

**DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING**

**NORTH SOUTH UNIVERSITY**



**SENIOR DESIGN PROJECT**

**FLOATING PHOTOVOLTAIC DUAL AXIS SOLAR TRACKER:  
Wave model and its effect on the tilt angle**

**Shahriar Ahmed Khan Kaif      ID# 1721492043**

**Md. Abdullah Al- Hamim      ID# 1712678643**

**Nazifa Reza      ID# 1631304043**

**Fatin Anwar      ID# 1620901043**

**Faculty Advisor:**

**Dr. Md. Shahriar Karim**

**Assistant Professor**

**Department of Electrical and Computer Engineering**

**Spring, 2021**

## DECLARATION

This is to declare that this is an original report of our senior design project, has been written by us, and has not been submitted for any previous degree or program. The experimental work is entirely our work; the collaborative contributions from any additional materials have been indicated clearly and acknowledged.

*Shahriar Ahmed Khan Kaif*

---

Shahriar Ahmed Khan Kaif  
Electrical and Computer Engineering (ECE)  
North South University, Bangladesh

*Shahriar Ahmed Khan Kaif*

---

Md. Abdullah Al- Hamim  
Electrical and Computer Engineering (ECE)  
North South University, Bangladesh

*Md. Abdullah Al- Hamim*

---

Nazifa Reza  
Electrical and Computer Engineering (ECE)  
North South University, Bangladesh

*Nazifa Reza*

---

Fatin Anwar  
Electrical and Computer Engineering (ECE)  
North South University, Bangladesh

## APPROVAL

The senior design project titled “**FLOATING PHOTOVOLTAIC DUAL AXIS SOLAR TRACKER: Wave model and its effect on tilt angle**” by **Shahriar Ahmed Khan Kaif (ID#1721492043)**, **Md. Abdullah Al- Hamim (ID# 1712678643)**, **Nazifa Reza (ID# 1631304043)**, and **Fatin Anwar (ID# 1620901043)** has been accepted as satisfactory and approved in partial fulfillment for the requirement of the Degree of Bachelor of Science in Electrical and Electronics Engineering for the Spring semester of 2021.

### Supervisor’s Signature:



Md. Shahriar Karim  
Assistant Professor  
Department of Electrical & Computer Engineering  
North South University

---

### Dr. Md. Shahriar Karim

Assistant Professor

Department of Electrical and Computer Engineering

North South University

Dhaka, Bangladesh.

### Department Chair’s Signature:

---

### Dr. Mohammad Rezaul Bari

Associate Professor and Chair

Department of Electrical and Computer Engineering

North South University

Dhaka, Bangladesh.

## ACKNOWLEDGEMENT

First and foremost, we would like to express our deep and sincere gratitude to our honorable faculty advisor, **Dr. Md. Shahriar Karim**, for his guidance, supervision, and encouragements that pushed us to complete a final design project of this standard.

We would also like to extend our thanks to North South University for allowing us to experience an industrial-level understanding during the course of our undergraduate program.

Lastly, we would like to express our thanks to our family and friends for their constant moral support that helped keep us motivated throughout.

## ABSTRACT

This report presents the design and practical implementation of a cost-effective floating active photovoltaic dual-axis solar tracker (PV DAST) that can keep track of the sun's movement every hour from sunset to sunrise. The performance of a solar panel is maximum when the incident solar radiation is normal on the surface of the panel. For obtaining the best results, in terms of collected energy, the PV DAST must first be appropriately aligned towards the sun and tilted at the optimum angle. The optimization of the tilt angle of the solar panels aims to maximize the solar energy collected, thus reducing the active solar-thermal surface with the constant maintenance of thermal energy production, installation, maintenance cost, etc. In our project, we mainly focused on the rotating and floating structures of the plant. This system is mainly based on following a light source by angling the PV panel through two servo motors, ideally in the direction of sunlight rays. For higher efficiency, the solar panel has to track in two axes, the elevation and altitude axis. Hence, dual-axis tracking system. DASTs move along with the two fundamental directions, horizontal and vertical, making them more flexible and adaptable in constantly following the moving sun in any direction, whether from east to west or seasonal, without losing any sunlight. Our main objective was to study the effect of water waves on the tilt angle of the solar PV panel and overall produced energy from the system. This paper discusses the development of a floating dual-axis mechanism that absorbs shock from incoming wind and water waves and, in turn, keeps its initial resting angle constant. The floating PV (FPV) can adjust with the wind and wave partition to find the best tilt angle.

## Table of Contents

<b>CHAPTER 1: Introduction to Floating PV DAST System</b> .....	9
1.1 Introduction .....	10
1.2 Floating Solar PV System .....	10
1.3 Summary.....	12
<b>CHAPTER 2: Dual-Axis Solar Tracking System</b> .....	13
2.1 Introduction .....	14
2.2 Working Principle of a PV DAST system .....	15
2.3 Difference between a Fixed panel and a Dual-Axis tracker .....	17
2.4 Advantages and Disadvantages of DAST.....	18
2.4.1 Breakdown of Advantages .....	18
2.5 Summary.....	19
<b>CHAPTER 3: Floating Solar PV System</b> .....	20
3.1 Introduction .....	21
3.2 Floating Solar PV Plant.....	21
3.3 Combination of DAST System and Floating Solar PV System .....	23
3.4 Advantages of Floating Solar PV Plant .....	23
3.5 Existing Plants .....	24
3.6 Summary.....	24

<b>CHAPTER 4: Project Overview .....</b>	<b>25</b>
4.1 Introduction .....	26
4.2 Project Description .....	26
4.3 Components .....	28
4.3.1 List of equipment.....	28
4.3.2 Circuit Diagram .....	29
4.3.3 Function of equipment.....	30
4.3.4 Mathematical analysis of Stepper Motor & Torque.....	32
4.3.5 Peak efficiency of solar panel .....	34
4.3.6 Floating Solar PV Structure .....	35
4.3.7 Cost Efficiency .....	35
4.4 Flowchart.....	36
4.5 Primary Target.....	36
4.6 Summary.....	37
<b>CHAPTER 5: Tilt Angle.....</b>	<b>38</b>
5.1 Introduction .....	39
5.2 Tilt Angle.....	39
5.3 Determination of the Optimum Angle of Tilt.....	39
5.3.1 Mathematical Approach .....	40
5.3.2 Practical Approach .....	41
5.4 Observation and Result .....	41
5.4.1 Data collected .....	42

5.5 Summary.....	44
<b>CHAPTER 6: Wave Model and its Effect on the Tilt Angle .....</b>	<b>45</b>
6.1 Introduction .....	46
6.2 Wave Model .....	46
6.3 Summary.....	51
<b>CHAPTER 7: Compliance with Standards .....</b>	<b>52</b>
7.1 Introduction .....	53
7.2 Compliance with IEEE Standards.....	53
7.3 Compliance with US Standards .....	53
7.4 Compliance with European Standards .....	54
7.5 Summary.....	54
<b>CHAPTER 8: Conclusion.....</b>	<b>55</b>
Bibliography .....	57
Appendices .....	61
Appendix A:.....	62

CHAPTER 1:

# Introduction to Floating PV DAST System

## 1.1 Introduction

In Bangladesh, we need more electricity to support our developing infrastructure. With the impending natural gas crisis, we have to think about alternative renewable energy resources. As a sub-tropical region, our country is perfect for solar radiation insolation. It is the cleanest source of energy which has the most negligible effect on the climate. Solar tracker devices ensure maximum efficiency by having the maximum intensity of sun rays hitting the panel's surface from sun-rise to sunset. Solar photovoltaic (PV) is the most common application in this instance. It is environmentally friendly, sustainable, and cost-efficient. Since the demand for power is increasing steadily, we use solar energy for most sectors, like transportation, home, industrial and commercial purposes. However, solar PV installation has become costly due to its intense land requirements. Thus, to meet the ever-increasing demands of solar energy usage, we have to utilize our water bodies to maximize power generation. The floating solar tracking PV plants are a buzzword in the solar market and are fast emerging as an alternative to land-based solar trackers.

## 1.2 Floating Solar PV System

In the wake of the emerging power crisis in Bangladesh, solar energy is the most attainable alternative for non-renewable energy. As solar insolation is abundantly available throughout the country, solar power can be generated from any suitable location. A solar system is a perfect solution to improve our power sector. Not only is it environmentally friendly, and it is also a cost-efficient energy source. Furthermore, it is free of energy and has reliable power. Although the prices of electricity are increasing rapidly, the prices of solar panels are declining. In recent years the most popular alternative for non-renewable energy has been photovoltaic (PV) plants.



*Fig. 1.* A Floating solar PV plant. *Source: Simemis.* This figure shows the design of a traditional floating solar PV plant. This consists of many solar panels which are floating together connected within a floating base. All of them work together to produce combined power output.

As solar power is becoming more and more in demand, the cost for its system installation is increasing due to its intense land requirements. Thus, as a solution, floating photovoltaic (PV) solar tracking systems have been creating much buzz in the solar market in recent years. A small number of such systems already exist in France, India, Japan, South Korea, the United Kingdom, Singapore and the United States. A floating solar tracking system has PV modules that are very lightweight and are mounted on anchored rafts, keeping them afloat on water body surfaces. Compared to land-based PV panels, floating type PV panels have several advantages - their efficiency can be increased by active cooling and tracking mechanism. The installation also offers additional advantages to the aquatic environment, which help in improving the water quality.

