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Speed Control of PV Based Three Phase Induction Motor used for Water Pumping System

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Abstract:
This thesis demonstrates a pumping system powered from Photovoltaic array. A low voltage DC is stepped by using DC to DC Push -Pull converter. DC output from the PV Cell is converted into high frequency DC using a Push Pull Inverter. This is stepped up using a high frequency steps up transformer. The modified MPPT (P&O) algorithm is used to increase the pulse with of the circuit. The output of step up transformer is rectified using an uncontrolled rectifier. The DC output is converted into three phase AC using inverter with voltage control controller. This drive has advantageous like utilization of nonconventional energy and improved efficiency.

Keywords: *Boost converter, Inverter, MPPT algorithm, Pumps, PV module, Speed Control, Three Phase Induction Motor, Three phase rectifier, Voltage Controller*

1. Introduction

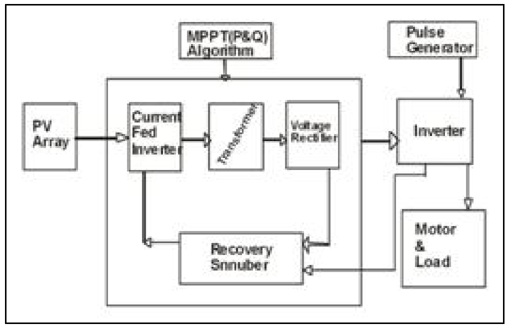
In the PV system based operation batteries allow the system to always operate at its rated power even in temporary conditions of low solar radiation. This facilitates the coupling of the electric dynamics of the solar panel and the motor used for pumping. DC motors have low efficiency and high maintenance cost and is not suitable for the premises of the project. For such applications this paper proposes the use of a three phase induction motor, due to its high degree of robustness, low cost, higher efficiency and lower maintenance cost compared to other types of motors.

The design of a motor drive system powered directly from a photovoltaic source demands creative solutions to face the challenge of operating under variable power restrictions and still maximizes the energy produced by the module and the amount of pumped water. These requirements make necessary the use of a converter with the following features:

- High efficiency – due to the low energy available;
- Low cost – to enable its deployment where it is most needed;
- Autonomous operation – no specific training needed to operate the system;
- Robustness – the minimum amount of maintenance as possible; and
- High life span – comparable to the 15 years of usable life of a PV panel.

2. Existing and proposed systems

2.1. Block Diagram Of Existing System



The block Presents an overview of the existing system. The energy produced by the panel is fed to the motor trough a converter with two power stages:

- DC/DC stage to boost the voltage of the panels and
- DC/AC three-phase inverter to convert the DC voltage to three phase AC voltage set.

The inverter is based on a classical topology (three legs, two switches/leg) and uses a sinusoidal PWM (SPWM) this paper proposes the use of a modified two inductor boost converter (TIBC) for the first stage of photovoltaic water pumping systems due to its very small number of components, simplicity, high efficiency and easy transformer flux balance. These features make it the ideal choice for achieving the system's necessary characteristics. Besides the high DC voltage gain of the TIBC, it also compares favourably with other current-fed converters concerning switch voltage stress, conduction losses and transformer utilization.

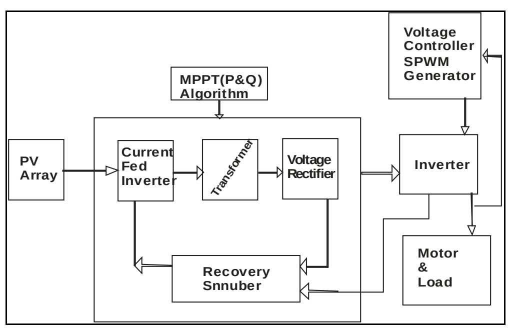
In addition, the input current is distributed through the two boost inductors having its current ripple amplitude halved and twice the PWM frequency. This last feature minimizes the oscillations at the module operation point and makes it easier to achieve the maximum power point(MPP).

2.2. Drawbacks

The main drawback of MPPT is that there is no regulation on output while it is tracking a Maximum power point. It cannot regulate both input and output at the same time. The example of load matching is elaborated here to show how the output voltage and current change with varying irradiation.

