters like buck, boost, buck-boost and cuk converters employs single transistor. Due to the current handling limitation of single transistor, the output power of these converters is small, typically tens of watts. In addition, there is no isolation between the input and output voltage, which is highly desirable criterion in most applications. The above drawbacks are overcome by using push-pull converters. The simulink model for power measurement of push pull converter is shown in Figure 5.14.

Figure 5.14 Simulink model for measurement of power in push-pull converter

It is seen that 51.48W of power is measured from the push-pull converter.

5.3 BOOST CONVERTER

The DC/DC converter boosts the photovoltaic panel voltage up to the value required to drive an off-the-shelf induction motor. This is needed to accommodate the requirement that relatively few photovoltaic panels be connected in series. The push–pull converter topology ensures galvanic isolation between input and output voltages, as well as provides the required voltage gain. The basic circuit diagram of the step-up converter is shown in Fig.2. The operation of this converter relies on the time intervals in which power switches qa and qb conduct. Fig. 3 shows a typical switching pattern for one period T. In this figure, D denotes the duty cycle defined by

\[ D = \frac{\text{Ton}}{\text{T}} \]  

(5.1)
Where $T_{on}$ corresponds to the total time interval that both switches conduct ($T_{on}=DT$). The output voltage ($E$) depends on the input voltage ($V$), the duty cycle ($D$), and the high-frequency transformer turns ratio ($n$), i.e.,

$$E = [n/1 - D] \ V$$

(5.2)

When designing a push–pull converter, it is convenient to select the transformer turns ratio $n$ such that duty cycle $D$ does not vary in a wide range. At the same time, high values for $n$ should be avoided to ensure that the pulse width modulation (PWM) voltage inverter operates with low modulation index.

**A. Push–Pull Gain**

Acting as an adjustable-ratio DC transformer, the DC/DC converter allows impedance matching between the panels and the motor drives the centrifugal pump. The choice of converter gain is most easily explained using an example. Consider the following:

1) The electrical load is a 230 V/50 Hz 0.5 hp induction motor;
2) The photovoltaic array is composed of ten 130 Wp panels arranged in a 2 (series) x 5 (parallel) layout; and
3) The losses are neglected. Fig. 4 shows the mechanical torque of the motor, the pump characteristic (upper plot), and the motor efficiency (lower plot) curves as functions of rotor (mechanical) speed. Assuming that the motor operates at a constant volt/hertz ratio, the operating points are determined by the intersection of the mechanical torque and load (pump) characteristic curves. Based on the power level demanded by the load, it is possible to determine the numerical values of the input and output push–pull voltages. For each operating point, therefore, it is possible to recover values for the motor line voltage to determine the minimum required DC-bus voltage, which corresponds to the push–pull output voltage. The push–pull input voltage is the MPPT panel array voltage. Thus given the motor output power, it is possible to numerically find the push–pull input voltage.

**5.4 SIMULATION RESULTS**

Push Pull inverter system alone is simulated as shown in figure 5.15. The output of the Push Pull inverter is stepped up using step up transformer. DC input voltage is shown in figure 5.16. Drive pulses for $M_1$ and $M_2$ are shown in figure 5.17. It is 24 volts. This voltage is stepped up to 220 volts as shown in figure 5.18.
Push Pull inverter based drive system is shown in figure 5.19. The transformer output is shown in figure 5.20. The rectifier output voltage is as shown in figure 5.21. The driving pulses for $M_1$, $M_2$ and $M_3$ are shown in figure 5.22. The phase voltage applied to the motor is shown in figure 5.23. The voltages are displaced by 120 degrees. The phase currents are shown in figure 5.24. The speed response is shown in figure 5.25. The speed increases and settles at 1460 rpm.

Figure 5.15 Push Pull DC to DC Converter
Figure 5.16 DC input voltage

Figure 5.17 Driving pulses for $M_1$ and $M_2$
Figure 5.18 Transformer primary voltages

Figure 5.19 Three Phase Inverter with Motor load
Figure 5.20 Transformer secondary voltage

Figure 5.21 Rectifier output voltage
Figure 5.22 Driving Pulses for $M_1$, $M_2$ and $M_3$

Figure 5.23 Phase Voltage waveforms
Figure 5.24 Phase Current Waveforms

Figure 5.25 Rotor Speed in RPM
5.5 EXPERIMENTAL RESULTS

The hardware of PV Powered Induction motor drive is fabricated and tested in the laboratory. The experimental set up of the hardware is shown in figure 5.26. This consists of inverter board, Push Pull board and control board. The hardware of control circuits alone is shown in figure 5.27. The hardware of Push Pull Converter is shown in figure 5.28. The Input voltage waveform of transformer is shown in figure 5.29. This consists of two MOSFETS. The switching pulses for the Push Pull Converter are shown in figure 5.30. The pulses are displaced by 180 degrees. The output of the Push Pull Converter is shown in figure 5.31. DC output of the rectifier is shown in figure 5.32. The phase voltage of the three phase inverter is shown in figure 5.33. The line voltage of three phase inverter is shown in figure 5.34.

![Figure 5.26 Hardware circuit](image-url)
Figure 5.27 Control circuit

Figure 5.28 Push pull converter
Figure 5.29 Input voltage waveform

Figure 5.30 Switching pulse for push pull converter
Figure 5.31 Output voltage of Push pull converter

Figure 5.32 Rectifier output voltage waveform
Figure 5.33 Phase voltage of three phase inverter

Figure 5.34 Line voltage of three phase inverter
5.6 CONCLUSION

This work has evaluated the strategy for utilization of PV Cells for induction motor pumping. The electricity bill gets reduced since solar energy is utilized for agriculture pumping. The Photo Voltaic powered three phase induction motor drive system is successfully designed, modelled and simulated using matlab simulink. The concept of Photo Voltaic pumping is proposed. The simulation and experimental results of three phase induction motor for Photo Voltaic pumping are presented. The simulation results are in line with the theoretical results. The scope of this work is the simulation and implementation of three phase PV Powered Induction motor drive system. The experimental results are similar to the simulation results.