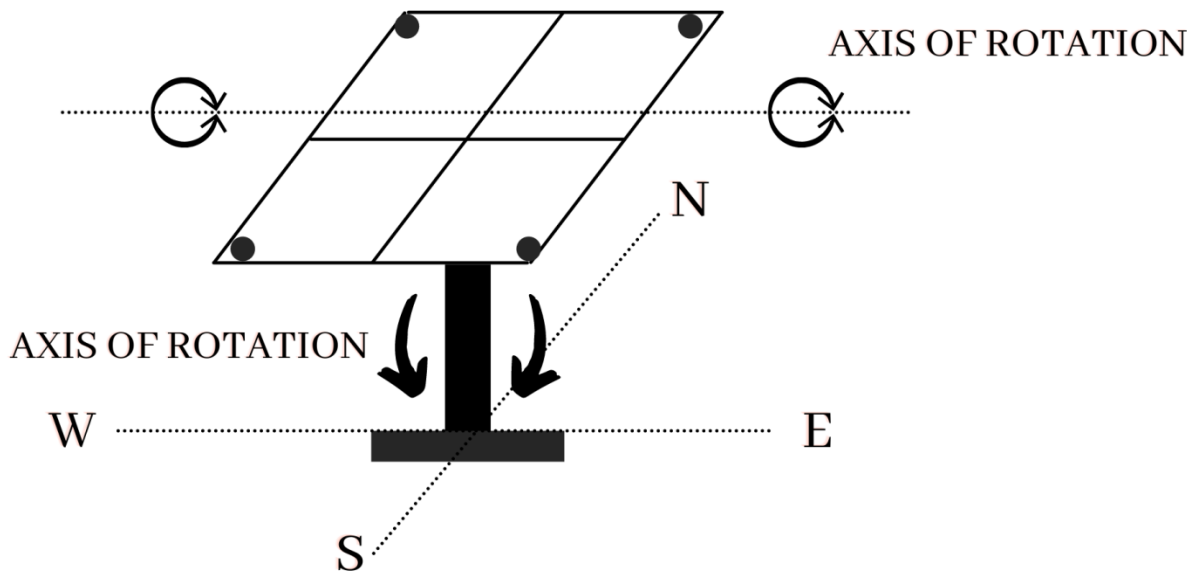
## 1.3 Summary

This chapter is a brief introduction to the floating PV DAST system. We discussed the background of the system. Furthermore, we mentioned how the latest technology could take on the impending natural gas crisis as it is renewable energy. We also mentioned how advantageous it is for both our environment and economy, which eventually motivated us to select this mechanism as our project.

CHAPTER 2:

# Dual-Axis Solar Tracking System

## 2.1 Introduction

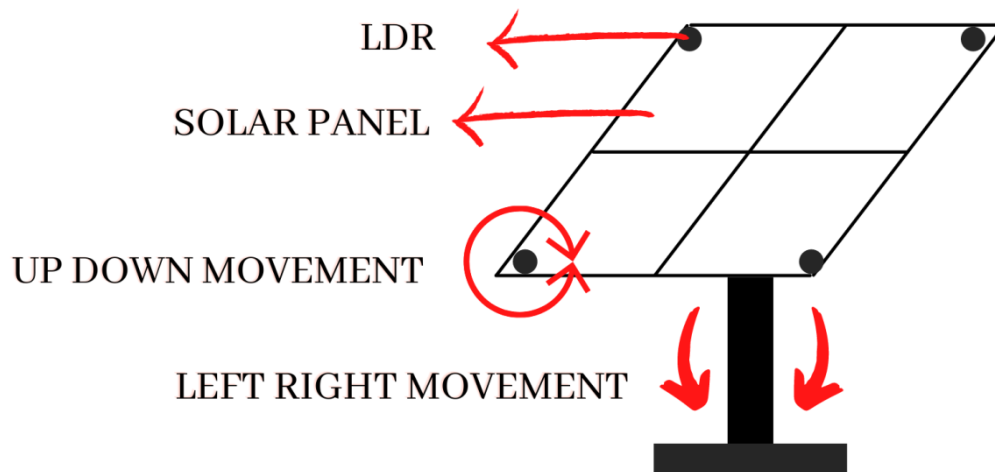


*Fig. 2.* Axes of Rotation of a PV DAST system. This 2D figure shows how the dual axis solar panel will move following the sun's direction. It contains 4 sensors which each corresponds to four side (NSEW)

DASTs have two degrees of freedom that act as axes of rotation, horizontal axis and vertical axis, as shown in fig. 2. These axes are characteristically normal to one another. Two standard applications of DAST are tip-tilt dual-axis trackers and azimuth-altitude dual-axis trackers [5]. The angle of the module to the sun's incidence is essential when observing modelling performance. DASTs typically have the modules parallel to the secondary axis of rotation [6]. No matter where the sun is situated in the sky, DASTs can angle themselves to direct contact with the sun's ray.

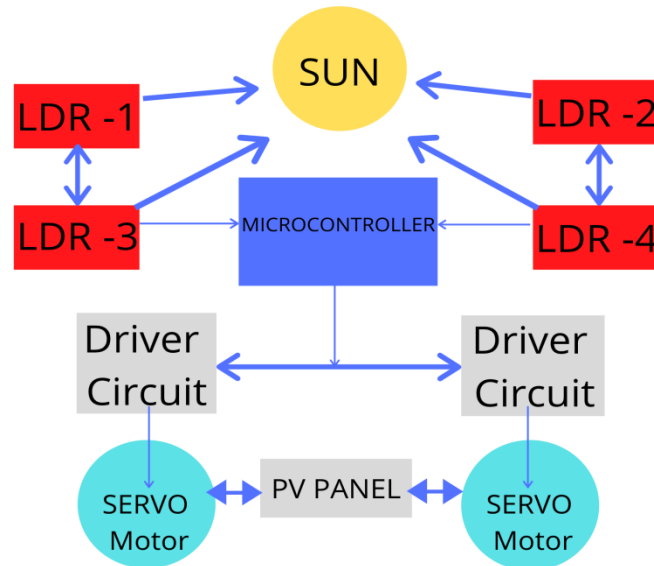
## 2.2 Working Principle of a PV DAST system

Initially, the panel stays fixed at a certain angle. The sun's position is tracked using 4 LDR sensors that are separated from each other to hide from each other.



*Fig. 3.* Direction of movement of a DAST system. Depending on the placement of sun. Here we can see how the solar panel will move according to the direction of sun tracking by the LDR's

From fig. 3, we can get an idea of how the solar panel will move according to the movement of the sun and the signal sent from the LDR, which will detect the sun's ray. The 4 Individual LDRs are responsible for moving the panel in the direction of the sensor with the most intensity of the sun's ray.



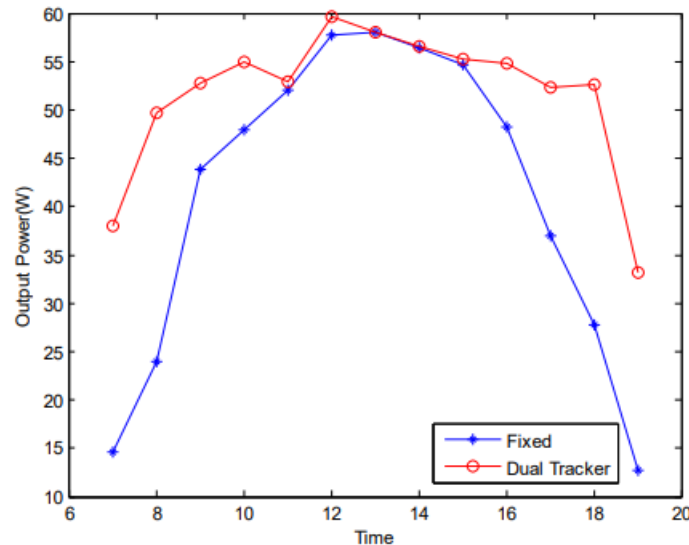
*Fig. 4.* Working principle of a DAST system. This flowchart is a summary of the whole working process of the dual axis solar tracker. This shows how sun, LDR, Microcontroller, Driver circuit and servo motor all work together to fluctuate the solar panel's movement

As shown in fig. 4, as the light falls on the LDR sensors the resistance decreases, the value of resistance from all these sensors are then sent to the Arduino UNO which then compares the data and generates an output [2]. The Arduino UNO sends the signal to the stepper gear and rotates the driver circuit to a particular angle tracking the sun at every hour to produce the output power.

The driver circuit consists of a driver gear that rotates the rotating platform in which the solar panel sits. It rotates according to the signal sent to the stepper motor by the Arduino UNO according to the processed signal of the LDRs. A linear actuator is sometimes also used to raise the panel base upwards, which can help make the detection of the sun's direction easier and more effective when the sun declines.

## 2.3 Difference between a Fixed panel and a Dual-Axis tracker

For this part, we will look into an example of an experiment conducted by some students in Tamil Nadu, India [7]. They set up a DAST system which consisted of two sets of phototransistor sensors, two AC motors and a PIC controller. A set of sensors and a motor was used to track the sun's horizontal direction, and the others were fixed at the bottom of the tracker to track in the sun's vertical direction [7]. They then experimented for a whole day, once at a fixed angle and then using the dual-axis tracker. After obtaining the results, they simulated the results and generated the graph using MATLAB.



*Fig. 5.* Output power results from the experiment simulated and generated from MATLAB. *Source: IJESIT.* This graph is a compare between fixed and dual axis solar tracker to show the output power difference between both systems.

The graph in fig. 5 shows that the dual-axis solar PV panel is more efficient in terms of electrical energy output compared to the fixed system. After calculation, they found that DAST has a 25% increase in output.

