MODELING AND SIMULATION OF MPPT CONTROLLER FOR SOLAR WATER PUMPING SYSTEM

A thesis submitted in partial fulfillment of the requirements for
the award of the degree of

Bachelor of Technology

in

Electrical and Electronics Engineering

By

ANAND P RAJ (EE19B1005)

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

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BONAFIDE CERTIFICATE

This is to certify that the project titled

MODELING AND SIMULATION OF MPPT CONTROLLER FOR SOLAR WATER PUMPING SYSTEM

is a bonafide record of the **EE401 Project Phase II** work done by

ANAND P RAJ (EE19B1005)

in partial fulfillment of the requirements for the award of the degree of **Bachelor Of Technology** in **Electrical And Electronics Engineering of** the **NATIONAL INSTITUTE OF TECHNOLOGY PUDUCHERRY,** during the year 2022-23.

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Project viva-voice held on ______________________

Internal Examiner

External Examiner

ABSTRACT

This paper presents a photovoltaic system for water pumping. The water pumping system consists of a PV array, a Voltage Source Inverter (VSI) and 3 phase induction motor that drives the centrifugal pump. For the purpose of improving the efficiency of the overall system, the incremental conductance algorithm based Maximum Power Point Tracker (MPPT) and Field Oriented Control scheme is applied to control the single stage of VSI fed three phase induction motor. An incremental conductance method is used for extraction of maximum power and the vector control is used to drive the motor which provides smooth startup and reduction of the starting current. The proposed system could be employed in agricultural irrigation under any operating condition of varying natures of solar irradiances and temperatures. Simulation results MATLAB/SIMULINK show that the performance of the PV pumping system is transient as well as in steady state is quite satisfactory.

ACKNOWLEDGEMENT

This project consumed a huge amount of work, research and dedication. Still, implementation would not have been possible if we did not have the support of many individuals. Therefore, we would like to extend our sincere gratitude to all of them.

I am grateful to **Dr. Venkadesan A**, Head of the Department (i/c), Electrical and Electronics Engineering and also our supervisor for his provision of expertise, and technical support in the implementation. The success of this project wouldn't have been possible without his support. His guidance, encouragement, suggestion and very constructive criticism have contributed immensely to the evolution of our idea on the topic and without his this work would not have been possible.

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Nevertheless, I express my gratitude towards my family and colleagues who kept us on track and provided hours of entertainment and stimulating conversation.

CONTENTS

LIST OF SYMBOLS

Iph	Photocurrent
Ish	Current across shunt resistance
Is	Diode Saturation Current
q	electron charge (1.6×10^{-19}C)
k	Boltzmann Constant (1.38×10^{-23} J/K)
A	Ideality factor
Tc	Actual cell temperature (°C)
Rs	cell series resistance
Rsh	cell shunt resistance
I_{PV}	Current in PV array
V_{PV}	Voltage in PV array
P_{PV}	Power in PV array
I_{sq}, I_{sq}*	Torque component of current vector and its reference value
I_{sd}, I_{sd}*	Flux component of current vector and its reference value
Te*	Reference Torque
Kp, Ki	Proportional and Integral gains of the PI controller
Lr	Rotor Inductance
Lm	Mutual Inductance
ϕr, $\phi r*$	Estimated rotor flux and its reference
Tr	Rotor Time constant
θe	Rotor Field angle
ω_m	Rotor speed
ω_{sl}	Slip frequency

LIST OF ACRONYMS

MPPT – Maximum Power Point Tracking

PV – Photo-Voltaic

IM – Induction Motor

FOC – Field Oriented Control

SVPWM – Space Vector Pulse Width Modulation

VSI – Voltage Source Inverter

PWM – Pulse Width Modulation

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

In order to meet human needs, safeguard health, ensure food production, energy, and ecosystem restoration, as well as for social and economic development and sustainable growth , water resources are vital . However, it has been estimated that two billion people are affected by water shortages in more than forty countries, and 1.1 billion do not have access to enough drinkable water, in accordance with the UN World Water Development Report from 2003 . Environmentally responsible technology must be made available immediately for the purpose of providing drinking water. Systems for remote water pumping are crucial in addressing this need. Additionally, it will be the first phase of the desalination and purification plants that will create potable water.

1.2 OBJECTIVE OF THESIS

The most important design constraints for this system are: efficiency and maximum power point tracking efficiency. The objective of this project is to find a solution for the minimization of power losses. To achieve a satisfying efficiency, a simple current mode control loop in a two-dimensional frame is implemented with Field Oriented Control (FOC) and Space Vector Pulse Width Modulation (SVPWM) in the solar connected three phase inverter. For tracking the maximum point on the power curve of the solar cell, a single MPPT plus speed control method is to be improved and integrated into the system. For simulations, Matlab Simulink software was used and input power versus output power was examined.

1.3 SCOPE

Power electronics has many uses, including MPPT, which is a relatively new and unexplored field. There isn't any textbook that covers MPPT in depth and in detail. A thorough understanding of PV behaviors is required in order to comprehend and design MPPT. The PV cell and module MATLAB models used in the thesis make it easier. The PV water pumping system's individual components are all modeled for MATLAB simulations. The operation of MPPT for water pumping systems is validated and verified at the end.