- Cannot get the exact pulse width for an regular interval
- No need for KPKI values

2.3. Block Diagram Of Proposed System



In this induction motor (IM) associated to a photovoltaic water pumping system in order to produce the required load power. A boost converter is used in the control scheme to adapt the DC voltage required to extract maximum power from PV system at any value of solar irradiance and load variations. Solar irradiance depends on whether conditions.The Push pull converter helps in boosting the voltage maximum up to three to four times from the PV system. The thus produced DC voltage is then converted to three phase AC voltage

With the help of the inverter which is pulsed with Voltage controller, thus maintaining constant speed of the motor in turn the flow of the pump is maintained. Thus the system is low cost and highly efficient.

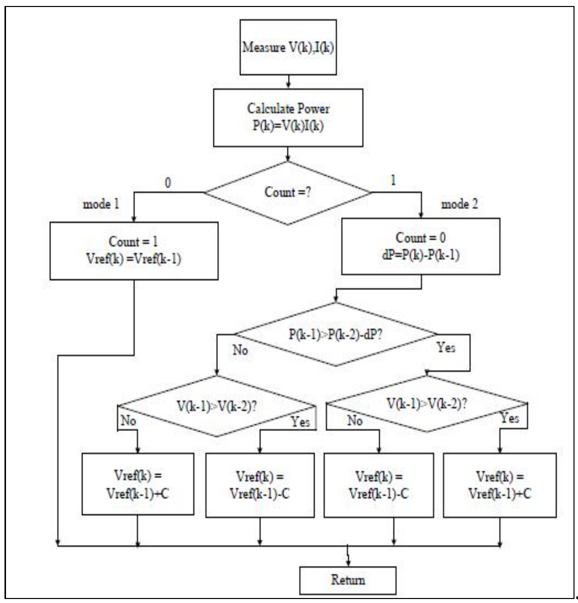
2.4. PV System

PV Modules collect solar radiation from the sun and actively convert that energy to electricity. are comprised of several individual solar cells and function similarly to large semiconductors and utilize a large-area p-n junction diode. When the solar cells are exposed to sunlight, the p-n junction diodes convert the energy from sunlight into usable electrical energy.

The energy generated from photons striking the surface of the allows electrons to be knocked out of their orbits and released, and electric fields in the solar cells pull these free electrons in a directional current (D.C.), from which metal contacts in the solar cell can generate electricity. The more solar cells in a PV Module and the higher the quality, the more total electrical output the PV Module can produce. The conversion of sunlight to usable electrical energy is otherwise known as the Photovoltaic Effect. The photovoltaic effect arises from the properties of the p-n junction diode, as such there are no moving parts in a Factors that affect the output of are weather conditions, shade caused by obstructions to direct sunlight, and the angle and position at which the PV Module is installed. PV Modules delivers the best output when placed in direct sunlight, away from obstructions that might cast shade, and in areas with high regional solar insolation ratings. PV Module efficiency can be optimized by using dynamic mounts that follow the position of the sun in the sky and rotate the PV Module to get the maximum amount of direct exposure during the day as possible.

2.5. Modified Perturb And Observe

The P&O method implements a hill climbing technique, which works well in slow changing environment but has some limitations under rapidly changing atmospheric conditions. The methods may lead to incorrect or slow maximum power point tracking. To overcome such problems the MP&O method, isolates the fluctuations caused by the perturbation process from those caused by the irradiance or weather change



This method adds an irradiance-changing estimate process in every perturb process to measure the amount of power change caused by the change of atmospheric condition. Because the estimate process stops tracking maximum power point by keeping the PV voltage constant, the tracking speed of MP&O method is only half of the conventional P&O method.

2.6. Features Of PV System

- High quality solar cells - Polycrystalline & Monocrystalline.
- Modules ranging from 35 Wp to 300 Wp
- Strong aluminium alloy frame, tempered glass and water proof lamination result in rugged protection against
- Hostile conditions & withstand high levels of ultra violet radiation & moisture.
- Juntion box with IP 65 protection.
- IEC 61215 certified Solar PV Modules.
- Bypass diodes to avoid partial shading.