## 2.4 Advantages and Disadvantages of DAST

Advantages	Disadvantages
<ul style="list-style-type: none"><li>• They have a higher efficiency (10-25% more) compared to a single-axis tracker.</li></ul>	<ul style="list-style-type: none"><li>• The system is a bit complicated to setup.</li></ul>
<ul style="list-style-type: none"><li>• They can produce 30-40% more energy output than a fixed system.</li></ul>	<ul style="list-style-type: none"><li>• The system can be expensive.</li></ul>
<ul style="list-style-type: none"><li>• Provides higher degree of accuracy in directional pointing.</li></ul>	<ul style="list-style-type: none"><li>• The maintenance cost is more but is cost effective in long run.</li></ul>
<ul style="list-style-type: none"><li>• It takes very less space to setup.</li></ul>	
<ul style="list-style-type: none"><li>• It is more cost saving to produce energy.</li></ul>	

### 2.4.1 Breakdown of Advantages

- Higher efficiency

When compared, a dual-axis is at least 40% more efficient than a fixed system. The process might seem complicated, but the basic theory is elementary. Every additional photon collected is more energy than polluting electrical generators like coal-burning power. Having a more efficient method of harnessing solar energy is a compelling argument towards installing solar trackers.

- Less space

Even though the size of a dual-axis panel is mostly the same as a fixed panel, but let us think in this way, if we wish to produce 10KW of electric power for that, we will need around 10-12 fixed system solar panel.

Whereas to produce the same power, we will need only about 3-4 dual-axis panels. So eventually, we will require much less space to keep them, which saves up our space.

- Can Produce more power at a lower cost

Initially, Panels with solar tracking systems are much more expensive than fixed ones, but they are cost-saving in the long run. If we wish to take dual-axis solar panels commercially, we will produce much more power at a very reasonable cost.

## 2.5 Summary

This chapter consists of a thorough discussion on the working principles of a DAST system. We then summarized an experiment conducted in Tamil Nadu, India to explain the differences in power output of a fixed panel compared to a DAST system. The experiment showed the DAST has a 32% increase in power output which proves it had greater efficiency. We also discussed the advantages and disadvantages of a DAST system.

CHAPTER 3:

# Floating Solar PV System

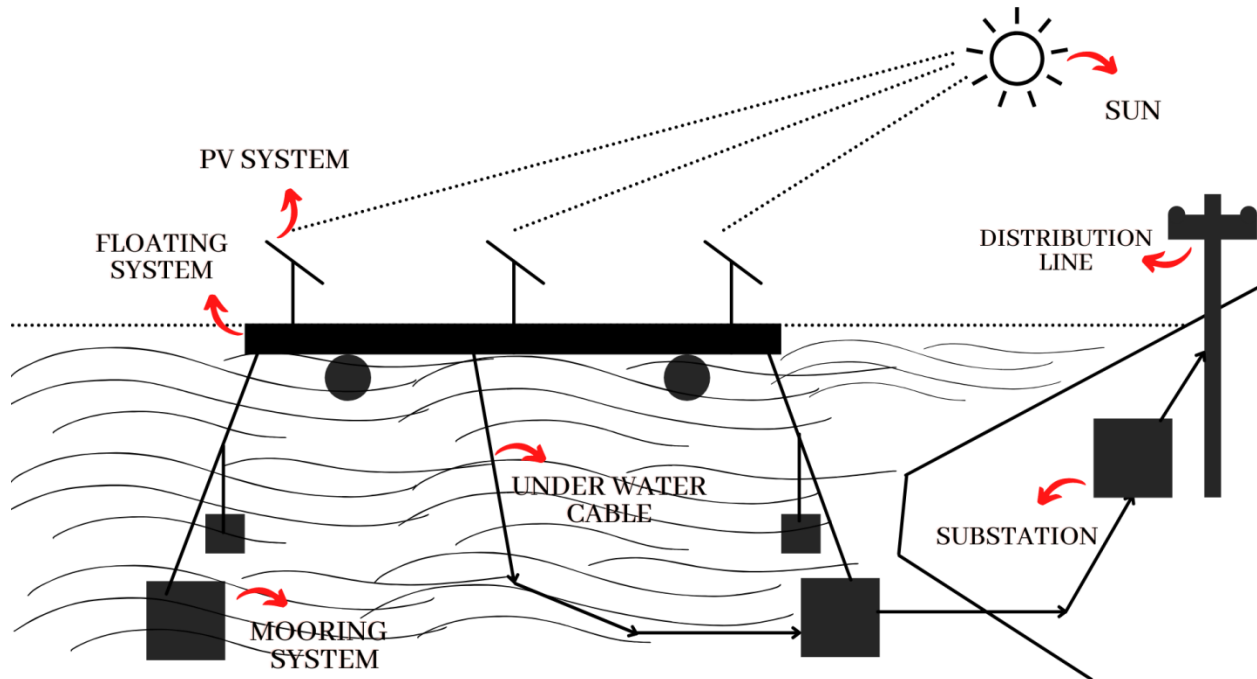
## 3.1 Introduction

A floating solar PV system is a groundbreaking approach to using PV modules on water bodies to conserve the land and increase module efficiency [8]. Not only are floating solar PV plants more economically friendly than land-based PV plants, but they also have several other advantages, including fewer obstacles to block sunlight, convenience, energy efficiency, higher power generation efficiency, which goes up as high as 16% owing to its lower temperature underneath the panels resulting from the cooling effects of the water.

Furthermore, floating solar PV enables a decrease in water evaporation and prevents water pollution by up to 70% by restricting the formation of algae. However, the system also suffers from scenarios such as wave and tidal disturbance. These causes quite a hindrance in the utilization of the sun's rays to their maximum capacity.

## 3.2 Floating Solar PV Plant

Floating solar tracking PV plants are the innovative concept revolutionizing the energy conversion technology to meet the needs of our time. This system utilizes bodies of water available on dams, reservoirs, lakes etc., for solar energy generation resulting from the amalgamation of PV mechanism and floating mechanism. A floating solar PV plant is made up of a floating system, mooring system, PV system and underwater cables. Fig. 6 shows the outline of a floating PV plant.



*Fig. 6.* Outline of a Floating solar PV plant. Here we can see how the power collected from the floating dual axis power will be transmitted from the underwater cable to the substation and eventually distributed to the main grid.

- Floating System: This consists of a pontoon, a type of floating body structure, designed to hold the PV system structure.
- Mooring System: Mooring structure, usually an anchor, prevents free movement of the floating structure and instead keeps the structure secured in place.
- PV System: This system includes the solar PV modules, solar inverter, sometimes a power battery or solar tracker and interconnected wiring.
- Underwater Cable: Special underwater cabling is used to transfer the power generated from the system to the substation.

### 3.3 Combination of DAST System and Floating Solar PV System

Generally, a floating PV system uses a fixed or single-axis panel. However, for our project, we have decided to use the DAST system on a floating PV. This is beneficial in many ways since a floating PV is much more efficient than a fixed PV.

So, when we combine both the dual-axis and the floating base, it produces much more power, and the system becomes more suitable to harsh weather conditions. Since whenever a heavy wind or wave flows and moves, the floating base changes the angle of the solar tracker. The automated system will again turn back the panel to face the sun's direction, minimizing the power loss compared to a fixed or single-axis system.

### 3.4 Advantages of Floating Solar PV Plant

- Generates more power output compared to land-based systems due to the cooling effect of the water.
- Designed and engineered to endure extreme physical climatic stress.
- By shading the water, the installations help reduce water evaporation and algae growth.
- Geographically is ideal to install on any water body due to abundance of sunlight.
- Helps conserve land for other uses.
- Easy installation.

### 3.5 Existing Plants

In the recent years, a number of floating systems have been constructed all around the world with varying degree of consumptions [9]. The collective installed capacity of Floating Solar PV plants was 225MW by 2018; of which 96 MW was installed in 2017 alone, with China installing 40MW and 20MW floating solar PV plants, as of now these are the two biggest plants in the solar market [9]. However, capacity wise Japan is higher with about 66% and rest of the Asian Nations altogether share 20% of the total installed capacity throughout the world. Similarly, USA has 3% and Europe 11% of the total installed capacity respectively [9]. In the forthcoming years, it is further estimated that the total installed capacity will be about approximately 1GW [9].

### 3.6 Summary

The latest technology of floating solar PV plants has become quite abuzz in the market of solar tracking. The concept is simple enough, and with its list of ever-increasing advantages, it is easily optimizable.

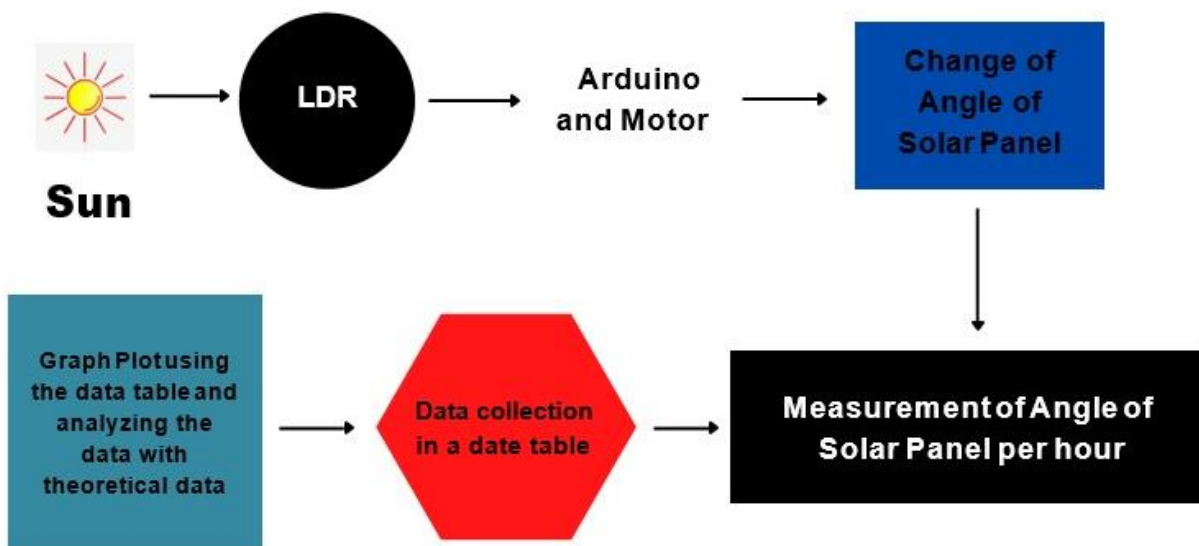
CHAPTER 4:

# Project Overview

## 4.1 Introduction

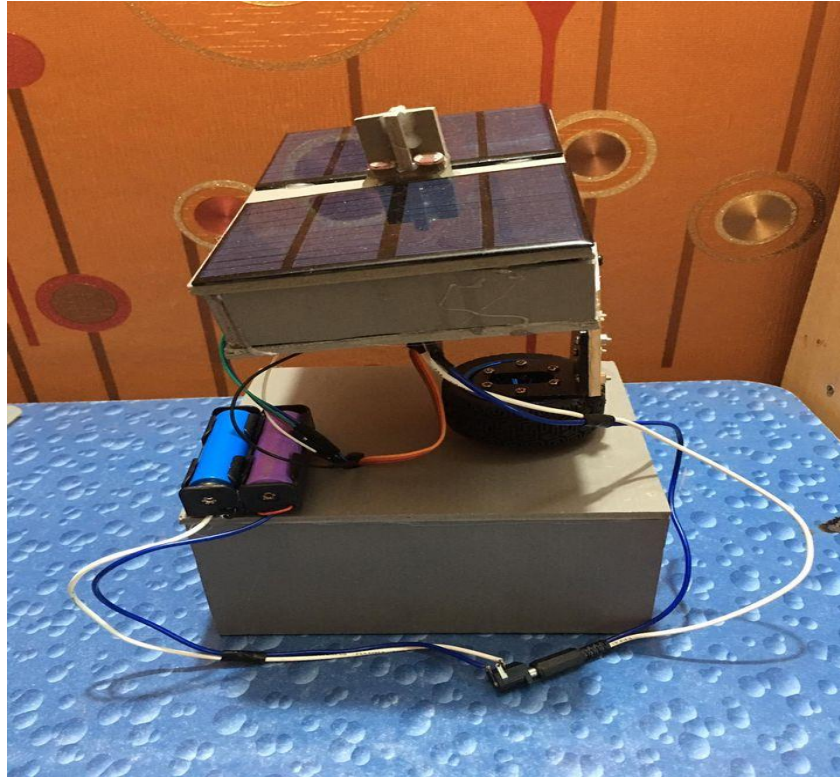
The goal of our project is the design and practical implementation of a floating active PV dual-axis solar tracker (DAST) that can keep track of the Sun's movement at every hour from sunset to sunrise [1]. For the best results to be obtained, in terms of collected energy, the PV DAST must first be appropriately aligned towards the Sun and tilted at the optimum angle. In our project, we mainly focus on the rotating and floating structures of the plant. For higher efficiency, the solar panel should be tracking in two axes, azimuthal and altitude axis [2]. Hence, dual-axis tracking system. Our main objective was to figure out the tilt angle of the panels and optimize them in order to optimize them for maximum solar efficiency. Furthermore, we studied the effect of water waves on the tilt angle of the solar PV panel.

## 4.2 Project Description



*Fig. 7.* Block diagram of the working of the project. This is the process of the data collection of the project. This flowchart shows how we have collected the data for this project

In this paper, a simple and cost-efficient smart active floating PV dual-axis sun tracking (DUAST) system, using fewer components and inexpensive as well, is discussed. As shown in



*Fig. 8.* DAST system prototype. This prototype of the dual axis solar tracker consists of solar panels, Arduino, rotating base. This prototype will be used for the collection and measurement of data

fig. 8, we built a prototype with an automated system for our project to constantly rotate the solar panel facing the PV perpendicular to the sun's rays for maximum efficiency and constant output. This increases the power output of 30% to 60% compared to fixed PV. Furthermore, automatic sun trackers do not leave behind any footprints. The unique feature of this system is that it has a DAST system. Dual-axis trackers move along two fundamental directions, namely horizontal and vertical, making them more flexible and adaptable in constantly following the moving sun in any directions, whether from east to west or seasonal, without losing sunlight.

This system follows the direction of sunlight rays as light source by angling the PV panel through a servo motor and a gear motor. The motors are regulated based on the solar incidence measured by four LDRs [1]. The LDRs, one placed on each side of the panel, constantly monitor the sunlight and rotate the panel towards the direction of the intensity of sunlight [3].

We monitored the change of tilt angle of the panels and proceeded to collect the data in a table, which we then simulated and generated a graph using MATLAB.

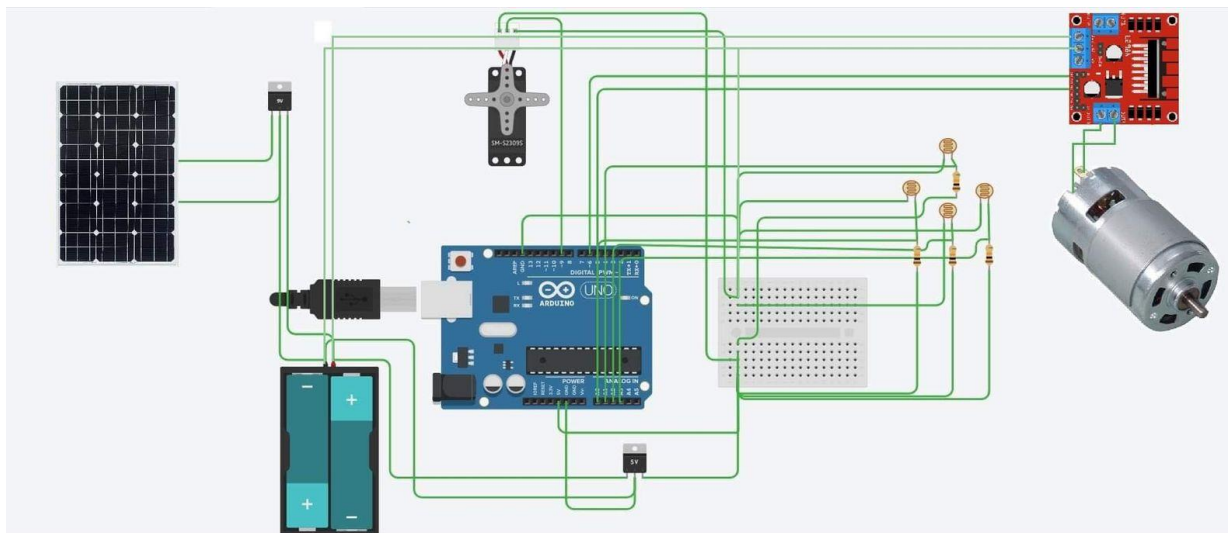
## 4.3 Components

### 4.3.1 List of equipment

- Servo Motor - 1
- Arduino UNO
- Gear motor -1
- Cables
- Jumper wire
- Voltage regulator (-9V, + 5V)
- 18650 batteries - 2
- 18650 battery holder
- PVC board
- Plastic bottles for floating base
- Floating pillow

- Resistors
- 12V PV panels - 2
- LED
- LDR - 4
- Lipo Battery -1
- Tire for rotation base -1
- BMS circuit – 1
- Motor gear – 1

#### 4.3.2 Circuit Diagram



*Fig. 9.* Circuit diagram of the PV DAST system. This circuit diagram shows how all the internal circuits are connected for the whole system.

### 4.3.3 Function of equipment

- PV panels and LDRs



*Fig. 10.* PV panels and LDRs

As shown in fig.10, we installed two 12V PV panels parallel to each other with the LDRs placed in between them. 1 panel and 2 of the diodes are for the sun's horizontal direction rotation, the others for the sun's vertical direction rotation.

- Rotating base



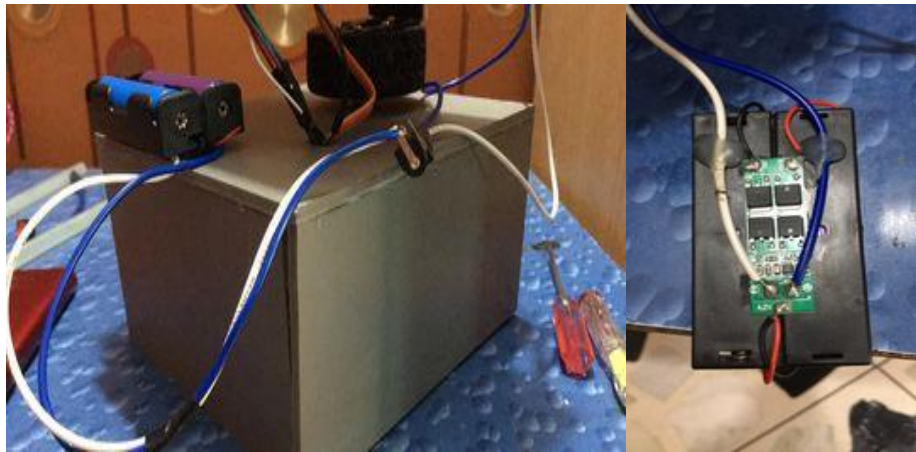
*Fig. 11.* Rotating base consisting of mechanical tire and servo motor



*Fig. 12.* Gear motor for the horizontal movement of the DAST.

The rotating base consists of a servo motor for elevation and a gear motor for rotation across the azimuth angle.

- Charging



*Fig. 13.* Charging base, here power from the whole DAST will be collected for further distribution to the main substation.

Battery to store charge using BMS circuit.