The theoretical analysis and simulations of a PV water pumping system with MPPT are the only ones covered in this thesis. This thesis will not construct the system; that is left for subsequent work. However, the model ought to deliver adequate outcomes for MPPT functionality verification.

1.4 APPROACH AND METHODOLOGY

The system mainly consists of a solar PV array connected directly to a three phase PWM inverter. A simple MPPT algorithm along with Field Oriented Control (FOC) and Space Vector Pulse Width Modulation are implemented into the inverter to ensure maximum performance. The abc to dq conversion technique is used, which simplifies the problem of controlling the inverter and makes possible power control also. In the dq-frame, in steady state, the signals are assumed to be DC waveforms, which permit the usage of simpler structure. The inverter is then connected to a three phase induction motor which further drives the pump

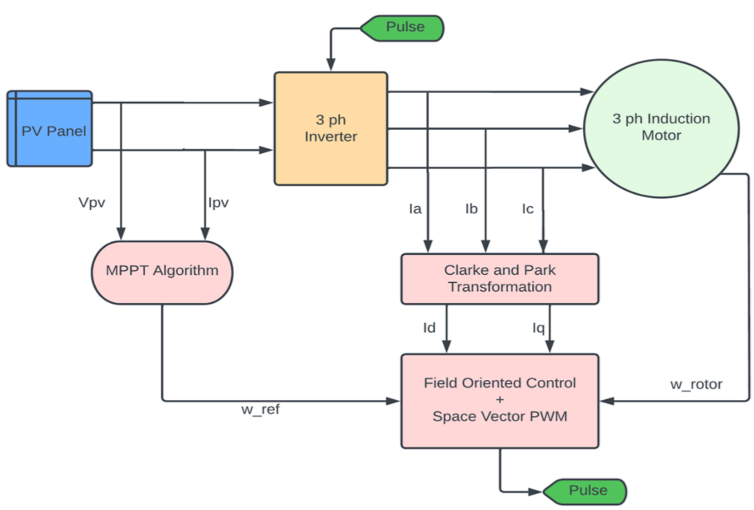

Fig 1 : Block Diagram of the proposed system

CHAPTER 2

LITERATURE SURVEY

In **[1]**, the system employs the maximum power point tracker (MPPT). MATLAB simulations perform comparative tests of two popular MPPT algorithms using actual irradiance data. It employs SIMULINK to model a DC pump motor, and the model is transferred into MATLAB. Then, MATLAB simulations verify the system and functionality of MPPT.

In **[2]**, the performance of a solar water pumping system is discussed in this paper, The system consists of a photovoltaic PV array, a PMDC motor and a helical rotor pump. The operation of the PV array is analyzed using Matlab .The efficiency of the system is improved with a maximum power point tracker and a sun-tracker.

In **[3]**, a stand alone photovoltaic water pump is proposed. The system is realized using two sensors and employs two conversions for the implementation of the solar water pump. The pump is run by an induction motor and the speed control is achieved through V/F control. The feasibility of the system is verified through simulation.

In **[4]**, this Paper deals with the design and simulation of a simple but efficient photovoltaic water pumping system. It provides theoretical studies of photovoltaic and modeling techniques using equivalent electric circuits. The system employs the maximum power point tracker (MPPT). The investigation includes discussion of various MPPT algorithms and control methods.

CHAPTER 3

MODELING OF AN MPPT CONTROLLED SOLAR WATER PUMPING SYSTEM

3.1 GENERAL INTRODUCTION

3.1.1 PV ARRAY MODELING AND CHARACTERISTICS

The photo-voltaic effect of semiconductor PN junctions is the fundamental operating mechanism of the PV array. A DC current is produced when it is exposed to light, and this current varies linearly with solar irradiation. The analogous electrical circuit based on single diode mode can be used to describe the complicated physics of a PV module, which is shown in Fig 2.

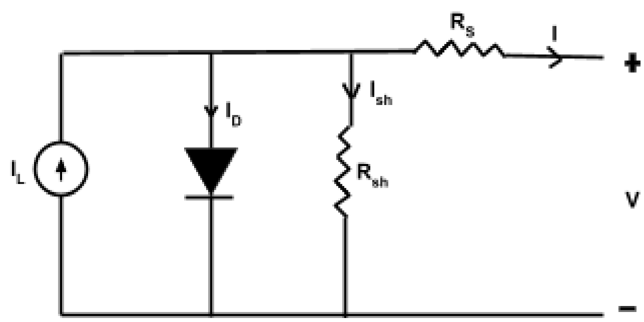

Fig 2: Equivalent Circuit of a PV Solar Cell

Applying node equations in which I_L, R_s, and R_{sh} are meeting together. The current equation is given as:

$$I= I_{ph} + I_S\left[\exp\frac{q(\ V+\ IR_S)}{KT_CA} - 1\right] - \frac{V+IR_s}{R_{sh}}$$

—- Eq 1

where Iph is the photocurrent (light generated current), I_{sh} is the current across the shunt resistance, I is the output current of the PV cell, I_s is the diode saturation current, q is the electron charge (1.6×10^{-19} C), K is the Boltzmann constant (1.38×10^{-23} J/K), A is the ideality factor of the diode (from 1 to 2), Tc is the actual cell temperature (°C), R_s is the cell series resistance (Ohm), and R_{sh} is the cell shunt resistance (Ohm).

