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DESIGN PID CONTROLLER BASED SOLAR WATER PUMPING SYSTEM FOR AN AUTOMATED IRRIGATION USING PARTICLE SWARM OPTIMIZATION ALGORITHM

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POST GRADUATE IN CONTROL SYSTEM ENGINEERING

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DESIGN PID CONTROLLER BASED SOLAR WATER PUMPING SYSTEM FOR AN AUTOMATED IRRIGATION USING PARTICLE SWARM OPTIMIZATION ALGORITHM

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Design pid controller based solar water pumping system for an automated irrigation using particle swarm optimization

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APPROVAL of thesis for Défense result

I hereby confirm that the changes required by the examiners have been carried out and incorporated in the final thesis.

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As members of the board of examiners, we examined this thesis entitled" Design PID controller based swps for an automated irrigation using PSO algorithm" by yitayish abeza. We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Masters of science in" Control Systems Engineering".

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DECLARATION

This is to certify that the thesis entitled" **Design pid controller based solar water pumping system for an automated irrigation using particle swarm optimization**", submitted in partial fulfilment for the degree of Master of science in Control System Engineering under **faculty of electrical and computer engineering**, Bahir Dar Institute of Technology, is a record of original work carried out by me and has been submitted to this or any other institution to get any other degree or certificates. The assistance and help I received during the course of this investigation have been duly acknowledged.

yitayish abeza

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31/07/2022

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ABSTRACT

The agricultural industry still relies heavily on manual labor and relatively little on technology. Automation systems can help and enhance Ethiopia's agricultural sector in a variety of ways. One of them is the utilization of solar energy for the extraction of groundwater and the optimization of irrigation through the use of optimal controllers This thesis discusses the design and simulation research of an automated agricultural system with solar pumping and the best moisture controller. The design process begins with calculating the amount of water needed for a specific piece of land and sizing the solar pumping system as a whole. The optimal controller used is PSO tuned PID controller. It is very well known that PID controllers are linear controllers which are widely used in the industry. They have good performance for linear systems and are easy and cost effective. However, they have an inherent drawback of achieving good performance when the system operating point is changing or the system is nonlinear. In this thesis, the irrigation automation system used brushless DC motor which is linear. The system also has wide variation in operating speed due to the highly nonlinear variation of the moisture content of the soil. Hence the PID controller needs to be tuned properly to give better performance at various operating conditions. Furthermore, the controller also integrates with the solar pumping system so that an optimal harvesting of the solar energy. Due to this the PID parameters are tuned with PSO which is an artificial intelligent-based optimization tool which has shown good performance for other systems. This system is applied on an average farm located in felege birhan which has an average water consumption of 64.8m3/day. 100m deep wells needs 2.38 kw pump 2.81 kw pv. The performance of the controller and overall system is tested through MATLAB simulation. The PSO tuned PID has no overshoot and has settling time 0.3sec less than the auto tuning method of MATLAB.

Key words: BLDC motor, solar panel, proportional integral and derivative controller (PID), particle swarm optimization algorithm (PSO).

LIST OF ABBREVIATIONS

AC	Alternating current
BLDC	Brushless dc motor
DC	Direct current
GIWR	growth irrigation requirement
NIWR	Net irrigation water requirement
IAE	Integral absolute error
IATE	Integral absolute time error
ISE	Integral square error
ITSE	Integral time squared error
MPPT	Maximum power point tracking
PID	Proportional integral controller
PSO	Particle swarm optimization
PV	Photovoltaic
PWM	Pulse width modulation
SPV	Solar Photovoltaic
SPWS	Solar plant watering system
TDM	Total dynamic head.
Th	total lifting height

LIST OF NOTATIONS

b_f	the friction constant
B_v	Viscous friction coefficient
C	mean velocity of fluid
D	Duty ratio
D	pipe diameter
E_a	Phase back emf
F	friction constant
I	line current
J	the rotor inertia
L_a	Equivalent line inductance of winding
K_e	Coefficient of line back-EMF
M	Mutual linkage
r_a	Line resistance of winding
θ	angular speed
Ω	Rotor speed
T	the electrical torque
T	irrigation hour per day(hr)
T_L	load torque
U_d	DC bus voltage.
V	Voltage
V_d	input voltage
V_O	output voltage
W	the angular velocity

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CHAPTER ONE

INTRODUCTION

1.1 Background

The constant rise in food consumption necessitates rapid advancements in food production technology. In developing countries, food insecurity is a big issue. In a country like Ethiopia, where agriculture is the main source of income, using technology to increase yields is critical. Ethiopian agriculture is primarily rain-fed. Climate change has resulted from global warming, making rain-fed agriculture systems unreliable. As a result, additional land has been irrigated in order to meet the rising population's food requirement.

Farmers are having severe difficulty watering their crops these days in the realm of agriculture. It's because they don't have a good notion of how much electricity is available. Even if it is available, they must pump water and wait for the field to be properly watered, which forces them to cease doing other chores that are equally vital to them, resulting in a waste of time and effort. Not only does it assist farmers, but it also assists others in watering their plants. When natural precipitation is insufficient to meet a crop's water needs, irrigation is required. Most commercial automated irrigation systems on the market today are set to water at predetermined intervals for predetermined durations of time. Watering the farming area is one of the most vital jobs in agriculture. The majority of farmers utilize manual land control, which involves visiting the site to check the pumping or watering of the land. This will almost certainly necessitate more and more labor, and as a result, work efficiency may suffer. To monitor all of the controlling operations, an automatic system can be constructed. The majority of irrigation systems are operated manually, resulting in excessive watering and water waste. Automated farm irrigation solutions can take the place of these obsolete techniques. Solar panels are becoming more affordable, which stimulates their application in a variety of industries, including agriculture irrigation systems. In terms of decision-making capability, the PID controller is quick and efficient. We combined PID for a simple application with its practical implementation in the agriculture sector, operating a PID algorithm in aggressive and non-aggressive mode for DC motor pump speed control and deciding whether to switch on or off the pump. The pump is controlled automatically by PWM, which varies the speed of the DC pump in various situations, primarily at the start and shortly before the end of the desired volume of water. Because they are simple and reliable, PID controllers are commonly utilized in industrial operations. Variations in parameters and parameter perturbations are common in.

industrial processes, and when they become severe, the system becomes unstable. As a result, control engineers are looking for ways to automate tuning procedures [1].

In a PID controller, proportional (P) control cannot eliminate steady-state error; instead, integral (I) control can erase this error. The amplitude is axed using the derivative (D) control mechanism [2].

Solar Water Pumping was a significant advancement for the world because agriculture is the foundation for any nation's progress [2]. Irrigation is the most important component of agriculture, and it is improving every day thanks to new technologies. Solar Water Pumping Method is the greatest option for all energy shortages and environmentally friendly irrigation. Agriculture is a vital sector for every country in the globe, and irrigation is the most significant aspect of that agriculture. This is critical since good yields can only be produced through adequate watering procedures. Irrigation is usually done with electricity in today's technological environment. So, electricity plays an important part in irrigation since, nowadays, everyone uses high-powered motors for pumping, which can only be driven by electricity. As a result, one of the best options is to use a solar panel to generate the necessary energy to drive these motors. Irrigation is the technique of using water to water crops, pastures, and plants. Surface, sprinkler, drip/trickle, and subsurface irrigation are the four types of irrigation. The photovoltaic system is made up of interconnected components that are designed to provide the desired amount of electricity from a tiny device to the load. Grid-connected photovoltaic systems, standalone photovoltaic systems, and hybrid photovoltaic systems, which combine multiple energy sources such as PV arrays, diesel engines, and wind generators, are the three primary categories of photovoltaic systems. Storage devices such as batteries or super capacitors may be used in grid-connected and stand-alone systems to store energy during the day when there is enough sunlight. In rural locations, hybrid and stand-alone systems are becoming more popular. As a result, the PV water pumping system discussed in this thesis is a stand-alone system designed to meet the urgent needs of rural residents.

The cost of solar photovoltaic (SPV) panels and power electronics devices has been steadily decreasing, encouraging academics and businesses to use solar PV array generated power for a variety of purposes. SPV array-generated energy is commonly utilized for irrigation in the fields, as well as for domestic and industrial uses.

Solar PV (photovoltaic) electricity is widely utilized for water pumping in the irrigation sector, which is one of the most important sectors. The DC has been used to achieve solar PV water pumps. Solar energy is being used more and more frequently. Power transmission in remote places is exceedingly challenging, and occasionally impossible. The most crucial function for irrigation is water pumping, but there are issues when there is no electricity. Solar energy is a completely clean kind of energy. After installation, it emits no greenhouse gases and is pollution-free. It can lessen the amount of pollution caused by fossil fuels like coal and gas that are used to generate power. One of the most practical uses of solar energy is water pumping. Solar energy may be produced everywhere, making it conceivable to use solar panels to create electricity in remote locations where transmission of electricity is not feasible [3].

1.2 Photovoltaic system

The photovoltaic system is made up of interconnected components that are designed to provide the desired amount of electricity from a tiny device to the load. Grid-connected photovoltaic systems, standalone photovoltaic systems, and hybrid photovoltaic systems, which combine multiple energy sources such as PV arrays, diesel engines, and wind generators, are the three primary categories of photovoltaic systems. Storage devices such as batteries or super capacitors may be used in grid-connected and stand-alone systems to store energy during the day when there is enough sunlight. In rural locations, hybrid and stand-alone systems are becoming more popular. As a result, the PV water pumping system discussed in this thesis is a stand-alone system designed to meet the pressing demands of individuals living in rural areas. In a stand-alone system, power from the photovoltaic array is supplied directly to the load, by passing the utility system [.

When grid electricity is unavailable and other options are prohibitively expensive, solar pumps are an attractive alternative. Solar pumps with both AC and DC motors are available in a variety of designs. Solar-powered AC pumps necessitate a large PV panel and have a low efficiency. Due to their great efficiency and wide operating ranges, solar-powered DC pumps are thought to be more suited than AC pumps. Because of its high efficiency, low maintenance cost, better speed-torque characteristics, low electromagnetic interference issues BLDC motor is found to be more suitable to be operated with solar DC power [4].

Furthermore, while comparing DC and AC pumps for a particular solar panel capacity, it is discovered that the BLDC motor pump produces more water.

1.3 Pv water pumping system energy storage

During moments of bright sunlight, the system operates effectively; nevertheless, the system output is particularly vulnerable to change during cloud cover, and progressively decreases and increases at the beginning and end of the day. Unless a storage element is provided, such as a battery, or a storage tank is filled and empties more slowly by gravity in the case of water pumping systems, there is a total loss of output throughout the night when it is dark.

Due to its relatively low cost and wide availability, lead-acid battery technology is considered to be the most cost effective for many PV systems. However, the typical life-time of the battery in PV systems is around three to eight years, but in hot climate countries, this drops to typically two to six years because internal corrosion dramatically increases with high ambient temperature.

Furthermore, batteries can handle far greater transient current surges than a PV array can provide. However, because around 15-25 percent of the energy is lost during charging and discharging procedures, this process results in additional power loss, and the PV array must be larger to compensate the energy losses. Furthermore, the batteries must be maintained on a regular basis, and if the electrolyte is not replenished, the batteries will rapidly degrade. As a result, these factors considerably increase the cost and maintenance burden of the system. So that energy in a water pumping system can be stored in water tanks and used at night and on days when solar radiation is insufficient to operate the system. In my thesis submersible pumps are used [5].