- Arduino Uno

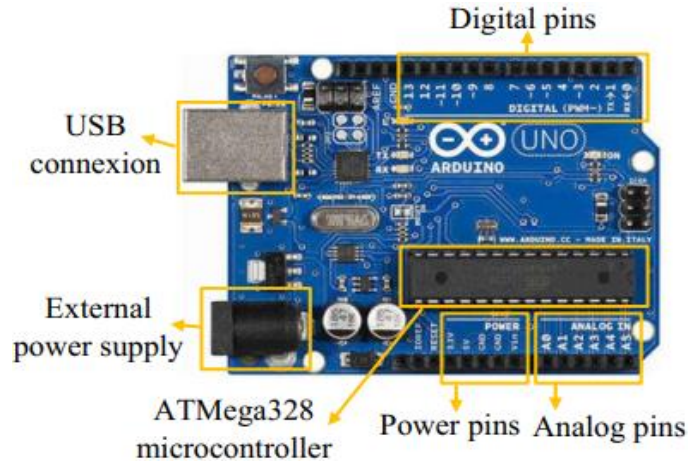


Fig. 14. Arduino UNO which was used as the primary microcontroller.

The Arduino UNO is embedded with ATMega328 Microcontroller to guide the rotating base according to the direction signals sent from the LDRs. Fig. 14 shows the labelling and working principle an of Arduino UNO.

#### 4.3.4 Mathematical analysis of Stepper Motor & Torque

Here, given, radius of spur gear,  $R = 0.3 \text{ rad}$

And if total platform mass,  $m = 30 \text{ kg}$

Then, we set moment of inertia,  $I = 0.5 \times m \times R \times R$

$$= 0.5 \times 30 \times (0.3)^2$$

$$= 1.35 \text{ m}^2$$

But, if we set the gear radius =  $0.5 \text{ rad}$  ----- (i)

Then, the inertia,  $I = 0.5 \times 30 \times 0.5 \times 0.5$

$$= 3.75 \text{ rad}$$

We know, to rotate  $180^\circ$  in 12 hours,

$$\omega = 0.25 \text{ rad/sec}$$

$$\therefore \text{angular acceleration, } a = \omega/t = 0.25/1 = 0.25 \text{ rad/sec}^2$$

So, required torque for equation (i) =  $3.75 \times 0.25$

$$= 0.9315 \text{ N-m}$$

$\therefore$  we need a stepper motor with torque 0.9315 N-m

For the model we chose, it has,

Holding torque = 1.2 N-m (max)

Phase current = 2.8 A

Phase voltage = 2.5 V

Phase resistance = 0.9  $\Omega$

Phase inductance = 2.5 H

$\therefore$  power of the stepper motor,  $P = VI = 2.5 \times 2.8$

$$= 7 \text{ W}$$

But, previous power of the motor,  $P = 2.8 \times 1.7 = 4.76 \text{ W}$

#### 4.3.5 Peak efficiency of solar panel

For a solar panel,

Length,  $L = 13.5 \text{ cm} = 135 \text{ mm}$

Width,  $W = 12.5 \text{ cm} = 125 \text{ mm}$

Voltage,  $V = 9 \text{ V}$

Current,  $I = 220 \text{ mA}$

So, power of solar panel,  $P = VI = 9 \times (220 \times 10^{-3})$

$$= 1.98 \text{ W}$$

To get  $\text{m}^2$ , we have to multiply width with length,

$$W \times L = 125 \times 135 = 16875 \text{ mm}$$

$$= 16875 \div 1000 \text{ m}^2$$

$$= 16.875 \text{ m}^2$$

$\therefore$  Peak efficiency =  $(1.98 \div 16.875) \times 100\%$

$$= 11.73\%$$

### 4.3.6 Floating Solar PV Structure



*Fig. 15.* Floating structure of the PV DAST system. The floating base was created using plastic bottles and floating pillow as a prototype.

For the floating structure, we attached two plastic bottles to a floating pillow making it cost-efficient. We then attached the PV DAST structure on top of the pillow and tested the whole floating PV DAST system on a bathtub, as shown in fig. 15. As expected the whole system was balanced and supported by the floating structure.

### 4.3.7 Cost Efficiency

To minimize the system cost, the developed smart DAST controller is implemented on an ATmega328 microcontroller integrated into an Arduino Uno, both of which are low-cost [1]. In addition, we used plastic bottles as pontoons in the floating structure to further lower cost.

## 4.4 Flowchart

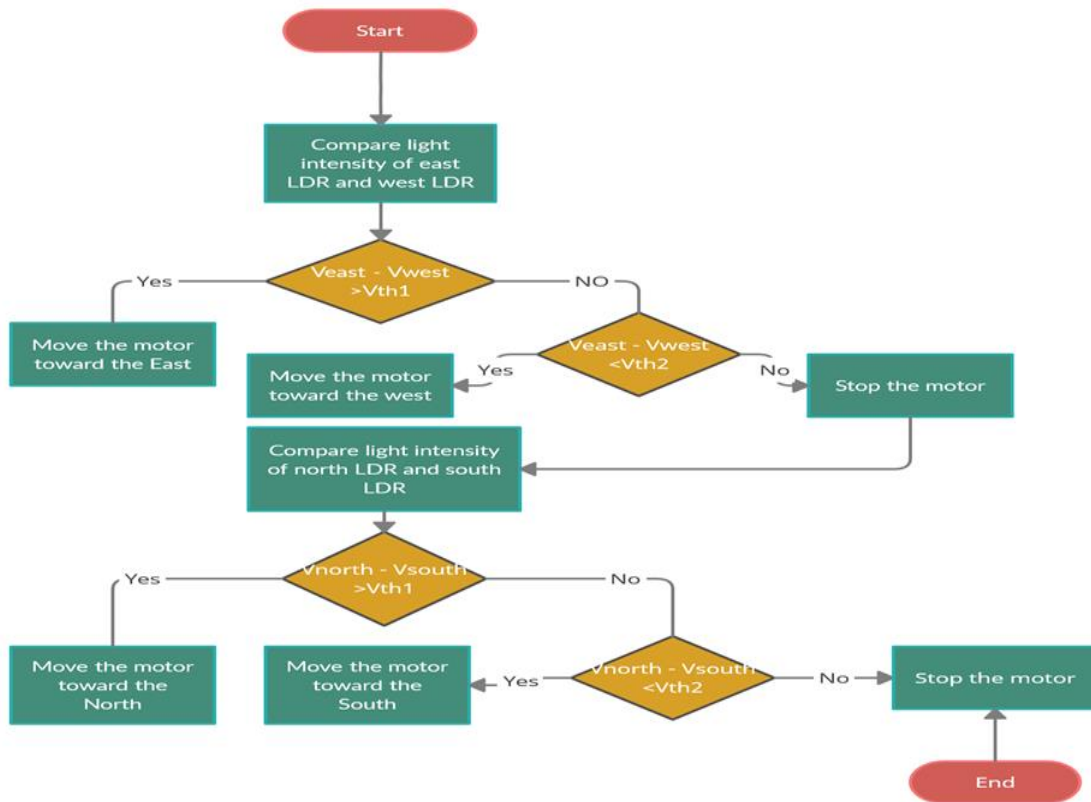


Fig. 16. Working principle of the PV DAST system.

## 4.5 Primary Target

The optimization of the tilt angle of the solar panels aims to maximize the solar energy collected, thus reducing the active solar-thermal surface with the constant maintenance of thermal energy production, installation, maintenance cost etc. The primary target of our project was to create a system that absorbs the shock from wind, wave and tidal disturbances. Whenever the panel gets hit with these disturbances, it interrupts the panels initial resting angle, which results in fluctuating input of the sun's rays. We studied how the wave model affected the tilt angle of the PV panels and explained them in mathematical equations. We then embedded the Arduino UNO with a specific code, which we developed from our equation.

## 4.6 Summary

This chapter explains the working principle of the project model that we have generated in depth, along with the equipment list and the working principle flowchart. We also explained the primary target of our project.

CHAPTER 5:

# Tilt Angle

## 5.1 Introduction

The performance of a solar panel is maximum when the incident solar radiation is normal on the surface of the panel. The optimization of the tilt angle of the solar panels aims to maximize the solar energy collected, thus reducing the active solar-thermal surface with the constant maintenance of thermal energy production, installation, maintenance cost etc.

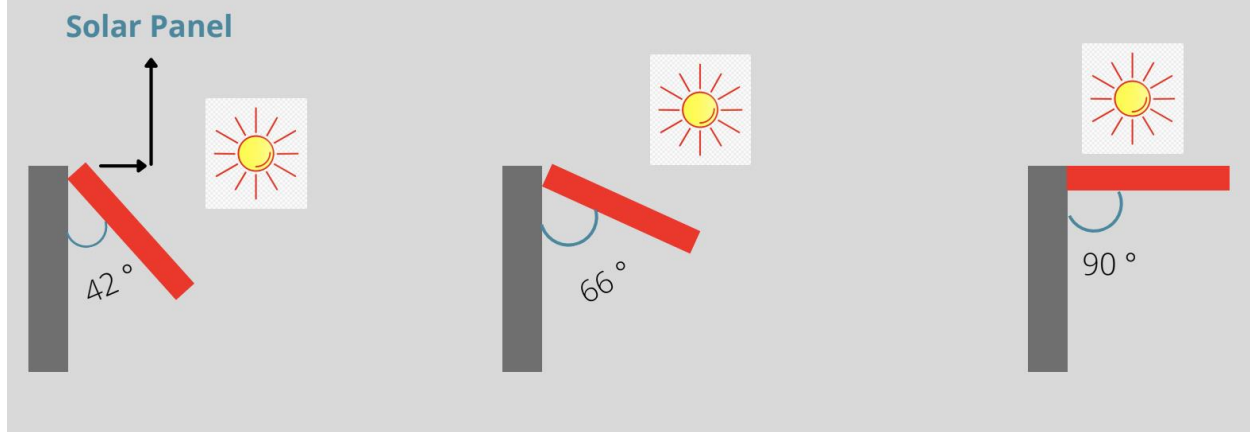
## 5.2 Tilt Angle

PV tracking systems mechanisms adjust solar panels toward the sun's rays to improve the PV system's productivity and efficiency through maximum utilization of solar irradiation. The maximum power output can be extracted from the PV panel when the tilt angle of the panel and the daily and seasonal changes of the sun's directions are synchronized. Tilt angle is another way of describing the vertical tilt of the PV system. The tilt angle can affect the amount of solar electricity generated and is based on two factors: latitude and the season. Optimizing and adjusting the solar panel tilt according to these factors can help maximize solar power production.