Table 1: SOLAR ARRAY SPECIFICATIONS

Peak Power (W)	213.15 W
Open Circuit Voltage (V)	36.3 V
Short Circuit Current (A)	7.84 A
Max. Power Voltage (V)	29 V
Max. Power Current (A)	7.35 A

The model $I_{PV} - V_{PV}$ and $P_{PV} - V_{PV}$ characteristics curves under different irradiances are given in Figure 3 at 25 °C.

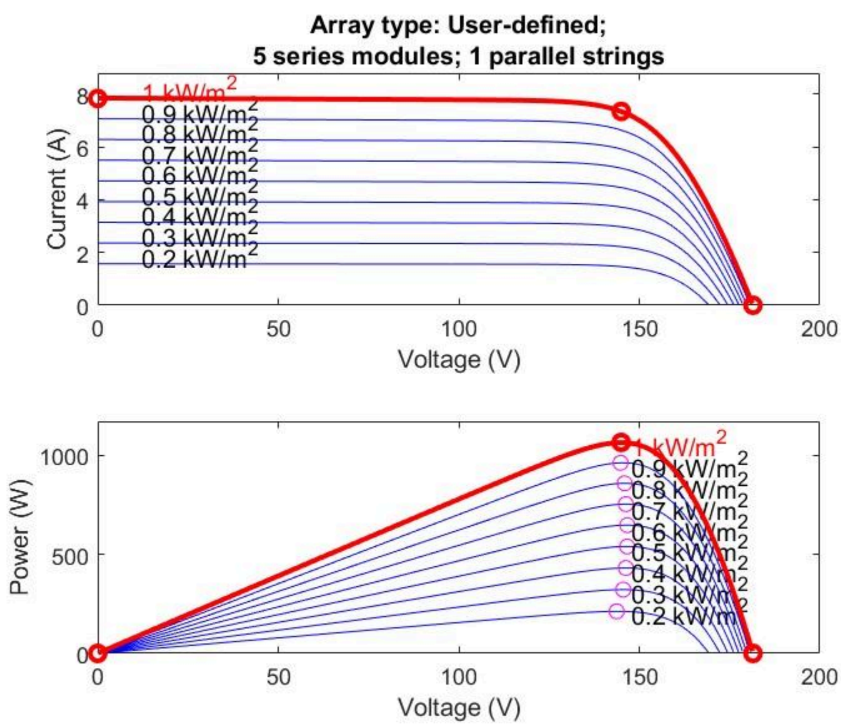

Fig 3: $I_{PV} - V_{PV}$ and $P_{PV} - V_{PV}$ characteristics curves

3.2 ALGORITHM/FLOWCHART

3.2.1 FIELD ORIENTED CONTROL (FOC)

The field oriented control consists of controlling the stator currents represented by a vector. This control is based on projections that transform a three phase time and speed dependent system into a two coordinate (d and q frame) time invariant system. These transformations and projections lead to a structure similar to that of a DC machine control. FOC machines need two constants as input references: the torque component (aligned with the q coordinate) and the flux component (aligned with d coordinate).

This current space vector represents the three phase sinusoidal system. It needs to be transformed into a two time invariant coordinate system. This transformation can be divided into two steps:

- (a, b, c) → (α, β) (the Clarke transformation), which gives outputs of two coordinate time variant systems.

- (a, β) → (d, q) (the Park transformation), which gives outputs of two coordinate time invariant systems.

The (a, b, c) → (α, β) Projection (Clarke transformation)

Three-phase quantities either voltages or currents, varying in time along the axes a, b, and c can be mathematically transformed into two-phase voltages or currents, varying in time along the axes α and β by the following transformation matrix:

$$i_{\alpha\beta o} = 2/3 * \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

But these two phase (α, β) currents still depend upon time and speed.

The (α, β) → (d.q) projection (Park transformation)

This is the most important transformation in the FOC. In fact, this projection modifies the two phase fixed orthogonal system (α, β) into d, q rotating reference system. The transformation matrix is given below:

$$i_{dqo} = 2/3 * \begin{bmatrix} cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

Where, θ is the angle between the rotating and fixed coordinate system.

The torque and flux components of the current vector are determined by the following equations:

$$i_{sq} = i_{s\alpha}\sin\theta + i_{s\beta}\cos\theta$$
$$i_{sd} = i_{s\alpha}\cos\theta + i_{s\beta}\sin\theta$$