2.7. PV Module Descriptions

Power (P max)	**90 W**
Max.Power voltage(Vmax)	35.2 v
Max.Current(Imp)	2.56 A
Open circuit voltage(Voc)	44.0V
Short circuit current(Isc)	2.74A
Max. System Voltage	600V
Series fuse rating	10A

Temperature co-efficient voltage	-60.8 mV/c
Temperature co-efficient current	2.2A/c
Cell efficiency	15.80%
Number of cells	72
Max Power tolerance	5%
Dimensions	1020*670*35
Weight	9.5 kg

3. DC/DC Converter

The DC-DC boost converter is used for voltage step-up applications, and in this case this converter will be operated at extremely high duty ratio to achieve high step-up voltage gain. However, the voltage gain and the efficiency are limited due to the constraining effect of power switches, diodes, and the equivalent series resistance (ESR) of inductors and capacitors.

Moreover, the extremely high duty-ratio operation will result in a serious reverse-recovery problem. Some literatures have researched the high step-up DC-DC converters that do not incur an extremely high duty ratio .

The transformer less DC-DC converters, such as the cascade boost type ,the quadratic boost type the switched-inductor type , the voltage-lift type ,the voltage doubler technique the capacitor-diode voltage multiplier and the boost type that is integrated using a switched-capacitor technique .

4. Three Phase Voltage-Fed PWM Inverters

Three phase voltage-fed PWM inverters are recently showing growing popularity for multi-megawatt industrial drive applications. The main reasons for this popularity are easy sharing of large voltage between the series devices and the improvement of the harmonic quality at the output as compared to a two level inverter. In the lower end of power, GTO devices are being replaced by IGBTs because of their rapid evolution in voltage and current ratings and higher switching frequency. The Space Vector Pulse Width Modulation of a three level inverter provides the additional advantage of superior harmonic quality and larger under-modulation range that extends the modulation factor to 90.7% from the traditional value of 78.5% in Sinusoidal Pulse Width Modulation.

An adjustable speed drive (ASD) is a device used to provide continuous range process speed control (as compared to discrete speed control as in gearboxes or multi-speed motors). An ASD is capable of adjusting both speed and torque from an induction or synchronous motor. An electric ASD is an electrical system used to control motor speed. ASDs may be referred to by a variety of names, such as variable speed drives, adjustable frequency drives or variable frequency inverters. The latter two terms will only be used to refer to certain AC systems, as is often the practice, although some DC drives are also based on the principle of adjustable frequency.

4.1. Three Phase Voltage Source Inverters

Single-phase VSIs cover low-range power applications and three-phase VSIs cover the medium- to high-power applications. The main purpose of these topologies is to provide a three-phase voltage source, where the amplitude, phase, and frequency of the voltages should always be controllable. Although most of the applications require sinusoidal voltage waveforms (e.g., ASDs, UPSs, FACTS, VAR compensators), arbitrary voltages are also required in some emerging applications (e.g., active filters, voltage compensators).

The standard three-phase VSI topology is shown in Fig. 4 and the eight valid switch states are given in Table 3. As in single-phase VSIs, the switches of any leg of the inverter (S1 and S4, S3 and S6, or S5 and S2) cannot be switched on simultaneously because this would result in a short circuit across the dc link voltage supply. Similarly, in order to avoid undefined states in the VSI, and thus undefined ac output line voltages, the switches of any leg of the inverter cannot be switched off simultaneously as this will result in voltages that will depend upon the respective line current polarity. Of the eight valid states, two of them (7 and 8 in Table) produce zero ac line voltages. In this case, the ac line currents freewheel through either the upper or lower components. The remaining states (1 to 6 in Table) produce non-zero ac output voltages. In order to generate a given voltage waveform, the inverter moves from one state to another. Thus the resulting ac output line voltages consist of discrete values of voltages that are Vi , 0, and -Vi for the topology shown in figure. The selection of the states in order to generate the given waveform is done by the modulating technique that should ensure the use of only the valid states.