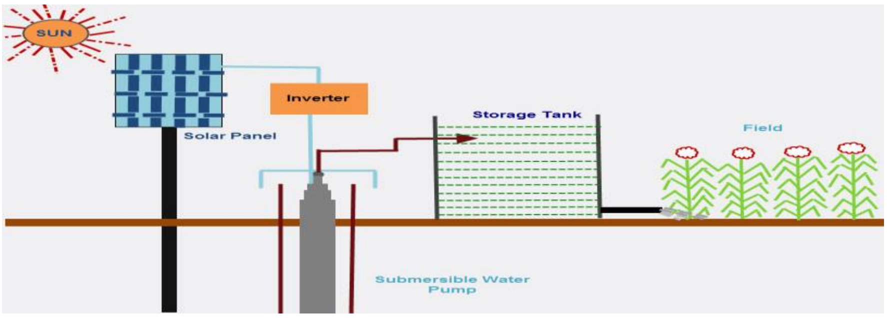

Figure 1. 1 solar powered auto irrigation system

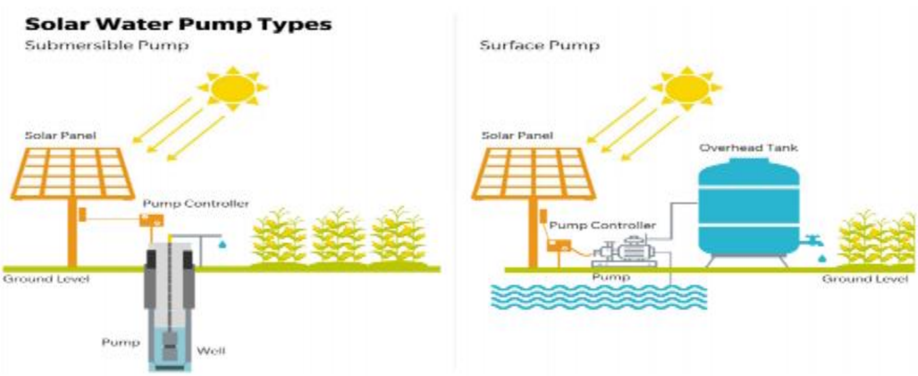

Figure 1. 2 solar water pump types

1.4 Objective of the thesis

The objective of this project is to design PID controller based solar water pumping system for an automated irrigation using particle swarm optimization algorithm. The objectives of our system can be divided into two categories which are as follows.

1.4.1 General Objective

To develop effective and convenient PID controller based solar water pumping system for an automated irrigation using particle swarm optimization algorithm to increase the productivity of crops.

1.4.2 Specific Objectives

- ✓ To design the solar system.
- ✓ To analyze mathematical modelling of the brushless dc motor.
- ✓ To tune PID controller with particle swarm optimization algorithm.
- ✓ Simulate using Matlab Simulink.

1.5 Statement of Problem

- ✓ The majority of the farmers need to travel to the field every time to switch on/off the motor, hence wasting time. In rural area most of the time there is no light, in the case of these planting water is not easy and tired the peoples and waste the money. In addition to these crops not efficiently watered. To overcome this problem, I designed PID controller based solar water pumping system for an automated irrigation using particle swarm optimization algorithm.

1.6 Methodology

The methodology of this paper are;

Literature review: is begin by reviewing journals articles, conference papers, farmer crops and, books related to plant watering systems for automated irrigation. After reviewing those I will be **collect and analysed data** and also prepared based on the need for the proposed paper problem. Then after **system modelling and simulation**, finally **result and conclusion.**

1.7 Scope of the work

The scope is limited to design PID controller based solar water pumping system for an automated irrigation using particle swarm optimization algorithm in Matlab Simulink. The system performance will be analysed by using Matlab simulation. This work does not have any practical implementation all things done on the simulation.

1.8 Significance of the thesis

This thesis deal with the design of PID controller based solar water pumping system for an automated irrigation using particle swarm optimization algorithm. The systems helps in saving water and thus more land can be brought under irrigation. Crops grown under controlled conditions tend to be healthier and thus give more yields. And also, in rural areas uses solar systems.

1.9 Thesis Organization

The thesis is organized into six chapters with each chapters has its own subsection. The chapters are briefly described as below;

Chapter one : these chapter is an introductory chapter and presents an overview of the thesis background, objectives, scope and significance and a brief summary of the thesis. It presents a brief introduction to PV energy, and how increasing the efficiency of PV water pumping systems attractive and economically viable in remote locations and applicable for irrigation purposes.

Chapter two: these chapter provides a review of the literature on some components of PV water pumping systems and the particle swarm optimization algorithms with pid controller techniques.

Chapter three: these chapter describes the mathematical modelling of the system and design of the Standalone PV Water Pumping System.

Chapter four: these chapter describes the design of the controller. And how to tun pid controller using particle swarm optimization algorithm.

Chapter five: these chapter describes the MATLAB/SIMULINK implementation results of the system and describes each of the subsystems in detail.

Chapter six: these chapter describes conclusions and contribution summary of the thesis are presented. Moreover, potential research ideas for future work in this field are proposed.

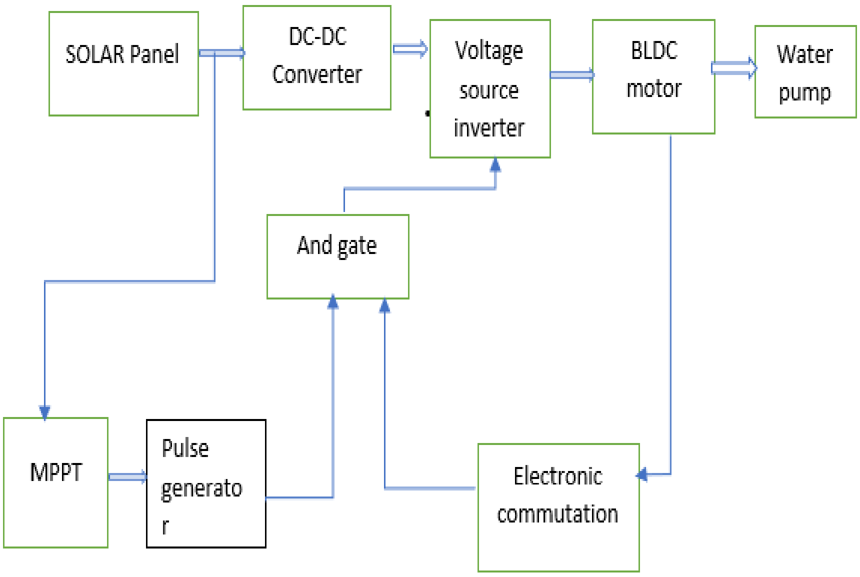

Figure 1.3 Diagram of SPV array dc-dc converter fed BLDC motor driven water pump

CHAPTER TWO

LITERATURE REVIEW

Goodchild S M et al (2015) A Modified PID Control Algorithm Sensors and Transducer Method for Precision Closed-loop Irrigation The amount of water necessary for irrigation is estimated, and the associated consequences are then simulated, using input factors such as air, temperature, soil moisture, radiations, and humidity. For design and tuning of PID controller parameters k_p, k_i, k_d, cannot use a modern optimization method, rather use Ziegler-Nichols rules, Cohen-Coon rule and so on. These are applied directly since they provide simple tuning rules to determine the PID parameters. However, since they rely on a minimum amount of dynamic information by making a certain assumption about nature of the controlled process, such as linearity, weak interactions within the process, absence of noise [6].

U. K. Das et al (2011) this paper proposed fuzzy logic-based controller for automation of greenhouse irrigation system. Fuzzy logic is more complex and require high cost than PID controller. In contrast to a PID controller, which can only manage three inputs (e, e, and de) and one output, a fuzzy controller can handle as many inputs and outputs as you like and your system can support. It is used to control things like temperature, speed, and pressure. It is a tool used in applications for industrial control. The most precise and reliable controller is one that has a feedback loop. It is a tried-and-true method of directing a system toward its goal. It runs automatically to fix a control function with accuracy and responsiveness [7].

proposed a model of variable rate automatic microcontroller irrigation system. This is basically JiaUddin et al., (2012) for farming purposes using sensors and mobile phones. Moisture sensors, an analog to digital converter, a microcontroller, a relay driver, a solenoid valve, a solar panel, and a battery make up the microcontroller-based automated irrigation system. The method can be employed in locations where obtaining electric power is challenging [8].

M.Abu-Aligah, (2011) At the global level, agriculture uses the most water consumption. The average amount of water used for irrigation on agricultural land is close to 70%, according to estimates. Up to 95% of all water uses in some developing nations are for irrigation, which is crucial for both food production and food security. The ability to preserve, enhance, and grow irrigated agriculture is crucial to the future agricultural development policies of the majority of these countries [9].

Carlos Mendoza (2014) One of the most straightforward and practical applications of photovoltaic energy is water pumping. Photovoltaic-powered pumping systems can be utilized for residential purposes, stock watering, agriculture irrigation, and more. Most of these systems also have the benefit of storing water for usage when the sun is not shining, which improves simplicity, eliminates the need for batteries, and lowers system costs. For model predictive control to achieve optimization, a significant computational burden is needed. A mathematical model is used to forecast future control inputs and process reactions, which are then optimized using a cost function. Model predictive control has been used successfully to regulate processes in a variety of industries, including petrochemical, food, refining, and polymer. PID controllers are practical and simple to implement. If the system parameters can be obtained or precisely estimated, the PID gains can be created based on those values. Additionally, if the system parameters are unknown, the PID gain can be designed solely based on the system tracking error and treats the system as a "black box.". In addition to these pid controller is not requires mathematical model [10].

Prakhar Srivastava1 et al (2020) The usual brushes functionality of a BLDC motor is implemented, and this requires knowledge of the location and direction of the rotor (w.r.t. stator coil). It allows for the direct measurement of rotor position utilizing rotary encoders or Hall Effect sensors. Sensor less controllers are those that can determine rotor position without the use of a hall sensor by measuring back-EMF in the undriven coil. A PID controller uses a proportional, integral, and derivative term to apply a difference between a desired value and a measured value in order to calculate error value e(t), which is what gives the name to the device. It is a traditional controller that is mostly employed because to its straightforward structure, high level of reliability, and simplicity of implementation. PID controllers, on the other hand, struggle with non-linear issues and are challenging to design since they operate with ambiguous parameters. Therefore, with new methodologies, PID controller tuning is crucial. The Ziegler-Nichols approach, which is regarded as the very first method used to tune PID controllers, was initially introduced in 1942. This approach has a large overrun in time response and uses a time response dependent formula. PSO is a computer methodology that optimizes a problem by using an iterative process to enhance the result. in PI controller the system becomes less stable. [11].

T ABinshad et al., this paper proposed PV based pumping system for agricultural irrigation. In this approach, power electronic controllers were designed. They have been developed for the water pumping system. In this, the boost converter is used along with an inverter followed by an induction motor pump set but this is also again for agricultural purposes and this approach is complex [12].

2.1 Motor-Pump system for photovoltaic system

The motor, pump, and connections make up the motor–pump system. Depending on the type of application and water demand, many types of coupling are utilized for water pumping. Depending on the daily water consumption, the pumping head, the suction head for surface mounted units, and the water resource, many types of pumps and motors are available for water pumping applications. Belt and pulley, feed screw, direct coupling rack and pinion or bolt and flange, and gear trans- mission are the most frequent forms of coupling used to pump water. The coupling ratio, which is the ratio of the motor torque to the torque of the load, determines the efficiency of the drive mechanism. The power transfer loss in gear transmissions can be significant, depending on the gearbox design and gear ratio, as well as the size of the engine in proportion to the speed reduction [13].

The following are the most typical commercially available motor–pump subsystem configurations:

- Floating motor–pump: For pumping surface water for irrigation and drainage, this type of pumping equipment is ideal. It is lightweight and has a low risk of becoming dry.
- Submerged motor–pump unit: This is also known as a submersible centrifugal motor–pump. This is the most frequent and suitable form of pumping system for village water supplies since it is simple to install and safe.
- Submerged centrifugal pump with surface mounted motor: Although this type of subsystem is beneficial for motor maintenance, it is unappealing because to power losses in the shaft bearings and its expensive cost.

2.2 DC-DC converter for photovoltaic system

DC-DC converters are used to connect a solar module to an inverter, ensuring that the photovoltaic module is always running at its maximum power point and that the inverter receives the required input voltage level. This is accomplished by using maximum power point tracking techniques to manage the converter duty ratio (D) (MPPT) [14].

Isolated and non-isolated converters are the two most common types of converters. A small high frequency electrical isolation transformer is used in isolated topologies to provide DC isolation between the DC converter's input and output, and step up or down of the output voltage is performed by modifying the transformer turns ratio. These converters are used in switch mode power supplies (the most common are half bridge and full bridge).

An isolation transformer is not present in non-isolated converters. They're commonly seen in DC motor drives. Step up (boost), stepdown (buck), and step up & step-down converters are the three types of non-isolated converters (buck-boost) [16, 11].

2.2.1 Step-down (buck) converter

The average output voltage Vo produced by this sort of DC-DC converter is always lower than the DC input voltage. The buck converter is used in PV applications for voltage step-down, such as charging batteries.