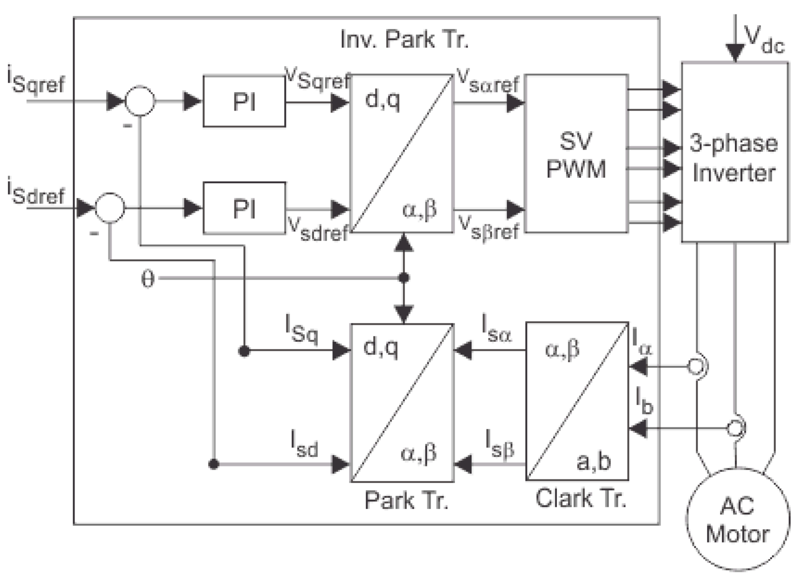

Fig 4: Simplified FOC Block Diagram

With the use of the field-oriented control scheme, the induction motor can compete with the DC motor in high-performance applications. This is achieved by decoupling the three phase winding into two windings (90 degrees apart) so as to facilitate independent control of torque and flux. The motor speed wm is compared to the reference wref and the error is processed by the PI speed controller which minimizes the error and produce the reference torque command Te*. The actual speed can be measured by using a speed sensor (tacho-generator) or can be estimated from sensorless algorithms. The reference torque Te* which is the output of PI controller is given by:

$$Te^{*} = Kp.e + Ki.\int e.dt$$

Where Kp, Ki are proportional and integral gains of the PI controller respectively. The stator quadrature-axis current reference Iqs* which corresponding to the torque can be calculated from the torque reference Te* as:

$$Iqs^{*} = \frac{4 \times Lr \times Te^{*}}{3 \times P \times Lm \times \phi r}$$

Where Lr is the rotor inductance, P is the number of star poles, Lm is the mutual inductance and ϕr is the estimated rotor flux linkage given by:

$$\phi r = \frac{Lm \times Ids}{1 + Tr\,.\,s}$$

Where $Tr = \frac{Lr}{Rr}$ is the rotor time constant, Rr is rotor resistance and Ids is the current command referred to the rotating d axis.

The stator direct-axis current reference Ids* which corresponding to the stator input flux is obtained from rotor flux reference input ϕr^{*} given by:

$$Ids^{*} = \frac{\phi r^{*}}{Lm}$$

At speeds higher than the rated synchronous speed of the IM field weakening technique is used where Iqs* increases and flux needs to be reduced in order to reduce the stator current thereby reducing the stress on the motor winding. The rotor-field angle θe required for coordinates transformation can be found by integrating the sum of the rotor speed wm and slip frequency wsl given by:

$$\theta e = \int (\omega_m + \omega_{sl}).\, dt$$

The slip frequency is calculated from the current command referred to the rotating q axis Iqs and the motor parameters

$$\omega_{sl} = \frac{L_m \times R_r \times I_{qs}}{\omega_r \times l_r}$$

3.2.2 SPACE VECTOR PULSE WIDTH MODULATION (SVPWM)

Space vector PWM is an extension of the sine triangle PWM. Here the PWM is done by using space vectors. The concept of a space vector is being derived from the revolving magnetic field of an induction machine. Three-phase quantities are transformed to two phase quantities . The active and zero switching conditions can be represented by active and zero space vectors, respectively. A typical schema of a space vector for two-level VSI is shown in the figure below. The six vectors V1 to V6 shape a symmetric hexagon with similar sectors (1 to 6). Each sector is separated by 60 degrees to each other. Vref is the reference voltage vector which is used to control the magnitude and frequency of fundamental voltage.

Table 2: Switching conditions of the inverter

Space Vector		Switching conditions	On-Status Switches
Zero Vector	V_0	111	s_1, s_3, s_5
		000	s_4, s_6, s_2
Active Vector	V_1	100	s_1, s_6, s_2
	V_2	110	s_1, s_3, s_2
	V_3	010	s_4, s_3, s_2
	V_4	011	s_4, s_3, s_5
	V_5	001	s_4, s_6, s_5
	V_6	101	s_1, s_6, s_5

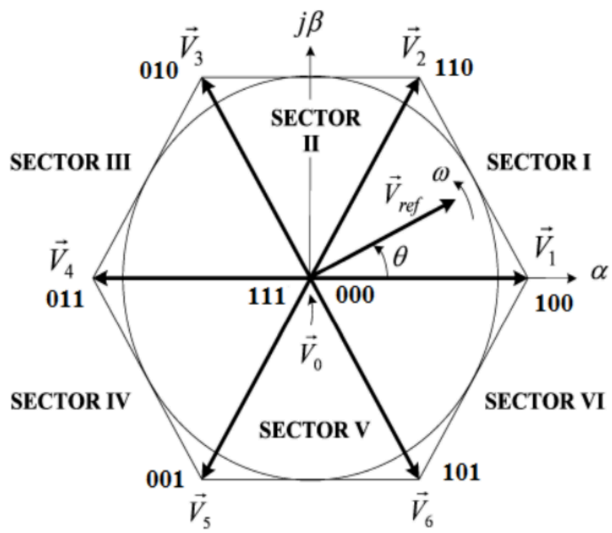

Fig 5:Schema of Space Vector

There are eight possible combinations of on and off patterns for the three upper power switches. The on and off states of the lower power devices are opposite to the upper one and so are easily determined once the states of the upper power transistors are determined.