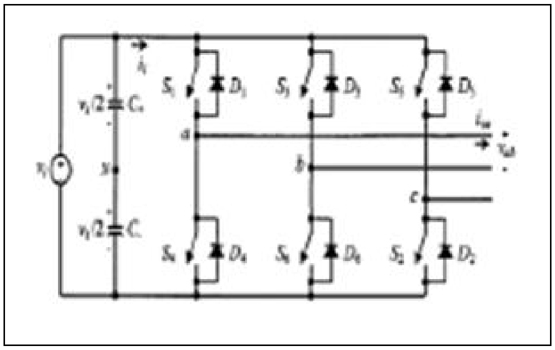


Fig: Three phase VSI topology

STATE ON	STATE OFF	STATE	VAB	VB	VA	SPACE VECTOR
1,2,6	4,5,3	1	V	0	-V	V1=1+J0.5
2,3,1	5,6,4	2	0	V	-V	V2=J1.155
3,4,2	6,1,5	3	-V	V	0	V3=-1+J0.5
4,5,3	1,2,6	4	0	0	V	V4=-1-J0.5
5,6,4	2,3,1	5	V	-V	V	V5=-J1.115
6,1,5	3,4,2	6	0	-V	0	V6=1-J0.5
1,3,5	4,6,2	7	0	0	0	V7=0
4,6,2	1,3,5	8	0	0	0	V8=0

Table: Switch states for three phase VSI

5. Solar Pumping System

DC Solar Pumps are available with both Screw & Centrifugal impellers suitable for different head and flow ranges. The Submersible Solar Pumps are powered by C.R.I. Oil filled motors and the Surface Pumps are coupled to specially designed motors. With regard to AC Pumps, C.R.I. Solar Pump Controller is used to convert DC Power generated by PV modules to 3Phase AC Power and drive these pumps.

5.1. Applications

These solar pump controllers are used to operate regular AC pumps using solar power in various places as listed below

- Residential
- Irrigation
- Live stock farms
- Public water supply
- Small farms
- De-watering
- Industries , etc.,

5.2. Three Phase Induction Motor

A 3-phase induction motor is theoretically self-starting. The stator of an induction motor consists of 3-phase windings, which when connected to a 3-phase supply creates a rotating magnetic field. This will link and cut the rotor conductors which in turn will induce a current in the rotor conductors and create a rotor magnetic field.

Motor Type	Oill filled motor
Maximum outer diameter	3"(78mm) & 4" (96mm)
Power Range	0.37 kW to 1.0 kW
Speed	2900 rpm
Versions	DC/AC, 1/0.5 Ph, 230V-50Hz
Type of Duty	S1(continuous)
Degree of Protection	IP 58
Class of Insulation	Y
Minimum Cooling Flow	0.15m/s
Max. outer Diameter	3" (80 mm) & 4"(101 mm)
Power Range	0.37 kW to 1.0 kW
Speed	2900 rpm
Discharge Range	upto 7.2 m^3/h
Head Range	upto 130 m
Max. Liquid Temparature	33 deg C
Permissible amount of sand (max)	3" - 25 g/m^3 , 4" 50 g/m^3
Allowable Solids	3000 ppm
Turbidity	50 ppm SIlica scale

Table: Motor descriptions

5.3. Features

- More longevity & Hygiene
- High operating efficiency
- floating impeller design prevents sand blockages
- Easy to dismantle & repair
- Rigid construction
- Highly durable
- can handle more upthrust loads
- NEMA mounting standard [4"]

6. Submersible Pumps

A submersible pump or electric submersible pump (ESP)) is a device which has a hermetically sealed motor close-coupled to the pump body. The whole assembly is submerged in the fluid to be pumped. The main advantage of this type of pump is that it prevents pump cavitation, a problem associated with a high elevation difference between pump and the fluid surface.

Power range	0.37kW – 5.5 kW (0.5HP – 7.5HP)
Speed	2880 rpm
Version	Single Phase, 200 – 240V, Three Phase, 380 – 415V, 50 Hz, A.C. Supply
Maximum total head	395 metre (39.5 bar)
Maximum flow rate	18000 LPH (18 M3 / Hr)
Maximum outer diameter in mm	97 & 98.
Nominal outlet size in inches	1 ¼, 1 ½, 2 & 2 ½
Degree of Protection	IP 58.
Direction of Rotation	Clockwise from driving end.
Thrust Load	1500 lbs.
Minimum cooling flow along the motor	0.15 m/sec
Type of duty	S1 (Continuous)
Method of starting	Direct on Line, Capacitor Start Capacitor Run (CSCR) / Permanent split Capacitor (CSR)
Maximum starts per hour	12 times.