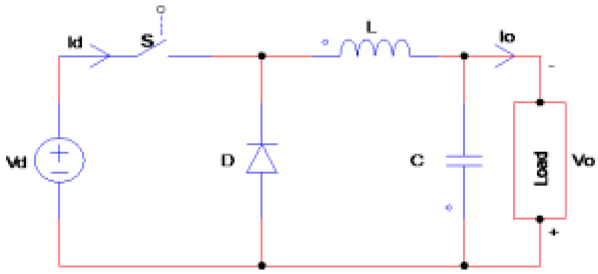

Figure 2. 1 step-down buck converter

The diode (d) is used to improve output filtering and prevent the switch from absorbing or dissipating inductive energy, which would cause the switch to overheat. In addition, a low-pass filter consisting of an inductor and capacitor is present at the converter's output to reduce output voltage fluctuations. As a result, the diode allows the converter to convert the inductor's stored energy to the load. This is why, as compared to a linear regulator, DC-DC Converters have a higher efficiency. The current climbs linearly when the switch is closed. The freewheeling diode causes a linear reduction in current when the switch is opened.

When the circuit is turned on, the inductor limits the current slew rate (current in rush) across the power switch. The current flowing through the inductor cannot abruptly shift. When the current through an inductor starts to fall, the inductor acts as a source to keep the current flowing. The main benefit is that the inductor stores energy when it is used to lower voltage.

Also, the inductor controls the percent of the ripple and determines whether or not the converter is operating in the continuous conduction mode. The smaller inductor value enables a faster transient response; it also results in larger current ripple, which causes higher conduction losses in the switches, inductor, and parasitic resistances. Also, the smaller inductor value requires a larger filter capacitor to decrease the output voltage ripple.

The capacitor filters the harmonic currents by providing a path for them to go away from the load. To reduce voltage overshoot and ripple at a step-down converter's output, output capacitance (across the load) is necessary. The capacitor is large enough that its voltage does not vary noticeably when the switch is turned off.

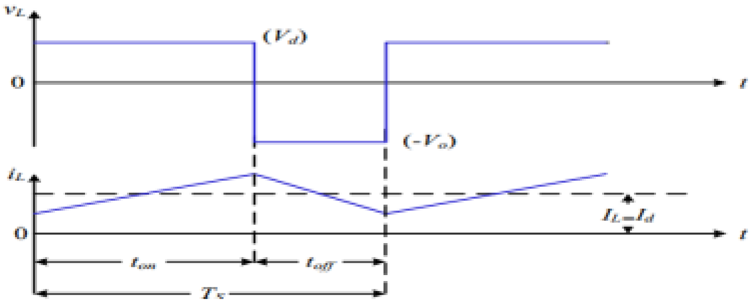

Figure 2. 2 buck converter wave form

The following equation can be used to define the relationship between the duty ratio of the converter and the output voltage Vo under steady-state conditions.

$$\frac{V_o}{V_d} = \frac{D}{1-D} \tag{2.1}$$

According to the duty ratio value, the output voltage from the equation above may be higher or lower than the input voltage. The output is greater than the input when the duty ratio condition D > 0.5, just like in a boost converter. In a buck converter, if D< 0.5, the output is less than the input.

$$L = \frac{(1 - D^2)R}{2fs} \tag{2.2}$$

$$C = \frac{D}{(Rfs(\frac{\Delta V_o}{V_o})} \tag{2.3}$$

2.2.2 Step-up (boost) converter

The regenerative braking circuit of DC motors and controlled DC power sources are examples of boost converter applications. The output voltage of this sort of converter is always greater than the input voltage. As a result, the step-up converter can be used in MPPT systems that require a higher output voltage than the input voltage. In a grid-connected system, for example, the boost converter keeps the output voltage high even when the PV array voltage drops to low levels.

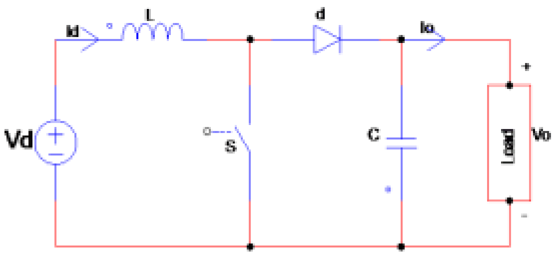

Figure 2. 3 step-up boost converter

The diode d is reverse based when the switch S is on. As a result of the input voltage source, the current in the inductor L rises linearly, and the output stage is isolated, and the capacitor (C) is partially discharged, supplying the current load. The diode is conducting when the switch is off during the second interval, and the output stage receives energy from both the inductor and the input source during this period.

To feed the power generated by the PV array to the load, a two-stage power electronic system with a boost type dc-dc converter and an inverter is employed. Between the PV array and the inverter, a DC-DC step up converter is used to keep the load voltage constant. A MPPT system's DC-DC converter is the most important component. These are commonly used in DC power supplies to convert uncontrolled DC inputs into a controlled DC output at a desired voltage and current level. A three-phase fixed amplitude and fixed frequency supply is obtained to feed an inverter or voltage converter as input by feeding the voltage across the DC-DC converter to a three-phase sine wave six step inverter.

$$D = 1 - \frac{V_d}{V_o} \tag{2.4}$$

Where Vd and Vout stand for the converter's input and output voltages, respectively, and D stands for the duty ratio and efficiency. The output voltage, V_{out}, will grow as the duty ratio D increases, as can be seen from the equation above. Additionally, the converter's input and output currents fluctuate as a result of a change in duty ratio.

The following equations can be used to calculate the filter inductor and capacitor needed to operate the converter in continuous conduction mode.

$$L = \frac{V_{d_{min}}}{\Delta I L f s} \tag{2.5}$$

2.2.3 Cuk (buck-boost) converter

Using the duality principle on the circuit of a Buck Boost architecture, the Cuk converter can be created. Cuk converter's input circuit is clearly a Boost converter, while the output circuit is clearly a Buck converter. As a result, the Cuk converter is similar to the Buck Boost converter in that it produces a negative polarity regulated output voltage in relation to its input voltage terminal.

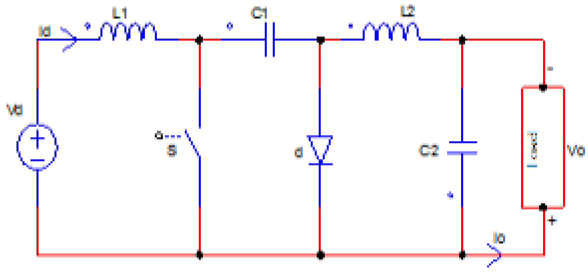

Figure 2. 4 cuk converter

CHAPTER THREE

MATHEMATICAL MODELLING

3 .1 DESIGN CALCULATIONS OF SOLAR PUMP

A PV generating system's fundamental power conversion unit is the PV module.

Felege birhan is asmall town in east gojjam of Ethiopia, within 76 kilometers of Ethiopian Bahirdar border.in these town many peoples work in farming. due to these peoples done irrigations, that are irrigate onions, tomatos, wheats and other crops. But most of the crops are not grown due to shortage of waters.

Solar energy receives the most attention among alternative energies. Solar energy is used in two different ways: solar thermal and solar cell technology. The photovoltaic effect transforms sunlight into electrical energy in a PV cell (solar cell). PV module energy has a number of advantages, including low maintenance and no pollutants. PV arrays have recently been employed in a variety of applications, including battery chargers, solar-powered water pumps, grid-connected PV systems, solar hybrid vehicles, and satellite power systems. A PV module is the most basic power conversion equipment in a PV generating system. The voltage current (V-I) characteristic of a PV cell can be modelled using current sources, diodes, and resistors. PV characteristics are commonly simulated using single-diode and double-diode models. The single-diode model accurately and faithfully simulates PV properties.

For the MATLAB Modelling and simulation, a simple model was utilized. A basic PV cell consists of a light-dependent current source (I_{sc}) in antiparallel with a diode driven by current I_d and a series resistance in the current channel through semiconductor material, metal grid, contacts, and the current collecting bus. The ground water is located 50 to 700 meters below the surface of the land. The selected well depth becomes 100m, static water level is 50m, draw down is 20m,

Table 3.1 Monthly crop water and net irrigation requirements output

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1.banana	89.1	85.9	54.3	0.8	0.0	0.0	0.0	0.0	0.0	2.8	30.9	68.2
2.barley	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0
3. onion	111.2	82.6	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.9	78.6
Net scheme irrigation requirement												
In mm/day	2.9	3.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	1.8
In mm/month	89.7	82.7	27.0	0.6	0.2	0.3	0.0	0.0	0.0	1.7	15.0	56.7

Steps for a simple power calculation of designing a solar DC Pump for a required capacity are;

Step1: calculate Amount of water required per day, to calculate amount of water from monthly crop water requirements of onion month of January are 111.2. the net irrigation water requirements NIWR, is 2.9mm/day, represents the daily quantity of water that is required to be applied. This water quantity is also used for the determination of canal discharge in consideration of the time of flow and is defined as the duty, expressed as l/s/ha. Then duty is calculated by:

$$Q = \frac{10000 * GIWR}{t * 60 * 60} \tag{3.6}$$

Where, q=unit design discharge (lit/sec/ha)

GIWR=irrigation requirement (mm/day)

t=irrigation hour per day(hr)

the duty of the NIWR of 2.9 mm/day and 4 hours of daily irrigation time is supported to be used with my thesis. Since, duty for 4 working hour is computed as follows;

$$\text{q} = \frac{10000 * \text{GIWR}}{(t * 60 * 60)} == \frac{10000 * 6.51}{(4 * 60 * 60)} = 4.5 \text{ lit/sec/hectare} \tag{3.7}$$

where,

$$\text{GIWR} = \text{NIWR}/\text{Efficiency} = 6.51\ \text{mm}/\text{day} \tag{3.8}$$

4.5 lit/sec/hectare *360l/hour =16,200L/hour. (3.4)

But the onion irrigates four hour per day then, to know amount of water required per hectare is;

16,200*4=64,800L/day/hectare. (3.5)

But, solar works for 8 hours,

64,800/8=8,100L/day. (3.6)

Pump flow rate becomes,

$$8100/360 = 2.25\ \text{L/sec/hectare} = 0.00225\text{m3/sec} = 8.1\text{m3/h}. \tag{3.7}$$

Therefore, amount of water required per hectare is;

64,800 L/day=64.8m3/day. (3.8)

Step2: calculate Total Dynamic Head (TDH). It depends on two factors.

In solar pumping system, the total lifting height (Th) is the main parameter to determine the necessary power to move the water from the well depth level to the required place.

- Total Vertical Lift.
- Total frictional losses.

$$\text{TDH} = \text{Vertical lift} + \text{Frictional losses} \tag{3.9}$$

Vertical lift =pump level head+ A velocity head+ Dynamic head loss + horizontal length of the pipe.

TDH= pump level head+ A velocity head+ Dynamic head loss + horizontal length of the pipe. + Frictional losses.

To Determine head due to friction (fh) apply Darcy-Weisbach formula.

That is;

$$f_h = \frac{fL}{d}\frac{c^2}{2g} \tag{3.10}$$

where;

f = friction factor

L= length of pipe

d = pipe diameter

c = mean velocity of fluid

Darcy-Weisbach formula relates the loss of pressure or head loss due to friction along the given length of pipe to the average velocity of the fluid flow for an incompressible fluid.