Table 3 : Switching vectors, phase voltages and output line to line voltages

Voltage Vectors	Switching Vectors			Line to neutral voltage			Line to line voltage		
	a	b	c	V_{an}	V_{bn}	V_{cn}	V_{ab}	V_{bc}	V_{ca}
V_0	0	0	0	0	0	0	0	0	0
V_1	1	0	0	2/3	-1/3	-1/3	1	0	-1
V_2	1	1	0	1/3	1/3	-2/3	0	1	-1
V_3	0	1	0	-1/3	2/3	-1/3	-1	1	0
V_4	0	1	1	-2/3	1/3	1/3	-1	0	1
V_5	0	0	1	-1/3	-1/3	2/3	0	-1	1
V_6	1	0	1	1/3	-2/3	1/3	1	-1	0
V_7	1	1	1	0	0	0	0	0	0

Space Vector PWM (SVPWM) refers to a special switching sequence of the upper three power transistors of a three-phase power inverter. It has been shown to generate less harmonic distortion in the output voltages and or currents applied to the phases of an AC motor and to provide more efficient use of supply voltage compared with sinusoidal modulation technique.

Space Vector PWM can be implemented by the following steps:

● Step 1. Determine Vd, Vq, Vref, and angle (α)

● Step 2. Determine time duration T1, T2, T0

● Step 3. Determine the switching time of each transistor (S1 to S6)

3.2.3 MPPT ALGORITHM

The output power of a PV cell is indeed a nonlinear function of the operating voltage and this function has a maximum power point (MPP) corresponding to a particular value of voltage. In order to operate at the MPP, an energy power converter must be connected at the output of a PV array; such converter forces the output voltage of the PV array to be equal to the optimal value, also taking into account the atmospheric condition.

For the MPPT algorithm a classical hill climbing method was chosen and improved. In the case of incremental conductance method the change of voltage is tested, but the MPP is more closely tracked by the current and power, because the current extracted from the PV panel is directly proportional with the irradiation. Therefore, the slope of PV current and power is similar to the irradiation: the power changes in the same direction as current.

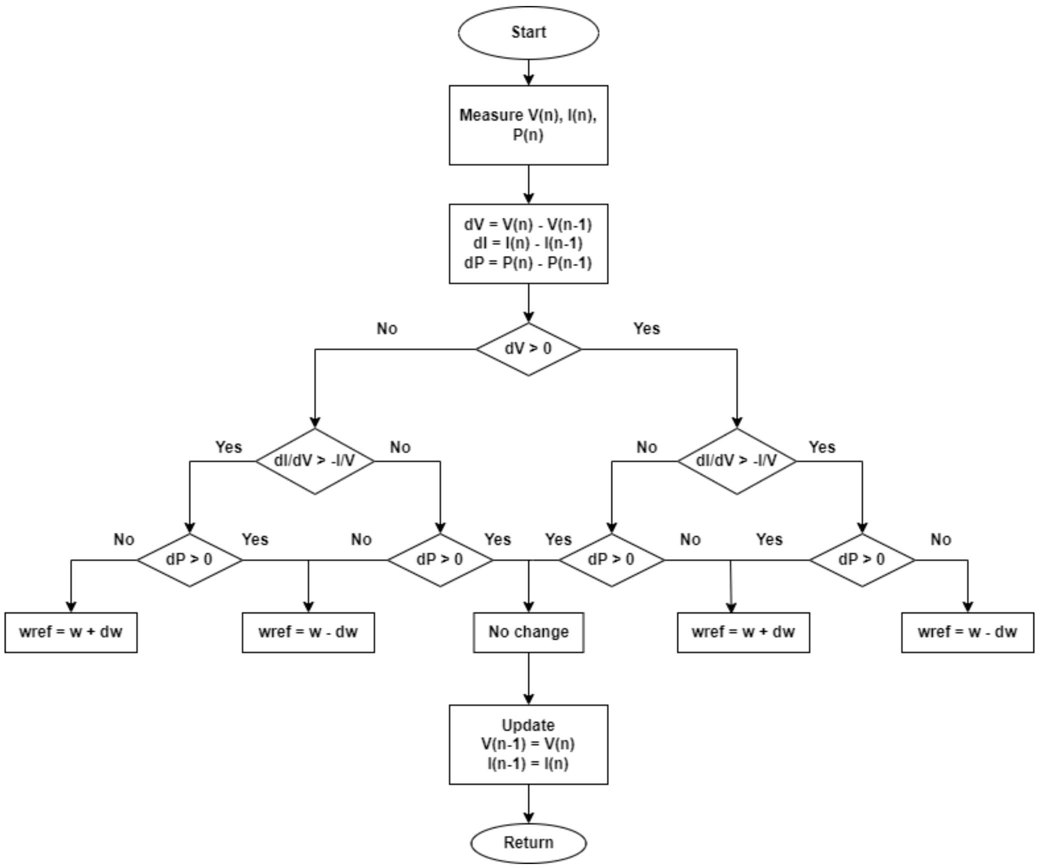

Fig 6: MPPT Algorithm Flowchart

CHAPTER 4

SIMULATION & RESULTS

Matlab/Simulink for the proposed mathematical model of the PV pumping system under variable solar radiation and ambient temperature is presented in figure .