## 5.3 Determination of the Optimum Angle of Tilt

The angle of the sun not only changes based on different latitudes, but also with the change of seasons. As shown in fig. 17, the angle of tilt is always determined according to the sun's position based on the season.

## The Angle of Solar Panel according to Sun's position based on Season



*Fig. 17.* Tilt angle according to the sun's seasonal position. Here we can see how the optimum angle of the solar panel changes as the position of the sun changes according to different seasons.

This means that in order to ensure that the solar panels are always positioned for maximum exposure to sunlight, they need to be adjusted for each season. And so to define the optimum angle of tilt we used two methods – using mathematical equations and collecting data practically. We then compared the two data with data collected from Google.

### 5.3.1 Mathematical Approach

In order to obtain the optimum tilt angle using arithmetic's, we first subtract  $15^\circ$  from the latitude,  $x$ , at our location during summer and add  $15^\circ$  to our latitude,  $x$ , during winter and for spring we find the average of the former results, we then subtract this average from 90 and this is our final optimum tilt angle aka the vertical tilt angle.

So, tilt angle for solar panel,

For summer,  $S = x - 15^\circ$

For winter,  $W = x + 15^\circ$

For spring,  $P = \frac{S+W}{2}$

∴ Final vertical tilt angle =  $90^\circ - P$

### 5.3.2 Practical Approach

For our practical approach, we used our model prototype to collect data. As the light falls on LDR the resistance decreases, the value of resistance from all the sensors are sent to the Arduino UNO and the program then compares the data and generates an output. The Arduino UNO then sends the signal to the stepper gear and rotate the driver circuit to a particular angle tracking the sun at every hour to produce the output power. The angle that we get here is what we are taking as our tilt angle.

### 5.4 Observation and Result

On the 20th and 21st of May, 2021 we set up our experiment and collected data at every hour from 10:00AM in the morning to 5:00PM in the evening, a total of 7 hours, when the sun was at its highest position. At first we figured out the latitude of the position of the prototype which we got at  $21.89^\circ$  we proceeded to collect data of the tilt angles throughout the day. At 10:00 AM, the tilt angle of the panel facing the sun was approximately  $62.30^\circ$  and  $62.55^\circ$  on the 20th and 21st respectively, at 11:00 AM it was at  $76.15^\circ$  and  $76.20^\circ$ , at 12:00PM it was  $85.55^\circ$  and  $85.70^\circ$ . We continued to do the same at for the next 7 hours from 1:00PM to 5:00PM.

### 5.4.1 Data collected

Tilt Angle Data collection for 20 <sup>th</sup> & 21 <sup>st</sup> May						
Per Hour (10am-4pm)	Collected data from Google		Measured data		Differences	
	20 <sup>th</sup> May	21 <sup>st</sup> May	20 <sup>th</sup> May	21 <sup>st</sup> May	20 <sup>th</sup> May	21 <sup>st</sup> May
	<b>10:00am</b>	63.13	63.17	62.30	62.55	0.83
<b>11:00am</b>	76.71	76.76	76.15	76.20	0.56	0.56
<b>12:00pm</b>	85.97	86.17	85.55	85.70	0.42	0.47
<b>1:00pm</b>	74.44	74.51	74.20	74.35	0.24	0.16
<b>2:00pm</b>	60.81	60.87	60.50	60.60	0.31	0.27
<b>3:00pm</b>	47.12	47.18	46.55	46.75	0.57	0.43
<b>4:00pm</b>	33.51	33.58	32.90	33.00	0.61	0.58
<b>5:00pm</b>	20.09	20.17	19.55	19.70	0.54	0.47

Using these data, we simulated and generated the following graphs on MATLAB:

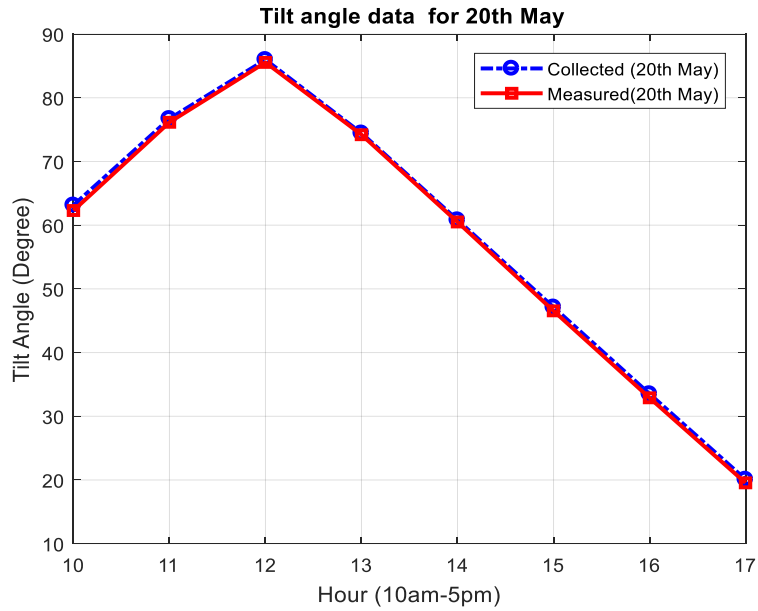


Fig. 18. MATLAB simulation of the data collected on 20<sup>th</sup> May. This graph is a contrast between the collected and measured tilt angle on 20<sup>th</sup> May

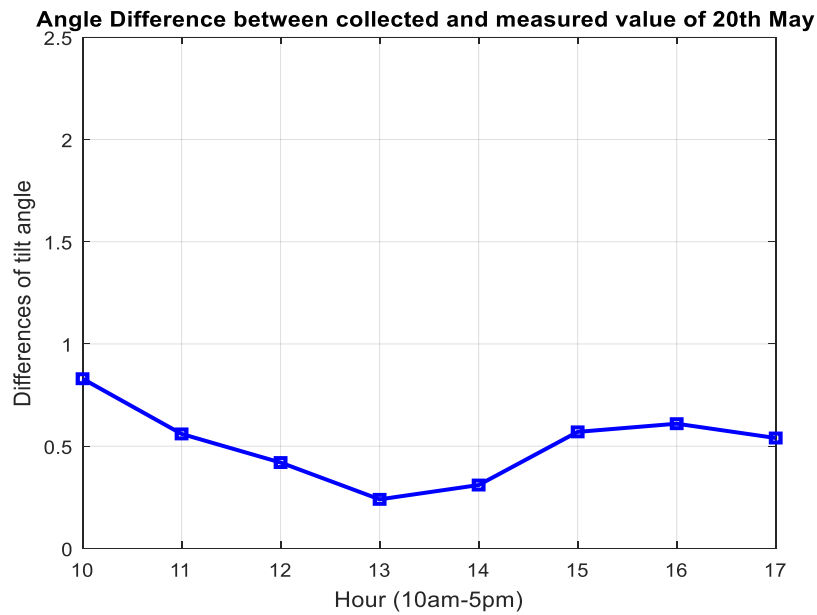


Fig. 19. MATLAB simulation of the angle difference in data on 20<sup>th</sup> May. Angle difference between the collected and measured value is shown in this graph

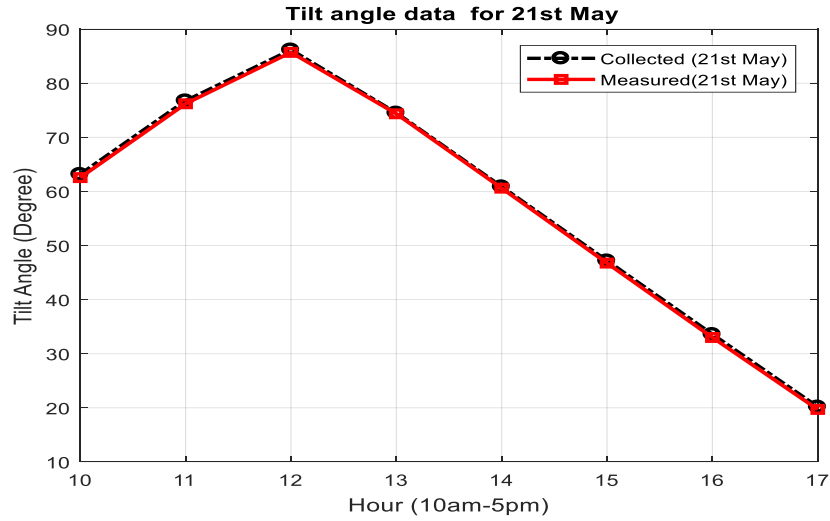


Fig. 20. MATLAB simulation of the data collected on 21<sup>st</sup> May. This graph is a contrast between the collected and measured tilt angle on 21<sup>th</sup> May

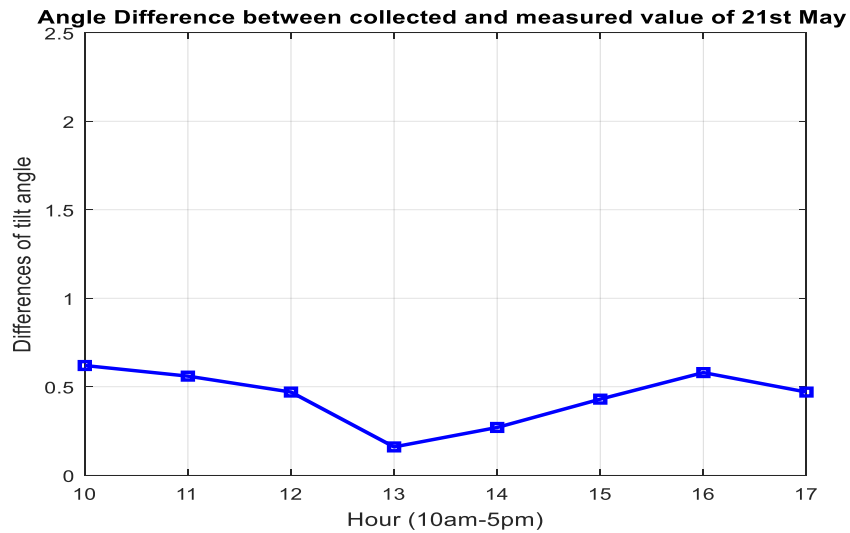


Fig. 21. MATLAB simulation of the angle difference in data on 21<sup>st</sup> May. Angle difference between the collected and measured value is shown in this graph.