But determine the friction factor, f‟ is more problematic, for smooth flow and smooth pipes, Blasius equation is applicable.

$$\text{f} = \frac{0.079}{Re^2} \tag{3.11}$$

where Re is Reynolds number (Re = $\frac{pvd}{\mu}$) and If Re>40

$$\text{f} = \frac{1.325}{[\ln\left(\frac{e}{3.7d} + \frac{5.74}{Re^{0.9}}\right)]^2} \tag{3.12}$$

where,

p= density of water,

μ= viscosity of water (1.14 $*10^{-4}$)

e= the roughness of the pipe takes PVC (0.009)

Re = $\frac{pvd}{\mu}$,where p= 1000Kg /m3,μ = 1.14 $*10^{-4}$, d=0.2m

$$\text{Re} = \frac{\text{pvd}}{\mu} = \text{Re} = \frac{1000 * 0.372 * 0.2}{1.14 * 10^{-4}} = 6.526\text{x}10^4 \tag{3.13}$$

Since Re > 400 I used equation,

$$f = \frac{1.325}{[\ln\left(\frac{e}{3.7d} + \frac{5.74}{Re^{0.9}}\right)]^2} = 0.783 \quad (3.14)$$

$$f_h = \frac{\mathrm{fL}}{d}\frac{\mathrm{c}^2}{2g} = \frac{0.783 * 76 *}{0.2}\frac{(0.0716)^2}{2 * 9.81} = 0.077\mathrm{m} \quad (3.15)$$

$L=P_h+V_{rh}+H_{pipe}=70+2+4=76m$

Then after, determine velocity head (V_h)

$$V_h = \frac{\mathrm{c}^2}{2g} \quad (3.16)$$

Where,

$$\text{water velocity(c)} = \frac{Q_{pump}}{A} \quad (3.17)$$

$$\text{but, cross section area (CSA) A} = \frac{\pi}{4}d^2 \text{ . (Assume d} = \text{200mm)} \quad (3.18)$$

Then water velocity(c)

$$\mathrm{c} = \frac{Q_{pump}}{A} = \frac{0.00225\ m^3/\mathrm{s}}{0.0314\ m^2} = 0.0716\ \mathrm{m/s} \quad (3.19)$$

Then velocity head loss will be:

$$V_h = \frac{\mathrm{c}^2}{2g} = \frac{0.0716^2}{2 * 9.81} = 0.00513\ \mathrm{m} \quad (3.20)$$

Then, calculate the total dynamic head

$$\text{TDH} = \text{Vertical lift} + \text{Frictional losses} \quad (3.21)$$

$$\text{TDH} = \text{pump level head} + \text{A velocity head} + \text{Frictional losses} \quad (3.22)$$

$$\text{TDH} = P_h + VR_h + H_{pipe} + f_h + V_h \quad (3.23)$$

$$\text{TDH} = 76\text{m} + 0.077\text{m} + 0.00513\text{m} = 76.08 \text{ m} \quad (3.24)$$

Step 3: Hydraulic energy required to raise the water level per day is:

This step is an important step to estimate what amount of power is required to take the ground water to the surface.

$$\text{E} = \frac{\text{Mass}*\text{g}*\text{TDH}}{efficency} = \frac{(\text{Density}*\text{volume})*\text{g}*\text{TDH}}{efficency} \quad (3.25)$$

Step 4: pump power determination and selection:

From the above equation determine the required pump power from the work done dividing by hour

$$P(KW) = \frac{Q_{ph}*\rho*g}{3.6*10^6*efficency}TDH = 2.38 \text{ kw} \quad (3.26)$$

Where, if it isn’t knowing the efficiency of the system the recommended value is between 65 to 70 percent (efficiency=0.66).

The pump should satisfy the required flow rate and move waters in to the total dynamic head of the system to fill the desired liters of water. That is to lift 64.8 m3 water at the head of 76.08 m in the flow rate of 8.1 m3 /h with the 2.38 kW motor standard. The motor for this thesis is Brushless dc motor.

Step 5: pv panel power determination.

determine Size and number of solar PV modules required.

The size of PV array has also had a relationship to the pump requirements. This is the required hydraulic power to be generated by PV panel.

$$\text{P(array)} = \frac{p(KW)}{\sigma} \quad (3.27)$$

Where, σ is mismatch factor, and the recommended standard mismatch factor is 60-70 percent, in my thesis 66% is selected. Assume this mismatch factor includes the losses that occur during power conversions between the load and the pv panel.

$$\text{P(array)} = \frac{p(KW)}{\sigma} = \frac{2.38\, kw}{0.66} \quad (3.28)$$

$$= 2.81\text{kw}$$

3.1.1 Determination of photovoltaic module characteristics in a 240w module

The solar panel's current output, the type of material used to make the PV panel (ideality factor n), shunt and series resistance, the number of parallel and series solar cells (Ns & Np), temperature, and irradiance changes are all important considerations in determining the required voltage, power, or current in PV panel models.

3.1.2 Determination of number of cells

I need to design a 240 watt of PV modules based on the aforementioned specifications and estimates. For minimal use, a single cell produces only 0.5-0.6V and a few watts of power. A number of pre-wired cells in series, all encased in a robust, weather-resistant packaging, create a module to provide a higher voltage. A module is made up of cells that are connected in series or parallel. As needed, a typical module may include 36, 54, 60, 72, or 96 cells in sequence. When solar panels are connected in series, the current is shared and the voltages are added. Ns is the number of cells in the series. Multiple modules can be wired in series to raise voltage and in parallel to increase current; in this case, I want to generate 240 watts of power and 8.17 amps of current, so I'll need to figure out how many cells I'll need and compare them to the "Sharp ND240QCJ Poly" data sheet figures. I would take solar cell data from Matlab Simulink.

Table 3. 2 Single solar cell data sheets

Open circuit voltage (Vd)	0.5-0.6	V
Irradations(irs)	1000	Watt/m2
Quality factor	1.5	-
Saturation current	$9.825{*}e^{-8}$	A
Single resistance	0	Ω

Then,

$$V\ module = 240W/8.17A = 29.38V \quad (3.31)$$

Ns=29.38/0.5=60 cells in series where 8.17 A is the required current to produce by the photon.

To generate 2.81 kw maximum voltage (V_{mpp}) selected as 267.4V [15].

Table 3. 3 pv module and pv array value

Pv module	
Open circuit voltage	37.5 V
Open circuit current	8.75 A
Voltage at mpp,v_m	29.3 V
Current at mpp, i_m	8.19A
Power at mpp, p_m	239.9 w
Pv array	
Voltage at mpp, $v_{mp}=v_{pv}$	267.4V
Power at mpp, p_{mp}	2.813 kw
Current at mpp, $i_{mp}=i_{pv}$	10.5A
No of modules connected in series, N_s	$N_s=\frac{VPV}{VM}=\frac{276.4}{29.3}=10$
No of modules connected in parallel,N_p	$N_p=\frac{Ipv}{Im}=\frac{10.5}{8.19}=2$

Design of boost converter

At STC solar pv array maximum voltage is Vmpp=267.4 and output of the boost converter maintained to be at 325V at dc link (Vdc) which is rated voltage of BLDC motor.so the estimated duty cycle(D) is given by;

Table 3.4 DC-DC Boost Converter Design

Power rating	2.813 kw
Input voltage (V_d)	262.7

Output voltage (V_o)	325
Duty cycle(D)	$D=\frac{Vo-Vd}{Vd}$ =0.18
Maximum input current (I_{in})	$I=\frac{P}{Vd}=\frac{2813}{262.7}$ = 10.5
Maximum load current	$\frac{P}{Vo}=\frac{2813}{325}$ = 8.65
Switching frequency	20000
V_{out} ripple	2%Vo
I_{in} ripple	8% Iin
Inductance	$L=\frac{Vpv*D}{Fsw*\Delta Iin}=\frac{262.4*0.18}{20000*10.5*0.08}$ =2.81Mh=3mh
Capacitance	$C=\frac{Io}{6*w*\Delta Vo}=\frac{8.65}{6*1632.8*0.02*325}=136\mu F$ $W=\frac{2*\pi*N*P}{120}=\frac{2*3.14*2600*12}{120}$ =1632.8 rad/sec

3.1.2 Module I-V characteristics

The I-V Qualifiers Curves depict the current and voltage (I-V) properties of a specific photovoltaic PV cell, module, or array, providing a complete description of its capacity and efficiency for converting solar energy. The output performance and solar efficiency of a solar cell or panel are directly related to its electrical I-V properties, particularly its Pmax.

The relationship between the current and voltage produced on a typical solar cell I-V characteristics curve summarizes the key electrical properties of a PV cell or module. The amount of solar radiation (insolation) that strikes the cell determines how much current (I) flows through it, whereas an increase in the solar cell's temperature lowers its voltage (V).

3.1.3 Factors Affecting the Performance of Solar PV Systems

Understanding these variables will enable us to make informed predictions for managing them and deft choices for minimizing the difficulties they cause. The photovoltaic systems are impacted by a variety of elements.

Irradiance

Irradiance is a measurement of how much light strikes a specific surface. A solar cell will produce more energy the greater its irradiance. It is clear that the PV output voltage and current rise as the level of irradiation increases. When there is no change in the cell temperature, an increase in the irradiation level generally results in a theoretical increase in the maximum power voltage.

Temperature

Following the p-n junction voltage temperature dependency of the diode factor circuit, the band gap of the intrinsic semiconductor narrows as temperature rises, and the open voltage (Voc) lowers. Therefore, the temperature coefficient of V_{oc} for solar cells is negative. [16]

Again, when temperature rises, the intrinsic semiconductor's band gap narrows, causing a greater proportion of incident light to be absorbed since it contains enough energy to raise charge carriers from the valence band to the conduction band. Solar cells have a positive temperature coefficient of I_{sc} and a rise in I_{sc} for a given insolation as a result of the greater photocurrent [15].

Since the band gap energy drops and more photons have enough energy to produce electron-hole pairs, the short circuit current Isc generally increases somewhat as the temperature rises with a constant irradiation level. On the other hand, as temperature rises, the power output of PV panels is clearly reduced due to a drop in open circuit voltage and a fill factor, which lowers module efficiency [15].

3.1.4 Photovoltaic arrays

A single solar cell typically produces very little output power. Normally, it is less than 2W at 0.6V. As a result, the photovoltaic cells are connected in specific ways to create an array known as a photovoltaic module. The modules are made up of a collection of cells coupled in parallel and series to produce the desired output voltage. Additionally, a PV array is formed by connecting a number of PV modules in parallel and series to produce the necessary voltage and current values for a solar system. When multiple solar panels are connected in series, when two or more solar modules are connected in series, the output voltage is the sum of the voltages produced by each module, and the same current flows through each module. However, when two or more solar modules are linked in series, the voltage across each module would be the same, and the output current would be the total of the generated currents. The following basic criteria must also be taken into consideration while determining the construction of a PV panel [17] .

3.2 Simple solar cell modelling

A photovoltaic cell model using a real diode in parallel with an ideal current source is a simple solar cell model. The ideal current source produces current in proportion to the amount of solar radiation it receives.

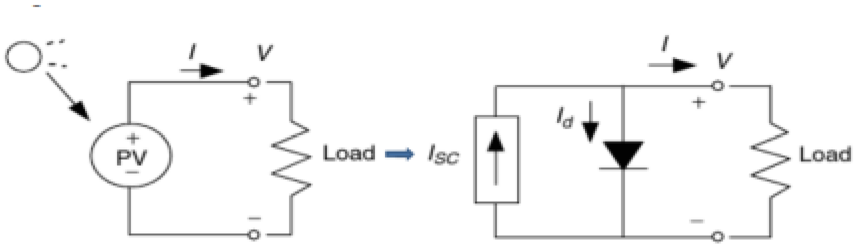

Figure 3. 1 simple equivalent circuit of PV cell

A basic solar cell model is a photovoltaic cell that uses a real diode in parallel with an ideal current source. The ideal current source generates current proportional to the amount of sunlight it receives.

$$\mathrm{I} = \mathrm{Isc} - \mathrm{Id} \qquad (3.32)$$

Then applying Shockley diode equation

$$\mathrm{I} = \mathrm{Isc} - \mathrm{Is}\ i_{sc} - i_s((e^{\frac{qvd}{nkt}}) - 1) \qquad (3.33)$$

Where q is the electron charge (1.602 × 10−19 C), k is Boltzmann’s constant (1.381 × 10−23 J/K), and T is the junction temperature (K), n is ideality factor a common value for n is 1.2 for Silicon mono and 1.3 for Silicon poly, 1.3 for AsGa, and 1.5 for CdTe. (I) load current, (Is) dark saturation current and (Id) is diode current. The open-circuit voltage can be found by setting the load current to zero:

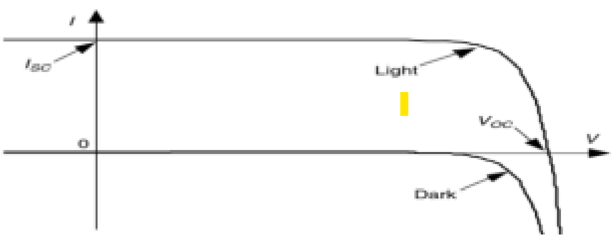

Figure 3. 2 open circuit and short circuit

General solar cell Modeling

Addition of series resistance Rs and parallel resistance Rsh, the current –voltage equation becomes non-explicit but a general PV cell equation is drive. And used to control the parameters that makes difficult to produce the desired out.