The induction motor used in this study of the PV water pumping system is a three phase squirrel cage induction motor with the parameters as shown in table .

Table 4: Induction Motor parameters

Nominal Power	50 HP
Nominal line-to-line voltage	460 V
Nominal frequency	50 Hz
Stator resistance & inductance	0.087 ohm, 0.0001 H
Rotor resistance & inductance	0.228 ohm, 0.0008 H
Mutual inductance	0.0347 H
Number of pole pairs	2

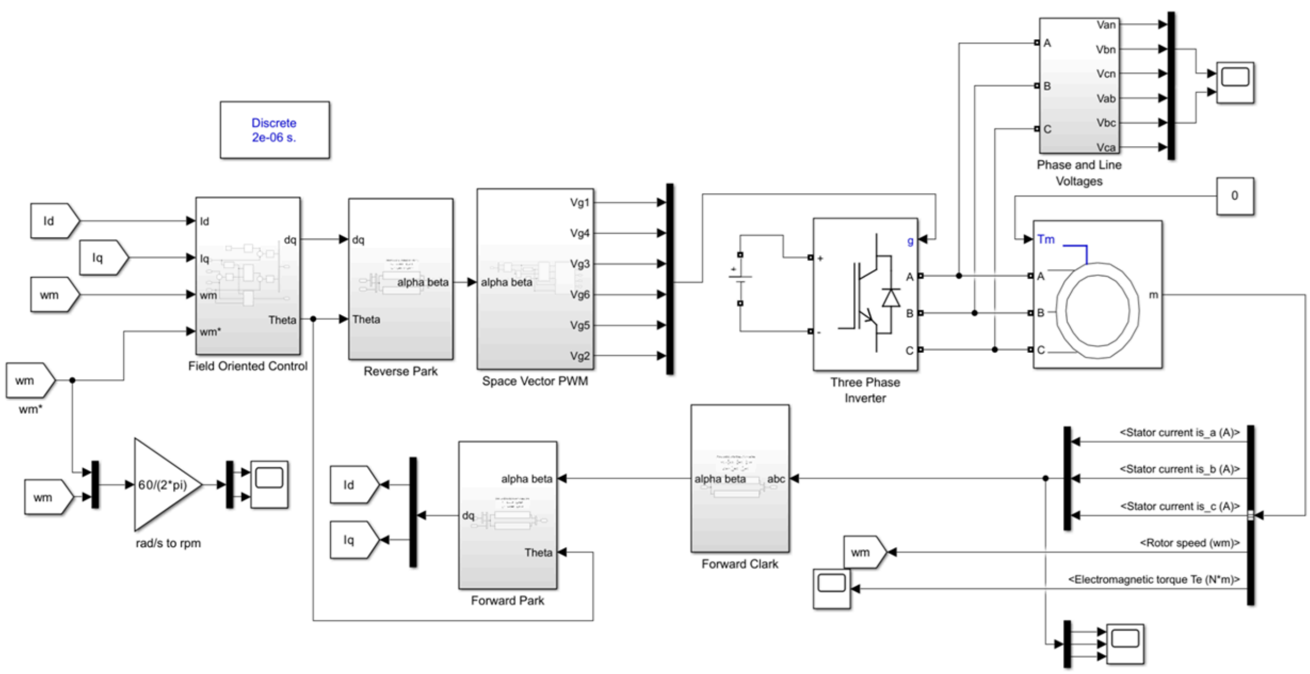