## 5.5 Summary

As a result, the difference in angle between the data collected from Google and the measured data is negligible, between 0.2% - 0.75%.

CHAPTER 6:

Wave Model and its Effect on the Tilt  
Angle

## 6.1 Introduction

The system also suffers from scenarios such as wave and tidal disturbance. These causes quite a hindrance in the utilization of the sun's rays to their maximum capacity. As the waves hit, there is a slight change in tilt angle.

## 6.2 Wave Model

For any water surface real successive waves have varying height, period and even direction [10]. For complex waves each wave is a combination of several small waves with different characteristics.

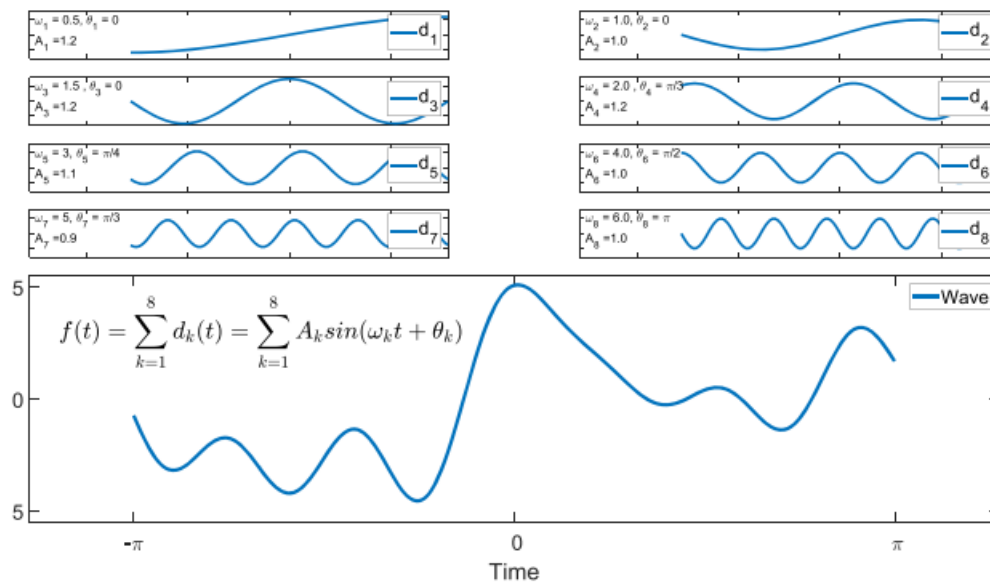


Fig. 22. Wave decomposition. Source: Wiley Photovoltaic. This figure shows the decomposition of different types of wave.

Complex waves are normally mathematically represented by Fourier models:

$$W(t) = \sum_{k=1}^{\infty} A_k \cos(\omega_k t + \theta_k)$$

Here,  $A_k$  = amplitude (or Fourier coefficient)

$\omega$  = angular frequency

$\theta$  = phase angle

In fig. 22, we can see in the bottom box the final decomposed wave, represented by  $f(t)$ , is the summation of all the single frequency waves ( $d_1$  to  $d_8$ ) where we can see the wave frequencies are increasing from  $d_1$  to  $d_8$  with slight difference in amplitude  $A_k$ .

Wind is the main generator of waves. A wave can be characterized with its frequency ( $f$ ), wavelength ( $\lambda$ ), time period ( $T$ ), amplitude ( $a$ ), and height ( $H$ ) which is typically double the amplitude. For our model we are focusing on the wind energy and its conversion to force. The force from the wave can move the pontoon and as a result is liable for the tilting of the angle of the panel.

The energy and power density of a harmonic wave are:  $E_{density} = \frac{\rho_w g H^2 \lambda}{8}$ ,  $P_{density} = \frac{E_{density}}{T}$

Here, gravitational constant,  $g = 9.81 \text{ m/s}^2$

From linear wave theory, wave energy per unit crest width for a specific wave is calculated as:

$$E = \frac{\rho g H^2 \lambda}{8} \text{ (J/m)}$$

Under ideal conditions, maximum power is proportional to the calculated energy/meter of the wave, and is equal to:

$$P_{ideal} = \frac{1}{32\pi} \rho g^2 H^2 T \text{ (W/m)}$$

On the other hand, irregular waves, or real waves, obtaining these parameters should be calculated in a different way. The characteristics of wave are generated by the JONSWAP spectrum as shown below:

$$S(\omega) = \alpha \frac{g^2}{\omega^2} e^{\left[ -\frac{5}{4} \frac{\omega_p^4}{\omega} \right]} \gamma^r,$$

$$r = e^{\left[ -\frac{1}{2} \frac{\omega - \omega_p^4}{\sigma \omega_p} \right]},$$

$$\alpha = 5.061 \left( \frac{\omega_p}{2\pi} \right)^4 H_s [1 - 0.28 \log \gamma]$$

Here,  $\omega_p$  = peak spectrum angular frequency

$\gamma$  = peak enhancement factor

$\sigma = 0.07$  for  $\omega < \omega_p$  and  $0.09$  for  $\omega \geq \omega_p$

For a real wave, the wave energy and maximum power/meter, will be calculated as:

$$E = \rho g \int_0^{\infty} S(\omega) d\omega$$

$$P = \rho g \int_0^{\infty} V_g S(\omega) d\omega$$

Here,  $V_g$  = group velocity

For which, deep water conditions  $V_g = g/2\omega$ .

After calculating these values and acquiring the pontoon's weight and dimensions, we estimate the tilted angle for the pontoon as a function of time.

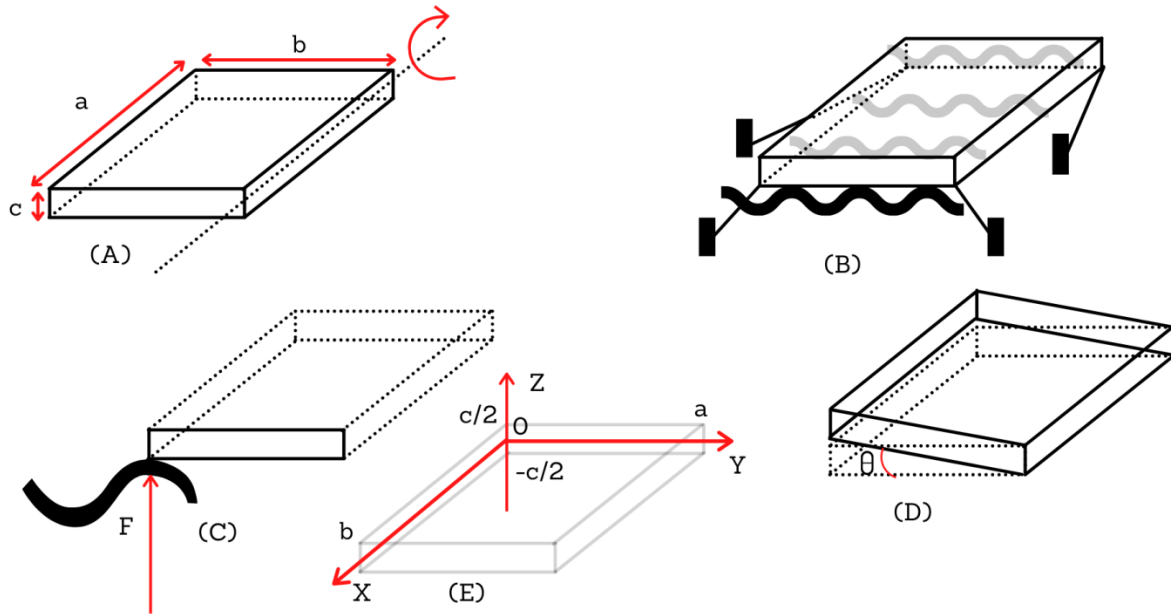


Fig. 23: (A) Pontoon's dimension, (B) pontoon at sea level, (C) torque  $\tau$  touches the pontoon and tries to rotate it around the shown axis, (D) pontoon rotated by  $\theta$ , (E) coordinates and the pontoon dimensions

Assuming the energy from wave is transferred to kinetic energy that can rotate the pontoon, for instance, an axis in line with its length approximately.

$$E_R = \frac{1}{2} I \omega_r^2$$

Here,  $E_R$  = rotating kinetic energy

$I$  = moment of inertia

$\omega_r$  = angular velocity for the pontoon

We know, the fundamental definition for moment of inertia is

$$I = \int_0^m r^2 dm$$

Here,  $m$  = mass of substance

$r$  = radius from the axis

From fig. 23(E), let's assume that the pontoon is symmetrical to the  $z$ -axis. The coordinates are such that the point ' $z=0$ ' is in the middle of the pontoon's height. A small rectangular box inside the pontoon is considered, while its vector is parallel with the  $y$ -axis (rotational axis) and its radius from that axis is ' $r$ '. According to these assumptions, the following proportional equation is valid:

$$\frac{dm}{dx dz} = \frac{m}{bc}$$

$\therefore$  equation for moment of inertia can be written as:

$$I = 2 \times I_{1/2} = 2 \times \int_0^b \int_0^{\frac{c}{2}} \frac{m}{bc} (x^2 + z^2) dz dx$$

From this, the moment of inertia for the pontoon and the rotating axis is as follows:

$$I = \frac{1}{3} mb^2 + \frac{1}{12} mc^2$$

However, if the rotating axis is on the  $x$ -axis:

$$I = \frac{1}{3} ma^2 + \frac{1}{12} mc^2$$

Once the wave crest touches the pontoon, a perpendicular force makes a torque  $\tau$  as in:

$$\tau = \vec{F} \times \vec{r}_1, \quad |r_1| = b$$

Thus, trying to rotate the pontoon clockwise, as shown in Figure 23(D), which shows a change in tilt of  $\theta$ .