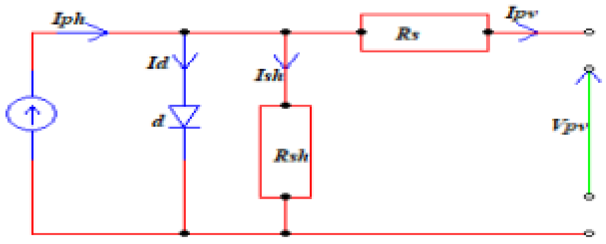

Figure 3. 3 Equivalent circuit of a general solar cell

3.2 MATHEMATICAL MODELLING OF BRUSHLESS DC MOTOR

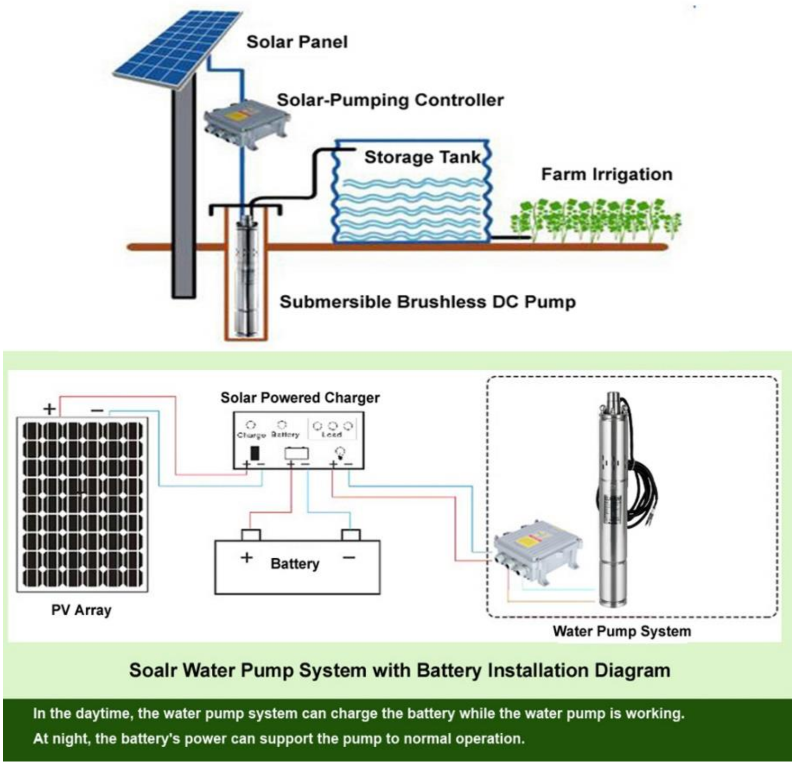

Figure 3. 4 solar well water pump

High liner control, retort concert, and prime lofty torque are all features of DC motors. In both industrial and home devices, DC motors are frequently employed. It is necessary to control the position of a motor with great precision. The armature's electric circuit and the rotor's free body diagram are displayed. Brush and brushless DC motors are the two types of DC motors available.

A brushless DC motor (BLDC) is a synchronous electric motor that runs on direct current (DC) and features an electronically controlled commutation mechanism rather than a mechanical commutation system based on brushes. Current, torque, voltage, and rpm are all linearly connected in such motors. Higher efficiency and dependability, lower noise, longer lifetime, elimination of ionizing sparks from the commutator, and overall reduction of electromagnetic interference are all advantages of BLDC (EMI). Because of two concerns, the disadvantage is a higher cost. To begin, it necessitates the use of a sophisticated electronic speed controller. The acronym BLDC is inferred from the name. Brushes are attached to the stator of a standard dc motor, but not to the stator of a "brushes" DC motor. In addition, unlike a standard DC motor, the BLDC's commutation could be controlled electronically. The stator windings in a BLDC motor are activated in order for the motor to rotate. Furthermore, there is no physical contact between the stator and the rotor at all. The hall sensor(s) is another important component of the BLDC; these hall sensors are systematically attached to the rotor and are employed as the primary sensing device by the Hall Effect sensor placed in the stator. This is based on the Hall Effect principle. [18, 11, 19]

Hall-effect sensors are used in some BLDC motors to detect the position of the rotor in relation to the stator.

The sensor less scheme of a sensor less BLDC motor can work correctly when the rotor is revolving. When the rotor of the motor is stationary, however, this is not the case, which leads to one of the biggest disadvantages of employing sensor less BLDC motors. There is no back EMF generated while the rotor of the motor is not spinning. The drive circuitry lacks the information it requires to effectively regulate the motor without back EMF.

The link between back EMF and angular speed is another down side of employing sensorless BLDC motors. Because lower speeds result in lower back EMF, Hall-effect BLDC motors may be more effective in low-speed applications than sensorless BLDC motors.

The 3-phase BLDC motor runs in a variety of modes (phases), although it is the most popular. The three-phase system is more efficient and produces less torque. The 3-phase has a high level of precision in control, despite certain cost considerations. In terms of the stator current, this is necessary.

Brushless dc motor has many advantages over brushed dc motor and induction motor. These *are;

i. The brushless machine requires less maintenance.
ii. Electric noise generation is low.
iii. Brushless motors have low inertia which improves dynamic response.

iv. Better speed verses torque characteristics.
v. Long operating life.
vi. High efficiency

3.2.1 Application Area of BLDC Motors

- A brushless DC motor's design characteristics are what give it its key advantages. Better current switching is possible with electronic commutation. Increased torque, precise speed control over a broad range, and better motor performance are the results. As opposed to mechanical parts that need to be replaced, it uses electronics, making it a low-maintenance and long-lasting solution. Additionally, since there are no brushes, there is less noise and electromagnetic interference (EMI). Consequently, BLDC motors are frequently employed in machinery and systems with long operational lifetimes, including: Industrial applications.
- Electric vehicles.
- Unmanned aircraft systems.
- Computer equipment.
- Consumer electronics.
- Robotics.
- Irrigation purpose.

A Brushless DC motor's mathematical model is typically similar to that of a normal DC motor. The most important addition is the phase involved, which has an impact on the BLDC model's total result. The resistive and inductive aspects of the BLDC configuration are both affected by the phase.

The model of the armature winding for the BLDC motor is expressed as follows:

3.2.2 Transfer function model of BLDC motor

The transfer function is one of the most fundamental concepts in control theory, and mathematical models based on transfer functions are frequently utilized in the field of automatic control. The system transfer function is also used to build some control design and analysis approaches, such as the root-locus method and the frequency-response method. Assume that the full-bridge driving in the two-phase conduction mode is used to control the three-phase BLDC motor [19, 14].

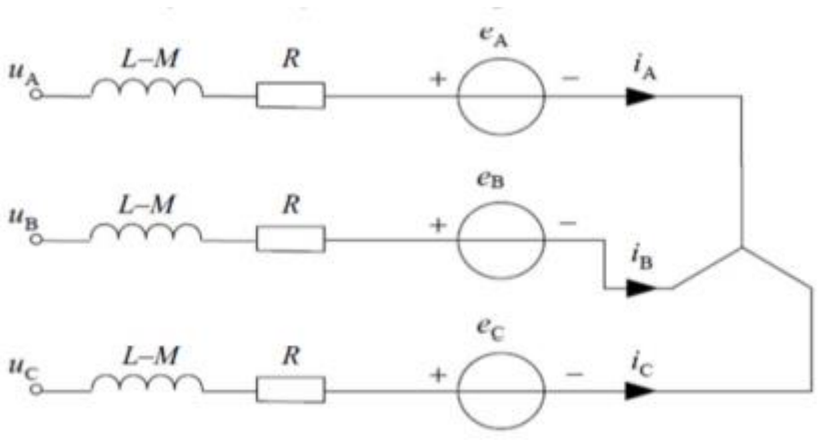

Figure 3.5 Equivalent circuit of the BLDC motor

The mechanisms of back-EMF and electromagnetic torque are all the same with those of the traditional brushed DC motor, thus similar analysis methods can be adopted.

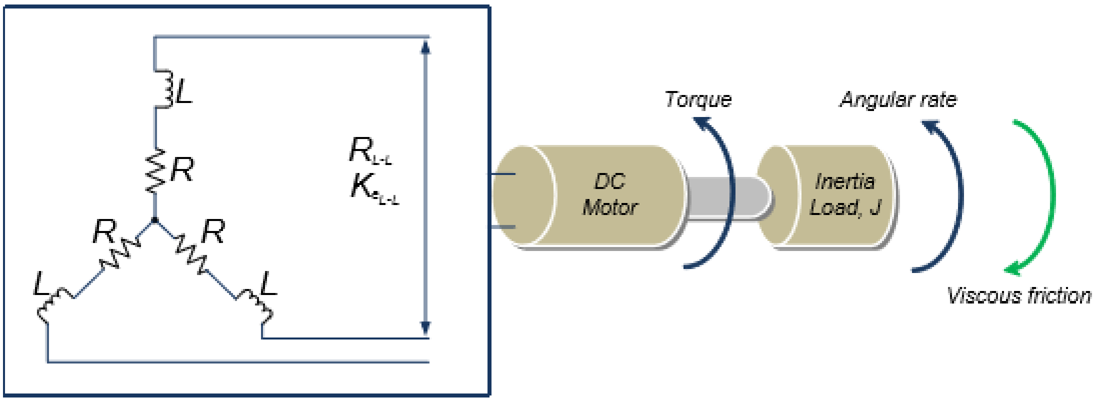

Figure 3.6 brushless dc motor schematic diagram

At any time, the two phases are excited either AB or BC or CA. the simplified equivalent circuit will be;

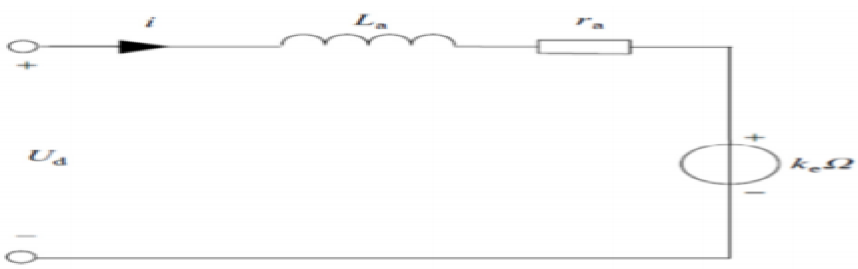

Figure 3.7 Simplified equivalent circuit of the BLDC motor

i_A =- i_B =$-i_C$ =i for three phases

$$i_A = i_B = -i_C = \mathrm{i} \quad (3.35)$$

$$\frac{d}{dt} i_A = -\frac{d}{dt} i_B = \frac{di}{dt} \tag{3.34}$$

$$Ud = Vabc = 3RI + 3(L - M)\frac{di}{dt} + (Ea - Eb - Ec) \tag{3.36}$$

$$Ud = Vabc = 3RI + 3(L - M)\frac{di}{dt} + (Ea - Eb - Ec) \tag{3.37}$$

Where,

$$Ea = -Eb = -Ec \tag{3.38}$$

$$V_{abc} = U_d = 3Ri + 3(L\text{-}M)\frac{di}{dt} + 3E_a \tag{3.39}$$

$$= r_a i + L_a \frac{di}{dt} + E \tag{3.40}$$

Where,

$$E = K_e \Omega \tag{3.41}$$

$$K_t i - T_L = J\frac{d\Omega}{dt} + B_V \Omega \tag{3.42}$$

Assume torque load $T_L = 0$.

$$i = \frac{J}{K_t}\frac{d\Omega}{dt} + \frac{B_V}{K_t}\Omega \tag{3.43}$$

Substitute equation (3.35) into equation (3.32)

$$U_d = r_a\left(\frac{J}{K_t}\frac{d\Omega}{dt} + \frac{B_V}{K_t}\Omega\right) + L_a\frac{d}{dt}\left(\frac{J}{K_t}\frac{d\Omega}{dt} + \frac{B_V}{K_t}\Omega\right) + K_e\Omega \tag{3.44}$$

$$U_d = L_a\frac{J}{K_t}\frac{d2_\Omega}{dt^2} + \frac{r_a J + L_a B_V}{K_t}\frac{d\Omega}{dt} + \frac{r_a B_V + K_e K_t}{K_t}\Omega \tag{3.45}$$

Using laplace transform

$$\boldsymbol{G}(\boldsymbol{S}) = \frac{\Omega(S)}{U_d(S)} = \frac{K_t}{L_a J S^2 + (r_a J + L_a B_V)S + r_a B_V + K_e K_t} \tag{3.46}$$

If the load torque is existed,

$$G(s) = \frac{\Omega(S)}{T_L(S)} = \frac{r_a + L_a S}{L_a J S^2 + (r_a J + L_a B_V)S + r_a B_V + K_e K_t} \tag{3.47}$$

Similarly, the mechanical properties of the dc motor, from the newtons second law of motion, the mechanical properties relative to the torque of the system. the product of the inertia load J, and the rate of angular velocity, w is equal to the sum of all the torques;
Considering the following assumptions;

1, the friction constant is small, that is, B_v tends to 0 this implies that

2. RJ >> $B_v L$ and

3. $k_e k_t$ >> RB_v

And the negligible values zero, the transfer function is finally written as;

$$G(s) = \frac{k_t}{(s^2 JL + SRJ + k_e k_t)} \quad (3.48)$$

Both side divide $\frac{1}{k_e k_t}$ of equation 3.40 I get,

$$\frac{\frac{1}{k_e}}{(\frac{RJ}{k_e k_t}\frac{L}{R}\ s^2 + S\frac{RJ}{k_e k_t} + 1)} \quad (3.49)$$

Let the mechanical time constant τ_m,

$$\tau_m = \frac{RJ}{k_e k_t} \quad (3.50)$$

The electrical time constant

$$\tau_e = \frac{L}{R} \quad (3.51)$$

Then the transfer function becomes,

$$G(s) = \frac{\frac{1}{k_e}}{(\tau_m \tau_e\, s^2 + \tau_m S + 1)} \quad (3.52)$$

For brushless dc three phase motor,

$$\tau_m = \varepsilon\ \frac{RJ}{k_e k_t} = J\ \frac{\varepsilon R}{k_e k_t} \quad (3.53)$$

$$\tau_m = J\ \frac{3R}{k_e k_t} \quad (3.54)$$

$$\tau_e = \frac{L}{\varepsilon R} = \frac{L}{3R} \quad (3.55)$$

$$k_e = \frac{k_e(L-L)}{\sqrt{3}} \quad (3.56)$$

Table 3. 4 specification of brushless dc motor [17].