Fig 7: Simulink model for the proposed system with dc voltage source

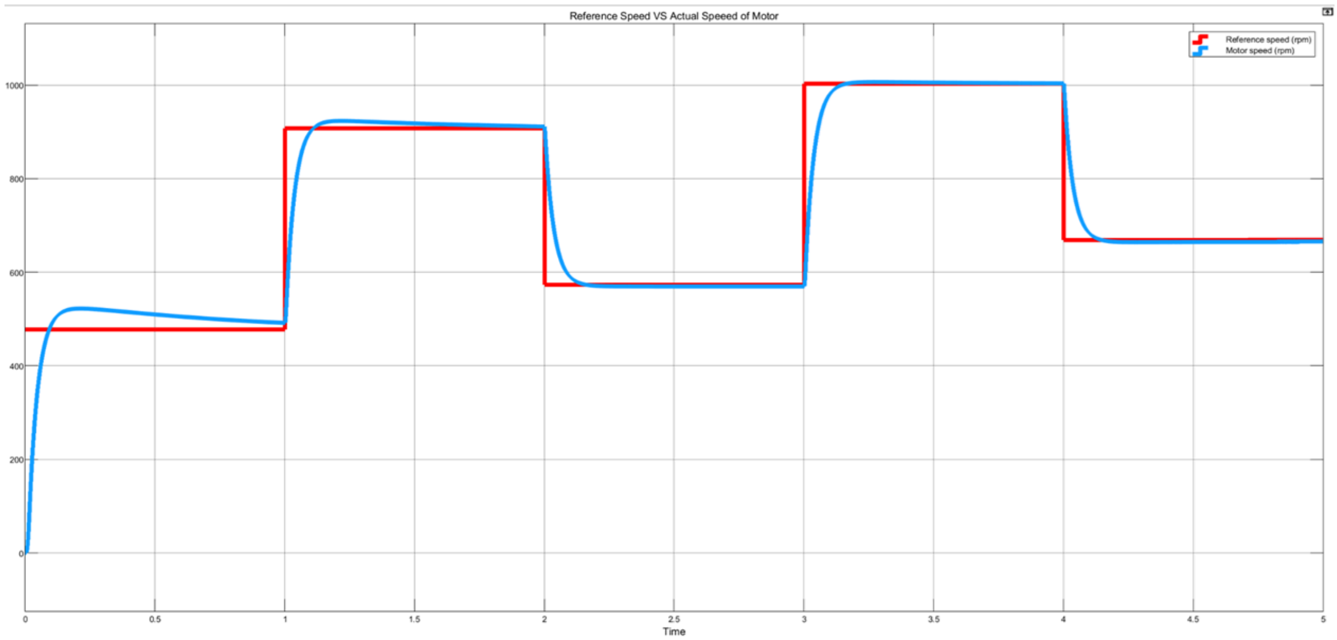

Fig 8: Reference speed curve vs Motor Speed curve

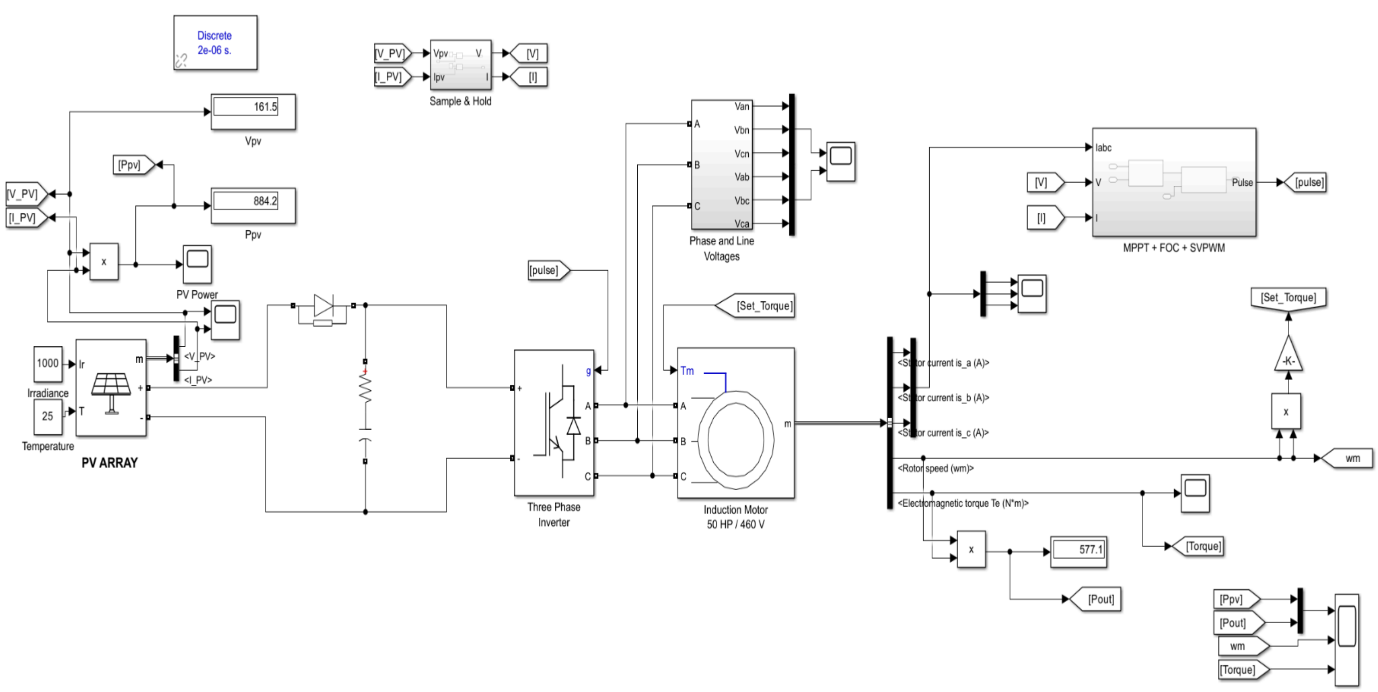

Fig 9: Simulink model for the proposed system with PV panel as source

Table 5: System readings under different irradiation values

Irradiance(W/m^2)	P_{pv} (W)	P_{in} of IM(W)	P_{out}(W)	Efficiency(%) of IM
600	647.5	646	604.7	93.60
700	753.9	678.3	628.3	92.62
800	858.9	694.4	680.6	98.01
1000	1065	719.5	714.4	99.29