Table: Pump specifications

6.1. Features

- Fitted with imported motor protector in single phase motors
- Silver brazed rotor
- 29 Feet head per stage in specific models
- High operating efficiency
- Extremely hardwearing water lubricated thrust bearings
- Designed for extensive voltage fluctuations
- Can be easily dismantled and repaired

Submersible pumps are found in many applications. Single stage pumps are used for drainage, sewage pumping, general industrial pumping and slurry pumping. They are also popular with pond filters. Multiple stage submersible pumps are typically lowered down a borehole and used for water abstraction, water wells and in oil wells.

Submersible pumps are used in applications, including sewage treatment plants, seawater handling, groundwater pumping, fire fighting (since it is flame retardant cable), bore hole drilling and pumping, water well and deep well drilling, offshore drilling rigs, artificial lifts, mine dewatering, irrigation systems, and water supply systems.

7. Simulations and Results

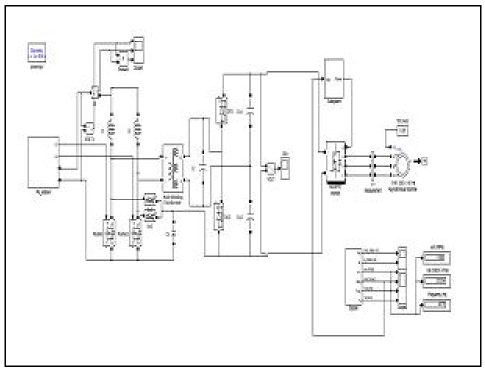


Figure 7.1: Mat Lab Simulink Diagram

7.2.1 Irradiance

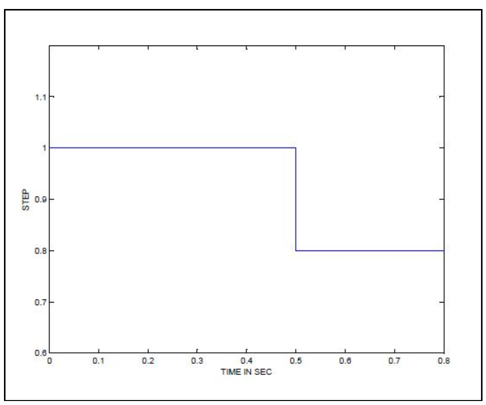


Figure 7.2: Irradiance on the PV module

The sample steps of irradiance for the PV cell are plotted verses of Time in seconds. The above specification are at standard test condition at - 25°C cell temperature & 1000 W / m² irradiance.

7.2.2 PV Current

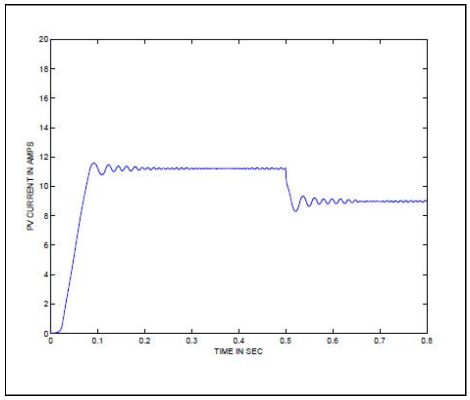


Figure 7.3: PV current vs Time

The graph is plotted for the PV current in amps against the time in seconds.

7.2.3. PV Voltage

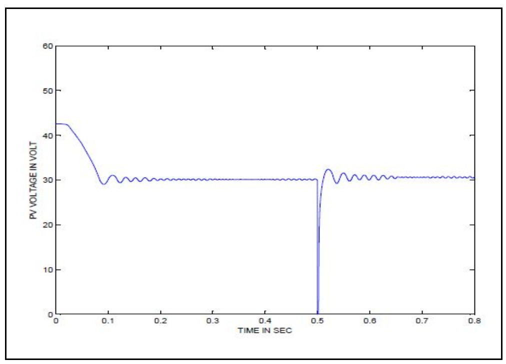


Figure 7.4: PV voltage vs Time

The graph is plotted for the PV Voltage in Volts against the time in seconds.