Power, P	Kw	2.38 kw
Resistance	Ohm	3.58
Inductance	MH	9.12
Torque constant	Nm/A	0.74
Speed	Rpm	2600
Dc voltage(vdc)	V	325
Current	A	7.35
Back emf constant	V-sec/rad	0.745
Rotor inertia	Kg.cm2	2.9
Number of phases		3

From the above specification the transfer function becomes

$$G(s) = \frac{\frac{1}{k_e}}{(\tau_m \tau_e\, s^2 + \tau_m S + 1)} \quad (3.57)$$

$$\tau_m = J\ \frac{3R}{k_e k_t} = \frac{0.00029\text{kg.m2} * 3 * 3.58}{0.745 * 0.74} = \frac{0.0031146}{0.5513} = 0.00565 \quad (3.58)$$

$$\tau_e = \frac{L}{3R} = \frac{0.00913}{3 * 3.58} = 0.00085 \quad (3.59)$$

$$G(s) = \frac{\frac{1}{k_e}}{(\tau_m \tau_e\, s^2 + \tau_m S + 1)} = \frac{\frac{1}{0.745}}{0.00565 * 0.00085\, s^2 + 0.00565S + 1)} = \frac{1.342}{0.0000048\, s^2 + 0.00565S + 1} \quad (3.60)$$

If load is existed,

$$G_L(S) = \frac{r_a + L_a S}{L_a J S^2 + r_a J\, S + K_e\, K_t} = \frac{\frac{1}{K_e\, K_t}(r_a + L_a S)}{\frac{1}{K_e\, K_t}(\, L_a J S^2 + r_a J\, S + K_e\, K_t)} = \frac{\frac{r_a}{K_e\, K_t} + \frac{L_a S}{K_e\, K_t}}{\frac{L_a J S^2}{K_e\, K_t} + \frac{r_a J\, S}{K_e\, K_t} + 1} \qquad (3.61)$$

Interms of designing, a centrifugal submersible pump is selected by estimating the proportionality constant K, utilizing the accompanying relationship as;

$$T_L = \frac{POWER}{SPEED} = \frac{2810}{2*\pi*2600/60} = 10.32 \qquad (3.62)$$

CHAPTER FOUR

CONTROLLER DESIGN

By far the most popular type of feedback in use today is the PID controller. The proportional-integral-derivative controller is frequently employed in the process industries due to its functional simplicity and performance resilience.

A PID controller tries to correct the difference between a measured process variable and a desired set point by calculating and then outputting a corrective action that can change the process. Optimization strategies are used to create and tune PID controller parameters. Tuning methods for PID controllers have been developed, including Ziegler-Nichols rules, Cohen-Coon rules, and so on. These approaches are used right away since they offer straightforward tuning guidelines for determining PID settings. However, because they rely on a small amount of dynamic information and make assumptions about the nature of the controlled k_p, K_i, K_d process, such as linearity, weak interactions within the process, and the lack of noise, they rely on a small quantity of dynamic information [19].

Three-term control is frequently referred to as PID control. Three distinct constant parameters are used in the PID controller computation [20].

1. Proportional term

2. Integral term

3. Derivative term

PID controller can be described by the following equation.

$$\mathrm{U} = K_P \mathrm{e} \ + K_I \int edt \ + K_d \frac{de}{dt} \tag{4.1}$$

Taking Laplace transform I get,

$$\mathrm{U(s)} = \ (K_P(s) \ + K_i(\frac{1}{s}) + K_d\mathrm{(s)}\ \mathrm{e(s)} \tag{4.2}$$

$$\mathrm{E(t)} = y_s(t) \ - \mathrm{y(t)} \tag{4.3}$$

Because real-world processes are non-linear and complicated, the realized closed loop response is less than ideal.

4.1 PID Controller

Despite considerable advancements in sophisticated control theory, the proportional-integral-derivative (PID) controller has been the most widely used controller in the process industries for more than 60 years. Different types of controllers are employed nowadays in many different domains, including the industrial sector. These controllers can often be split into two categories: traditional and modern.

The traditional controllers, including P, PI, PD, PID and other controller types, have been around for a while. If the controller settings are properly calibrated, a PID controller can be used to handle a variety of nonlinear industrial processes [19] . To automate a specific more complex process in an industrial assembly, a bigger number of simple PID controllers are employed to regulate simpler processes as opposed to a smaller number of complex controllers. Today, PID controllers and its several varieties, such as P, PI, and PD controllers, serve as the fundamental building blocks in the control of many processes [21].

The most fundamental kind of controllers is the PID controller. It is a versatile feedback controller that may be used for a wide range of applications. Its three building blocks represent all the features required to govern the dynamic response of the system.

Table 4.1 effect of each PID control parameters

Parameter	Rise time	overshoot	Settling time	Steady state error	Stability
Increasing K_P	Decrease	Increase	Small increase	Decrease	Degrade
Increasing K_I	Small decrease	Increase	Increase	Large decrease	Degrade
Increasing K_D	Small decrease	Decrease	Decrease	Minor change	Improve

Because PID controllers are typically under-tuned for systems with the attributes listed above, tuning requires a higher level of expertise and technology. Natural-inspired algorithms have recently been developed in evolution (genetic algorithms, etc.), neurology (artificial neural networks), immunology (artificial immune systems), and social networks (ant colony optimization, particle swarm optimization). optimization, bee's algorithm, and others) have paved the way for a new era of advanced process control. Stochastic search approaches, particle swarm optimization, and genetic algorithms optimization techniques are among the techniques discovered and have found a position in parameter tuning. When it comes to tweaking the parameters of PID controllers, genetic algorithms and particle swarm optimization are far superior. Social networks, (artificial immune systems) (ant colony optimization, particle swarm optimization, bee's algorithm, etc),

4.2 Tuning PID controller using particle swarm optimization algorithm

Particle swarm optimization (PSO) approach for generating optimal PID controller tuning settings is used in this thesis to develop a Proportional-Integral-Derivative (PID) controller for solar water pumping for irrigation. The suggested method has several advantages, including ease of implementation, consistent convergence properties, and high computing efficiency. The PID-PSO controller for solar water pumping for irrigation is modelled in the MATLAB environment. When compared to a traditional PID controller, the planned method or PID -PSO controller is more capable of improving the speed loop response stability, the steady state error is reduced, the rising time is perfected, and changes in the required input have no effect on the driving motor's performance with no overtaking. Because they are simple and reliable, PID controllers are commonly utilized in industrial operations. Variations in parameters and parameter perturbations are common in industrial processes, and when they become severe, the system becomes unstable. As a result, control engineers are looking for ways to automate tuning procedures. Particle Swarm Optimization (PSO) approaches have been used to handle complicated optimization problems with great success. PSO, which was first introduced by Kennedy and Eberhard, is a modern heuristic algorithm inspired by organism behavior such as fish schooling and bird flocking. PSO is known for being a simple concept, simple to implement, and computationally efficient. PSO, unlike other heuristic algorithms, has a flexible and well-balanced mechanism for improving global and local exploration capabilities [22, 23]. The time-domain PID controller is;

$$u(t) = Kp\, e(t) + Ki \int e(t)dt + Kd\, de(t)\, dt \tag{4.4}$$

Where the proportional gain is K_p, the integral gain is K_i, and the derivative gain is K_d. The tracking error, denoted by the variable e(t), is the difference between the desired input value r(t) and the actual output, denoted by the variable y(t). The rising time is reduced by a proportional controller K_P, but the steady-state error is not. A crucial control K_i has the effect of eliminating steady-state error, but it may have a negative influence on transient reaction. The impact of a derivative control K_d is to reduce overshoot and improve transient response.

To find the best set of PID gains K_p, K_i, K_d. The most frequent performance criteria in PID controller design approaches are integrated absolute error (IAE), integrated time square error (ITSE), and integrated time absolute error (ITAE).

These three frequency-domain performance criteria each have their own set of benefits and drawbacks. For example, because the ISE performance criterion weights all errors identically regardless of time, reduction of the IAE and ISE criteria can result in a response with very modest overshoot but a considerable settling time. Although the ITSE performance criterion can solve the ISE criterion's shortcoming, the analytical formula's derivation techniques are complex and time-consuming [22].

The IAE, ISE, and ITSE performance criterion formulas are as follows:

$$\text{IAE} = \int_0^\infty |r(t) - y(t)|\, dt = \int_0^\infty |e(t)| dt \tag{4.5}$$

$$\text{ISE} = \int_0^\infty e^2(t) dt \tag{4.6}$$

$$\text{ISTE} = \int_0^\infty t e^2(t) dt \tag{4.7}$$

The objective function: minimize of error.

$$\text{J} = \int_0^\infty |e(t)| dt \tag{4.8}$$

4.2.1 Particle Swarm Optimization

Kennedy and Eberhart proposed the PSO algorithm for the first time in 1995 [25, 23]. Particle Swarm Optimization is abbreviated as PSO. It is determined by the behavior of a colony or swarm of insects like bees, termites, ants, and wasps, as well as a school of fish or a flock of birds. The PSO algorithm is designed to imitate the behavior of social organisms. The word particle refers to a colony of bees or a flock of birds. In a swarm, each individual or particle uses its own intelligence as well as the swarm's collective or group intelligence to behave in a distributed manner. For example, if one particle discovered the best food path, the rest of the swarm would be able to follow it as well. The swarm is assumed to be of a certain or constant size in multivariable optimization, with each particle starting at random places in the multidimensional design space. Initially, each particle was considered to have two properties: a position and a velocity. Each particle moves around in the design space, remembering the best spot it finds in terms of food source or objective function values. The particles exchange information or good positions with one another, and then adjust their individual positions and velocities in accordance with the information received about the best positions [24, 22, 21]. The particle velocity and position of the standard PSO can be updated by the following equations:

$$V_{i,j}{}^{k+1} = \text{w} * V_{i,j}{}^{k} + \text{c1} * \text{rand} * (Pbest_{i,j}{}^{k} - x_{i,j}{}^{k}) + \text{c2} * \text{rand} * (Gbest_{j}{}^{k} - x_{i,j}{}^{k}) \quad (4.9)$$

$$x_{i,j}{}^{k+1} = x_{i,j}{}^{k} + V_{i,j}{}^{k+1} \quad (4.10)$$

Where V (i, j) is the j[th] particle's velocity at iterations, x (i, j) is the j[th] particle's position at iterations, C1 and C2 are the cognitive individual and social group learning rates, rand1 and rand2 are uniformly distributed random numbers in the range 0 to 1, and N is the number of particles in the swarm The regular PSO method is improved by adding an inertia weight function. Shi and Eberhart introduced the inertia weight W in 1999 [14]. To damper the velocities over time, the inertia weight W was introduced to the velocity equation (or iterations). In comparison to the original PSO method, this dampening allows the swarm to converge more correctly and efficiently. This enhancement enhances the PSO's ability to fine-tune its ability to identify precise solutions. A higher W value improves the PSO's global exploration, whereas a lower W value improves the local search. As a result, a big W number causes the algorithm to repeatedly explore new areas with little local search, and so fails to locate the genuine optimum. To achieve a balance between global and local exploration and to speed up convergence to the true optimum, the value of an inertia weight has to decrease linearly with the iteration number, as shown in equation 4.11.