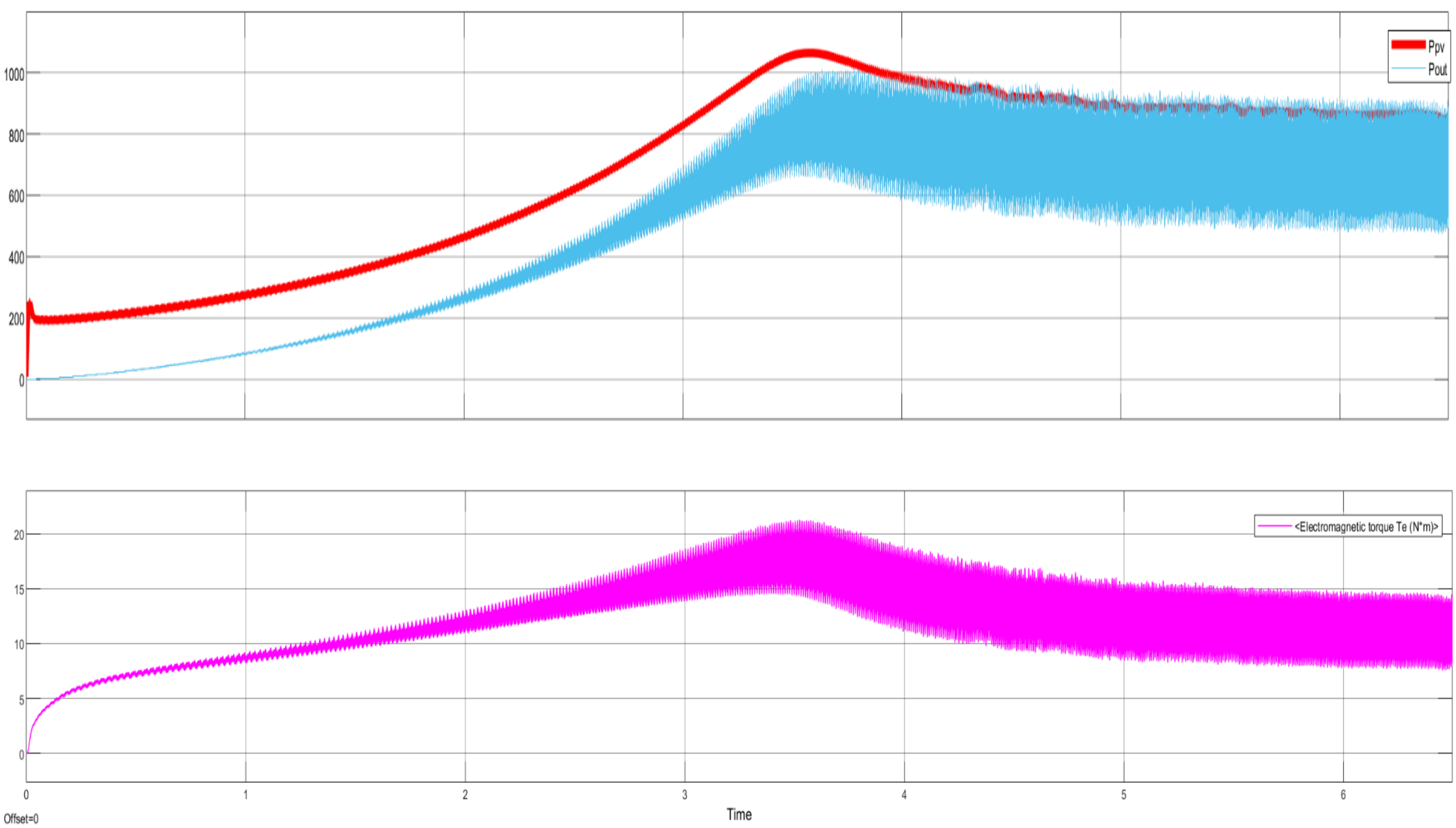

Fig 10: Power & Torque characteristics of the proposed system for irradiance = 1000W/m^2

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 SUMMARY

This study presents a simple but efficient photovoltaic water pumping system. It models each component and simulates the system using MATLAB. The result shows that the PV model using the equivalent circuit in moderate complexity provides good matching with the real PV module. Even a small improvement of efficiency could bring large savings if the system is large. In order to develop a simple low-cost system, this thesis adopts the direct control method which employs the P&O algorithm but requires only two sensors for output. Simulations also make comparisons with the system without MPPT in terms of total energy produced and total volume of water pumped a day. The results validate that MPPT can significantly increase the efficiency of energy production from PV and the performance of the PV water pumping system compared to the system without MPPT.

5.2 CONCLUSION

Without the usage of chemical storage components, a solar-powered induction motor water pumping system is simulated in this research. The findings of the integrated system simulation, which is presented, can be utilized to decide how to rate the individual components. According to the simulation results, the suggested approach might work well for a PV water pumping system. Additionally, it is a cost-effective, highly effective, and durable solution.

5.3 FUTURE PROSPECTS

Physical implementation of the system remains for future research. It may involve implementation of: a microcontroller, a method of supplying power to the controller, signal conditioning circuits for A/D converters, a driving circuit for Power- MOSFET, and a Boost converter. It may also involve performance analysis on the actual system and comparisons with simulations. Also, we plan on implementing Carrier Based PWM With Common Mode Voltage Injection Technique for the inverter which can increase the efficiency of the inverter

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