7.2.4. PV Power

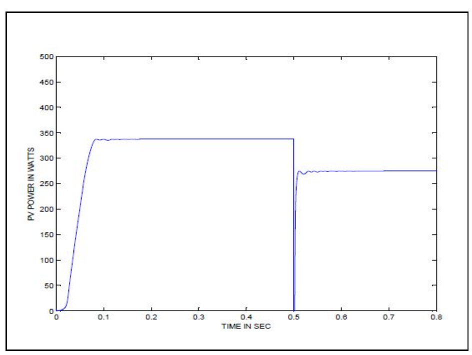


Figure 7.5: PV power vs Time

The graph is plotted for the PV power in Watts against the time in seconds.

7.2.5. VDC

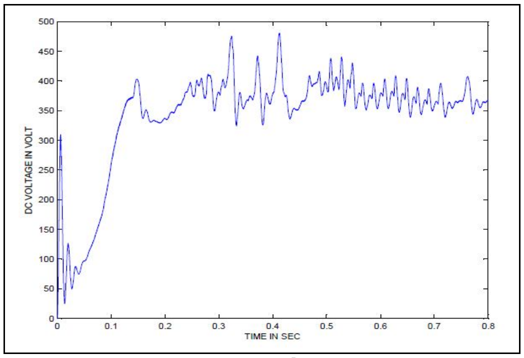


Figure 7.6: VDC in volts vs Time in Sec

The graph is plotted for the DC Voltage in volts against the time in seconds.

7.2.6. Frequency of Motor

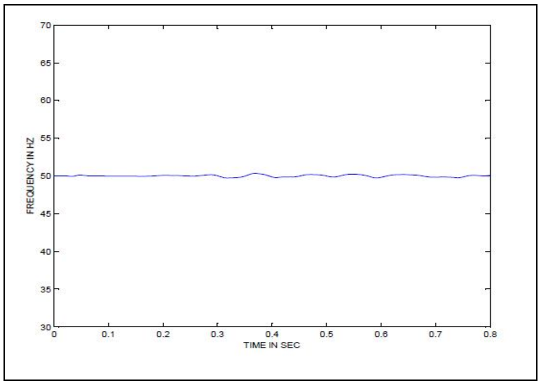


Figure 7.7: Frequency of the Motor

The graph is plotted for the frequency of the motor in Hz against the time in seconds.

7.2.7. RMS Phase Voltage

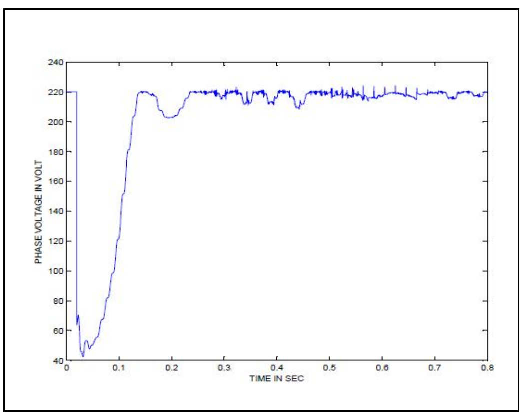


Figure 7.8: RMS phase voltage

The graph is plotted for the RMS phase voltage in volts against the time in seconds.

7.2.8. Motor Speed

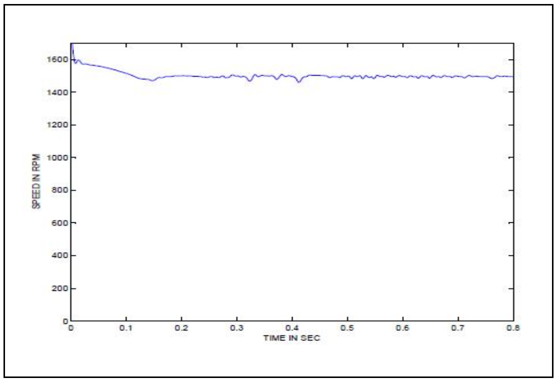


Figure 7.9: Speed of the Motor

The graph is plotted for the Speed of the motor in RPM against the time in seconds.