$$\text{W(k)} = w_{max} - (\frac{w_{max} - w_{min}}{k_{max}})\text{k} \quad (4.11)$$

Where, w_{max} is the maximum value of the inertia weight, w_{min} is the minimum value of the inertia weight, k_{max} is the maximum number of iterations used in PSO and k is the current iteration. The speed of the particles in swarm with the term of inertia is;

$$V_{i,j}{}^{k+1} = \text{w } V_{i,j}{}^{k} + \text{c1* rand *}(Pbest_{i,j}{}^{k} - x_{i,j}{}^{k}) + \text{c2*rand*}(Gbest_{j}{}^{k} - x_{i,j}{}^{k}) \quad (4.12)$$

Where,

$V_{i,j}$ is the velocity vector of particle in dimension j at time k;

$x_{i,j}$ is the position vector of particle in dimension at time;

$Pbest_j$ is the personal best position of particle in dimension j found from initialization through time k;

$Gbest_j$ is the global best position of particle in dimension j found from initialization through time k;

C1 and C2 are positive acceleration constants which are used to level the contribution of the cognitive and social components respectively;

Rand () are random numbers from uniform distribution (0,1) at time k.

suppose in PSO, a swarm consists of N number of particles moving around in a D dimensional search space. The i^{th} particle denoted as;

$$X_i = (X_{i1}, X_{i2}, \ldots\ldots X_{iD}) \tag{4.13}$$

whose previous best solution P_{best} is represented as;

$$P_i = (P_{i1}, P_{i2}, \ldots\ldots\ldots P_{iD}) \tag{4.14}$$

And the current velocity is described by;

$$V_i = (V_{i1}, V_i2, \ldots\ldots\ldots V_{iD}) \tag{4.15}$$

Finally, the best solution of whole swarm g_{best} also called global best is represented as;

$$P_g = (P_{g1}, P_{g2}, \ldots\ldots\ldots\ldots P_{gD}) \tag{4.16}$$

At each time step, each particle moves towards the P_{best} and g_{best} locations. the fitness function evaluates the performances of particles to determine whether the best fitting solution is achieved. The detailed PSO algorithm procedure can be implemented through the following steps;

The main steps in the particle swarm optimization and selection process are described as follows:

1. Initialize a population of particles with random positions and velocities in d dimensions of the problem space and fly them.
2. Evaluate the fitness of each particle in the swarm.
3. For every iteration, compare each particle's fitness with its previous best fitness ($pbest$) obtained. If the current value is better than $pbest$, then set $pbest$ equal to the current value and the $pbest$ location equal to the current location in the d-dimensional space.
4. Compare $pbest$ of particles with each other and update the swarm global best location with the greatest fitness ($gbest$).
5. Change the velocity and position of the particle.
6. Repeat steps (1) to (5) until convergence is reached based on some desired single or multiple criteria.

This problem considers a number of time domain integral performance indicators, such as IAE, ITAE and ITSE. Every integral performance index has its own set of benefits when it comes to control system design. When the parameters of a system are altered to the point that the fitness(cost) function reaches an extreme value, usually a low value, the system is considered an optimal control system.

4.2.2 Selection of PSO Algorithm Parameters

A number of time domain integral performance indicators, such as ITAE and ITSE, are considered in this problem. When it comes to control system design, each integral performance metric has its own set of advantages.

An optimal control system is one in which the parameters of a system are changed to the point where the fitness(cost) function reaches an extreme value, usually a low one [1, 19].

Swarm size

This problem considers a number of time domain integral performance measures, such as ITAE and ITSE. Each integral performance metric has its own set of advantages when it comes to control system design. The parameters of a system are altered to the point where the fitness(cost) function reaches an extreme value, usually a low value, in an optimal control system [24] .

Iteration numbers

The number of iterations required to achieve a satisfactory result is also determined by the problem. A small number of iterations may cause the search to end early, whereas a large number of iterations adds additional processing complexity and lengthens the time required [12].

Velocity Components

For updating the particle's velocity, the velocity components are crucial. The velocity of a particle has three terms.

I. The term ${V_{i,j}}^k$ refers to the inertia component, which serves as a recollection of the prior flight direction, implying movement in the past. This component indicates momentum, which prevents the particles from drastically changing their orientation and biasing towards the current direction.

II. The term C1 ∗ rand ∗ (${pbest_{i,j}}^k - {x_{i,j}}^k + 1$ refers to the cognitive component, which gauges the particle's performance in comparison to previous performances. This component appears to be an individual memory of the particle's optimal position. The cognitive component's effect shows people's proclivity to return to situations that have previously satisfied them. The particle's cognitive component is referred to as nostalgia.

III. The termC2 $*$ rand $*$ $(Gbest_j{}^k - X_{i,j}{}^k + 1)$ for Gbest PSO refers to the social component, which gauges the particle's performance in comparison to a group of particles or neighbors. The impact of the social component is that each particle flies to the best site discovered by the particle's neighbors.

Acceleration coefficient

The stochastic influence of the cognitive and social components of the particle's velocity is maintained by the acceleration coefficients c1 and c2, as well as the random value rand(). The constant indicates a particle's trust in itself, while the variable expresses a particle's confidence in its neighbors. The following are some of the qualities of c1 and c2 are:

• When c1 = c2 , all particles are attracted towards the average of $Pbest_{i,j}{}^k$ and $Gbest_j{}^k$.

• When c1 >> c2, each particle is more strongly influenced by its personal best position, resulting in excessive wandering. In contrast, when c1 << c2 then all particles are much more influenced by the global best position, which causes all particles to run prematurely to the optima.

Inertia weight

Shi and Eberhart created the inertia weight in 1999 to reduce velocities over time (or iterations), regulate the swarm's exploration and exploitation abilities, and more correctly and effectively converge the swarm.

If W ≥ 1, then the velocities increase over time and particles can hardly change their direction to move back towards optimum, and the swarm diverges.

If W ≪ 1, then little momentum is only saved from the previous step and quick changes of direction are to set in the process.

If W = 0, particles velocity vanishes and all particles move without knowledge of the previous velocity in each step. To control the balance between global and local exploration, to obtain quick convergence, and to reach an optimum, the inertia weight whose value decreases linearly with the iteration number is set according to the following equation.

$$W(k) = w_{max} - (\frac{w_{max} - w_{min}}{k_{max}})k \tag{4.17}$$

Commonly, the inertia weight decreases linearly from 0.9 to 0.4 over the entire run.

Fitness Function

In general, the optimal control cannot be clearly defined. A solution that is best for one application under a certain set of circumstances may not be best for another problem. In this scenario, optimal constants can be produced by specifying a performance criterion and minimizing the value of such a performance index, as necessary for an economic and practical problem.

CHAPTER FIVE

SIMULUATION STUDIES AND ANALYSIS RESULTS

5.1 Simulation Scenario

In this chapter analysis of PID controller-based plant watering system that gives good performance in terms of parameter variation. And how the MATLAB/SIMULINK models of the proposed PV power systems are implemented to test and verify the functionality of the proposed PID controllers. PV system is simulated in MATLAB, with a dc water pump load to demonstrate the feasibility and performance of the proposed particle swarm algorithm based PID controller of water pumping system for irrigation system.

5.2 Simulink Modelling

MATLAB/Simulink is a software package which is used to model, simulate, and analyze dynamic systems. Simulink has the advantage of being capable of complex dynamic system simulations, graphical environment with visual real time programming and broad selections of toolboxes. The mathematical equations presented in chapter three are used to model the brushless dc motor for water pumping system in MATLAB/Simulink R2018a environment.

To ensure the improved performance of the proposed approach of PID control optimized with the PSO method.

For irrigation the reference input is the moisture value of the soil. The input to the PID is error signal which is the difference between the set Point (SP) and the measured process variables. If the value of the error signal is positive, the set point is higher than the measured moisture, then the system will send the signal to the controller and in a couple of minutes the moisture of the crops will increase its level. when the value of the error becomes negative the system will send the signal to the controller and in a couple of minutes the moisture of the crops will decrease its level. The input parameters are moisture value of the soil (with range of 1 to 5). The dry moisture value is also the higher water requirement.

Table 5.1 Tuning PSO-method comparative analysis

PSO	k_p	k_i	k_d	f_{val}
IAE	4.0736	1.178	2.1938	0.28
IATE	0.2255	2.7183	0.0001	0.0589
ISE	0.3508	2.9103	0.0001	0.2228

Table 5.2 Tuning PSO-method comparative analysis

Tunning	k_p	k_i	k_d	Rise time	Settling time	Overshoot
PSO-PID	0.2255	2.7183	0.0001	0.719	2.2912	0
Auto tunning	0.148	1.804	0.048	0.3357	2.5671	2.7129

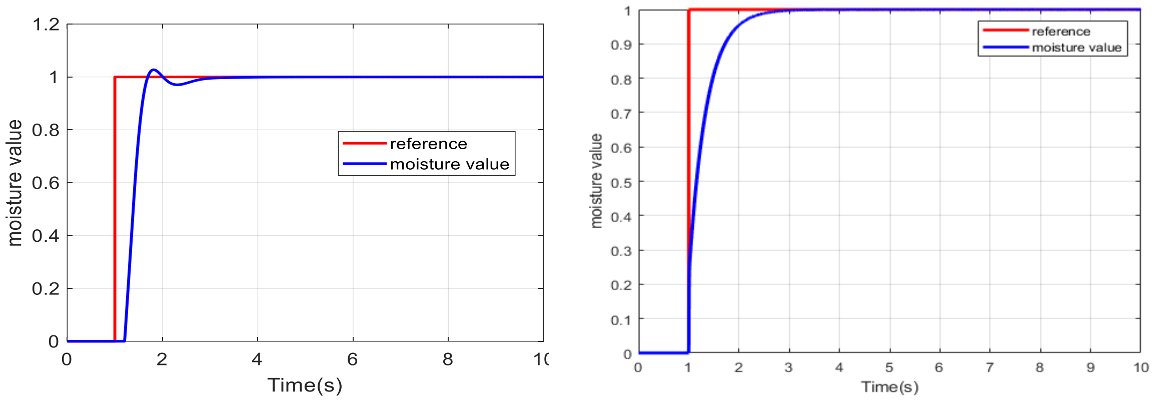

Figure 5.1 step response of tuning PID controller with automatic and PSO

In figure 5.1 in PID-PSO tunning of the IATE objective function the performance is better than automatic tunning methods of controller that is overshoot, settling time and rise time are better. But, in automatic tunning method is worse performance with pso tunning method of pid controller. The moisture value is dry the crop requires water then the motor shaft rotates and the pump pumping water to the crops.

The output of the PV array is recorded in different level of irradiation (1000, 500, 100) w/m2 at 25°C, as well as different environmental temperature (45, 25) at standard irradiation values or random value of temperature and irradiation level and the result of the characteristics curves are shown in figures below.

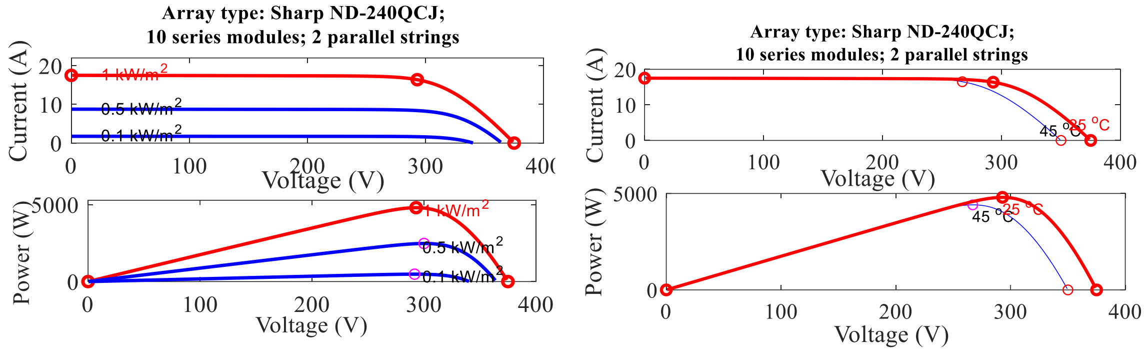

Figure 5.2 V-I and V-P characteristic of pv array at specified irradiation and temperature

In fig 5.2 the effect of irradiation at standard level of temperature is displayed. The irradiation had directly relationship with current and voltage, as the irradiation increased the current also increased and the voltage had slowly increased. The impact of temperature on current voltage and power is evident; as temperature rises, the voltage on the current decreases but the generated current increases. The output current and voltage have to be at their highest levels to get the most power; this phenomenon happens when the temperature is low.