## 6.3 Summary

Due to slight change in tilt angle of the panel from the waves, the irradiation will also falter over the tilted surface which affects the overall output power generation.

CHAPTER 7:

# Compliance with Standards

## 7.1 Introduction

There are several international standards that a system must comply, IEEE, European and US being some noteworthy ones. Accordingly, our system has also complied with these aforementioned standards.

## 7.2 Compliance with IEEE Standards

We could not find any specific standard that relates to our project, but we have used components like Arduino UNO, ATmega328 Microcontroller, motor gear etc., all of which are a few of the many types of equipment mentioned in the IEEE standard guideline website.

## 7.3 Compliance with US Standards

The US came with the International Electro-Technical Commission (IEC) standard prepares and publishes international standards for all electrical, electronic and related technologies. IEC TC82 covers all photovoltaic systems. Our system complies with the following standards,

- IEC 61836, Solar photovoltaic energy systems - Terms, definitions and symbols
- IEC 60904-2, Requirements for reference solar devices
- IEC 61215, Scope of the work in progress includes design qualification and type approval for crystalline silicon terrestrial PV module
- IEC 61730-2, Photovoltaic (PV) module safety qualification
- IEC 61853-2, Scope of work in progress includes spectral response, incidence angle and module operating temperature measurements for PV module performance testing and energy rating
- IEC 62124, Photovoltaic (PV) stand-alone systems – Design verification

- IEC 62446, Grid connected photovoltaic systems – Minimum requirements for system documentation, commissioning tests and inspection

## 7.4 Compliance with European Standards

Unfortunately, we could not find any specific standard that accommodates our system.

## 7.5 Summary

These standards have been set to maintain a safe and regulated environment when conducting scientific experiments. As we can see, our system complies with standards set by both IEEE and US.

CHAPTER 8:

# Conclusion

In this project, our main objectives were the design and implementation of a cost effective system, figuring out the tilt angle, and studying the effect of wave model on it.

We first focused on studying the mechanism of a floating solar PV DAST system. We then acquired components that eventually made our system cost efficient, like ATM328 Microcontroller embedded Arduino UNO, floating pillow as pontoon, plastic bottles for floaters etc.

After design implementation, we proceeded to calculate the tilt angle of the panels and collected data on power generation for 2 days, 20<sup>th</sup> and 21<sup>st</sup> of May. For accuracy, we compared the data results with the ones generated from Google for the particular days. After comparison we saw that error percentage in results came out extremely negligible, between 0.2%-0.75%.

# Bibliography

- [1] A. El Hammoumi, S. Motahhir, A. El Ghzizal, A. Chalh, A. Derouich. “A simple and low-cost active dual-axis solar tracker” (2018). Energy Science And Engineering: Research Article. DOI: 10.1002/ese3.236.
- [2] S. K. Natarajan, A. Kumar, R. Mohamed, Rathna R, S. Mondal, S. K. Suraparaju. “Design and development of dual axis sun tracking system for floating PV plant” (2019). IOP Conference Series: Earth and Environmental Science. DOI: 10.1088/1755-1315/312/1/012001.
- [3] B.Suchitha Samuel, B.Bharathi, J.Mrudula. “Design of PC Controlled Automatic Solar Tracker Robot” (2013). International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Issue 10. ISSN: 2319-8753.
- [4] Jagpreet Sandhu. “Best solar panel angle: How do you find it — and does it matter?”. Solar Reviews. <https://www.solarreviews.com/blog/best-solar-panel-angle>.
- [5] Solar track. Project Gutenberg Self-Publishing Press: Contemporary Books and Poetry for the Independent Reader. [http://self.gutenberg.org/articles/Solar\\_tracker?View=embedded](http://self.gutenberg.org/articles/Solar_tracker?View=embedded)'.
- [6] Autonomous Independent Wing Control - Single Axis Tracking. Solar Navigator's - Sun Tracker Electronics. [http://solarnavigator.net/solar\\_tracker\\_electronics.htm](http://solarnavigator.net/solar_tracker_electronics.htm).
- [7] Deepthi.S, Ponni.A, Ranjitha.R, R Dhanabal. “Comparison of Efficiencies of Single-Axis Tracking System and Dual-Axis Tracking System with Fixed Mount” (2013). International Journal of Engineering Science and Innovative Technology (IJESIT), Volume 2, Issue 2. ISSN: 2319-5967.

- [8] R. R. Bist, M. Saaqib. "Comparison between Floating Solar PV Plant and Grounded PV Plant at Bhimtal" (2019). International Journal of Research in Engineering, Science and Management, Volume-2, Issue-1. ISSN: 2581-5792.
- [9] L. Pacudan. "Floating Solar PV Global Development Through 2017" (2018). CWEN, Asian Development Bank.
- [10] S. Z. Golroodbari, W. van Sark. "Simulation of performance differences between offshore and land-based photovoltaic systems" (2019). Wiley Photovoltaic: Research Article. DOI: 10.1002/pip.3276.
- [11] Othman, N., Othman, Z. and Mannan, M., 2021. Performance analysis of dual-axis solar tracking system. [online] Ieeexplore.ieee.org. Available at: <<https://ieeexplore.ieee.org/abstract/document/6719992>> [Accessed 7 November 2020].
- [12] M.H.M.S.N.A.W.Z.W.H.M.Z.A.A.K.S.S.M.A.M.R. (2017, April 1). Automated positioning dual-axis solar tracking system with precision elevation and azimuth angle control. ScienceDirect. <https://www.sciencedirect.com/science/article/abs/pii/S0360544217301755>
- [13] Choi, Y. K., Lee, N. H., Lee, A. K., & Kim, K. J. (2014). A study on major design elements of tracking-type floating photovoltaic systems. International Journal of Smart Grid and Clean Energy, 3(1), 70–74. <https://doi.org/10.12720/sgce.3.1.70-74>
- [14] S. S. Gurfude and P. S. Kulkarni, "Energy Yield of Tracking Type Floating Solar PV Plant," 2019 National Power Electronics Conference (NPEC), 2019, pp. 1-6, doi: 10.1109/NPEC47332.2019.9034846.

[15] *Optimization and assessment of floating and floating-tracking PV systems integrated in on- and off-grid hybrid energy systems.* (2019, January 1). ScienceDirect.

<https://www.sciencedirect.com/science/article/pii/S0038092X18311459>

# Appendices

## Appendix A:

### Codes for Arduino UNO

```
#include <Servo.h>

Servo vertical; // vertical servo

int servov = 45;
int servovLimitHigh = 60;
int servovLimitLow = 1;

int motorL = 5;
int motorR = 6;

int thDif = 180;

// LDR pin connections
// name = analogpin;
int ldrLt = A0; //LDR top left - BOTTOM LEFT <--- BDG
int ldrRt = A2; //LDR top right - BOTTOM RIGHT
int ldrLd = A1; //LDR down left - TOP LEFT
int ldrRd = A3; //ldr down right - TOP RIGHT

int lDif;
int rDif;

void setup (){
  Serial.begin(9600);
  vertical.attach(9);
  vertical.write(45);
  pinMode(motorL,OUTPUT);
```

```

pinMode(motorR,OUTPUT);
delay(2500);
}
void loop() {
int lt = analogRead(ldr1t); // top left
int rt = analogRead(ldr1r); // top right
int ld = analogRead(ldr1d); // down left
int rd = analogRead(ldr1r); // down right
int dtime = 10; int tol = 90; // dtime=diffirence time, tol=toleransi
int avt = (lt + rt) / 2; // average value top
int avd = (ld + rd) / 2; // average value down
int avl = (lt + ld) / 2; // average value left
int avr = (rt + rd) / 2; // average value right
int dvert = avt - avd; // check the diffirence of up and down
int dhoriz = avl - avr; // check the diffirence og left and rigt

if (-1*tol > dvert || dvert > tol)
{
if (avt > avd)
{
servov = ++servov;
if (servov > servovLimitHigh)
{servov = servovLimitHigh;}
}
else if (avt < avd)
{servov= --servov;
if (servov < servovLimitLow)
{ servov = servovLimitLow;}
}
}
}

```

```
vertical.write(servov);
}
delay(dtime);
lDif=(ld+lt)-(rd+rt);
rDif=(rd+rt)-(ld+lt);

if(lDif>thDif){
  digitalWrite(motorR,LOW);
  digitalWrite(motorL,HIGH);
}
else if(rDif>thDif){
  digitalWrite(motorL,LOW);
  digitalWrite(motorR,HIGH);
}

else{
  digitalWrite(motorL,LOW);
  digitalWrite(motorR,LOW);
}
Serial.print("lDif: ");
Serial.println(lDif);
Serial.print("rDif: ");
Serial.println(rDif);

}
```