7.2.9. Motor Torque

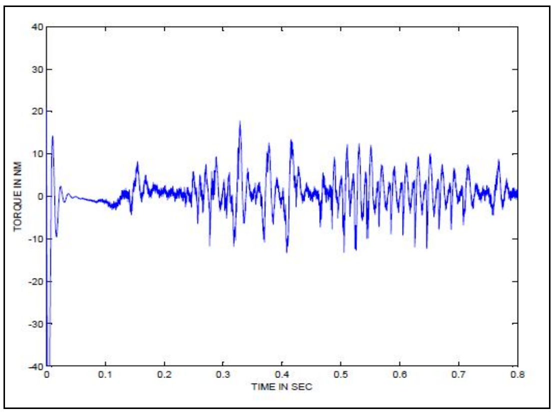


Figure 7.10: Torque of the Motor

The graph is plotted for the Torque of the motor against the time in seconds.

7.3. Practical Results Of Existing System

The below table shows the practical results obtained from the existing system. The speed of the motor and the water flow is noted for the respective DC voltage produced from the source.

DC Line Voltage Volts	AC Line Voltage Volts	Current Amps	Speed RPM	Flow LPS
326	400	14.2	2880	9.15
340	416	14.76	2995	9.5
365	447	15.86	3218	10.22
394	482	17.11	3470	11.02
409	500	17.78	3609	11.46

Table 7.1: Existing system

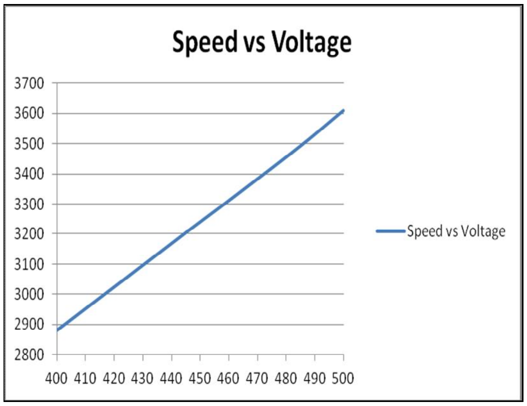


Figure 7.11: Existing System Model graph

7.4. Practical Results of Proposed System

The below table shows the practical results obtained from the Proposed system. The speed of the motor and the water flow is noted for the respective DC voltage produced from the source.

DC Line Voltage volts	AC Line Voltage volts	Current Amps	Speed RPM	Flow LPS
350	400	14.2	2880	9.15
380	401	14.2	2886	9.15
390	401	14.2	2889	9.15
400	402	14.2	2892	9.15
410	402	14.2	2894	9.15

Table 7.2: Proposed system

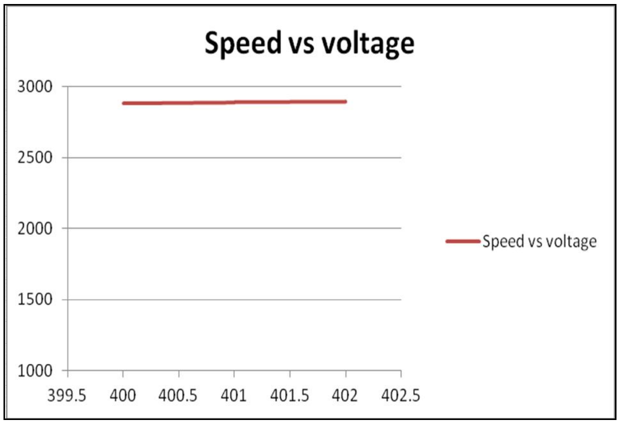


Figure 7.12: Proposed System Model graph

8. 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, modeled 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 designed under low cost compared with the DC PV pumping system.

8.1. Future Scope

In further with the same research the PV Pump set can be distributed with a battery in connection to store the excess power produced in the system. Moreover the Push pull converter can be replaced with a Boost Inverter so that, the losses caused by the inverter and the Converter can be reduced into one in the future.

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