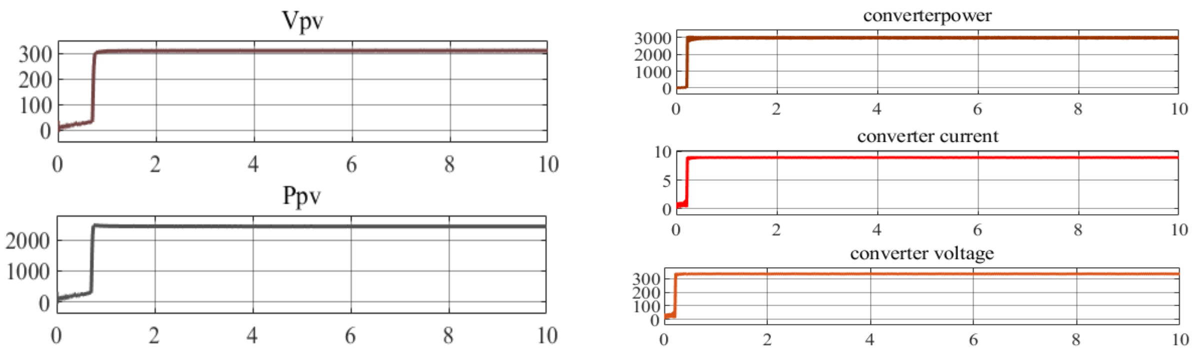

Figure 5.5 performance of SPV array and dc-dc converter at STC

Figure 5.5 observed that the PID-based MPPT technique can track maximum power of 2813 with a maximum voltage of 300v. it also observed that the proposed mppt has excellent tracking efficiency. While in dc-dc converter figure performance of the DC-DC boost converter where the converter output current is 8.66 and converter voltage Vd is maintained at 325 V.

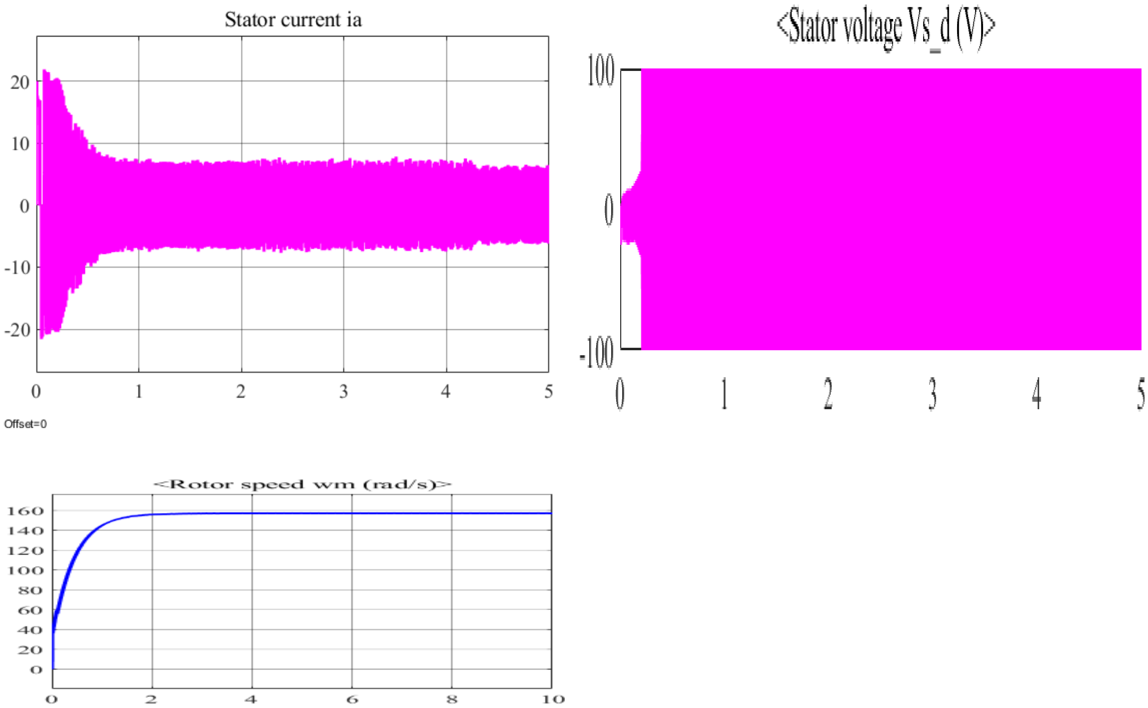

Figure 5.6 performance of BLDC motor under STV of SPV array

In figure 5.6 the BLDC motor builds up the rated speed at full load to derive the water pump. Smooth starting of bldc motor is also observed in speed -time characteristic curve.

In dynamic change of change in solar irradiance from Proposed mppt also successfully able to track maximum power.

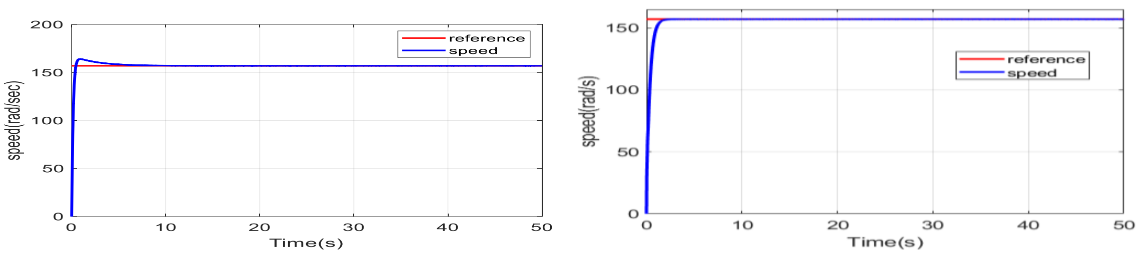

Figure 5.11 comparison of PI and PID Controller based rotor speed of solar fed bldc motor

In figure 5.11 observed that speed tracking of PI controller and PID controller comparison. in PI controller overshoot is high, but in PID controller overshoot is minimized.

CHAPTER SIX

CONCLUSION AND RECOMMANDATION

6.1 CONCLUSION

In this thesis, non-electrical input based PID mppt is introducing for solar power water pumping system using brushless dc motor. Solar water pumping system for automated irrigation is presented to supply water in remote location. And uses for irrigation of plants. Solar Water Pumping was an important development for this world because agriculture is the basic element for the growth of every nation. In agriculture the main part is irrigation this is developing day by day by using new technologies.

Comparing with other tuning method for PID controller using particle swarm optimization algorithm, this method is more proficient in improving the speed loop response stability, the steady state error is reduced, the rising time is perfected and the change of the required input do not affect the performances of driving motor with no overtaking. PID controllers are widely used in industrial plants because it is simple and robust. Industrial processes are subjected to variation in parameters and parameter perturbations, which when significant makes the system unstable. So, the control engineers are on look for automatic tuning procedures.

Soft starting of BLDC motor is also achieved using a proposed method which is desirable for smooth operation of the motor pump set.

6.2 FUTURE WORKS

In this thesis I considered for designing a controller which stabilizes and improve the performance of the system by applying PID controller using PSO tuning algorithm, but there are other optimization techniques like Local Search Optimization, Sequential Quadratic Programming, genetic algorithm, Ant colony optimization algorithm and cocko search those may improve the performance of controllers. This thesis is focused on the design of PSO tuned PID controller to see the effect of robustness and performance of the system in MATLAB software simulation. the performance evaluations will not be done on real hardware, so the thesis can be also extended for hard ware implementation. In addition to these use sensors like moisture sensor. humidity and temperature sensors and improve automatic systems. And also Use solar batterys if day is cloud.

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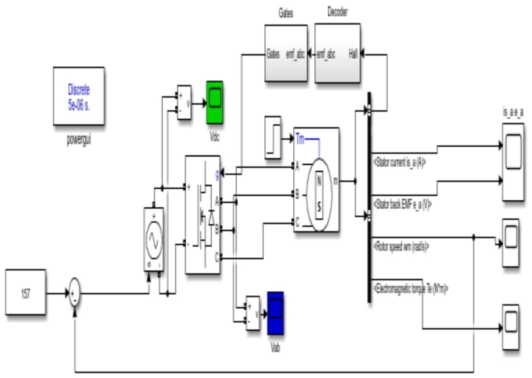
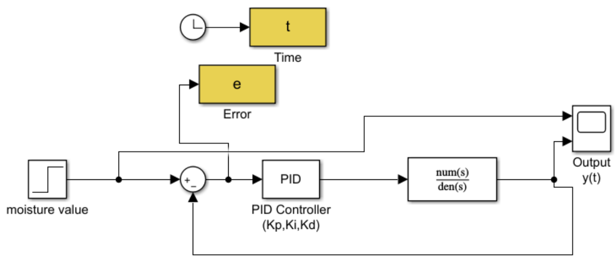
APPENDIX A

Open loop model of brushless dc motor



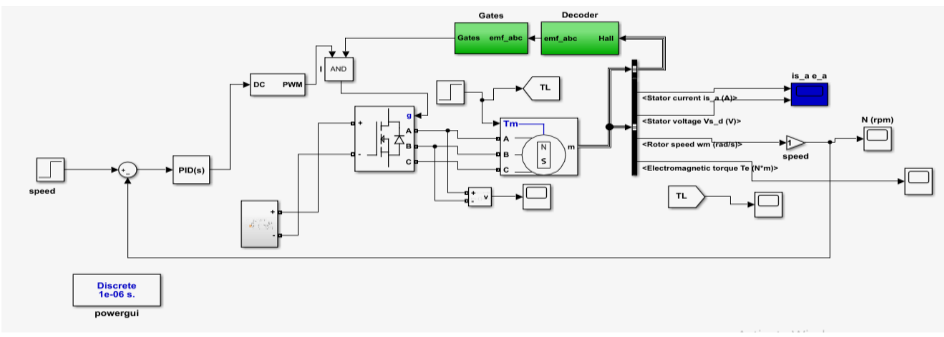
APPENDIX B

simulink model of pso tuned pid controller



APPENDX C

PID Controller based solar water pumping system using PSO algorithm



APPENDIX D

Proportional integral derivative controller tuned particle swarm optimization algorithm

```
function Tune_PIDModel1_SP1
clear all
nvar= 3; % Number of parameters
% iteration = 1;
% max iteration = 100;
LB= [0.0001 0.0001 0.0001]; % Lower bound of tuning parameters
UB= [5 5 5]; % Upper bound of tuning parameters
options=optimoptions('particleswarm','swarmsize',20,'MaxIterations',20,'display','iter','plotFc
n',@pswplotbestf);
[x,fval]= particleswarm(@EvalObj,nvar,LB,UB,options)

% Updates Kp, Ki and Kd in simulink model workspace for verification
simulink_model= 'PIDModel1_SP';
load_system(simulink_model);
gains= get_param(simulink_model,'modelworkspace');
gains.assignin('Kp', x(1));
gains.assignin('Ki', x(2));
gains.assignin('Kd', x(3));

function obj= EvalObj(x)
% Updates the values of Kp, Ki and Kd in Simulink model workspace
simulink_model= 'PIDModel1_SP1';
load_system(simulink_model);
gains= get_param(simulink_model,'modelworkspace');
gains.assignin('Kp', x(1));
gains.assignin('Ki', x(2));
gains.assignin('Kd', x(3));

% Simulates the simulink model to get the outputs
simOut= sim(simulink_model,'SaveOutput','on');

% Retrieves time t and error e
t= simOut.find('t');
e= simOut.find('e');+

% Calculate a performance index using the trapezoidal integration rule
n= length(e);
ee= abs(e);
obj= 0;
for i= 2:n
    stepsize= t(i)-t(i-1);
%     obj= obj+0.5*(ee(i-1)+ee(i))*stepsize; % IAE
```