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Techno-financial Analysis of Floating Solar Photovoltaic System in Nepal

by

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A THESIS

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled " Techno-financial Analysis of Floating Solar Photovoltaic System in Nepal " submitted by Shweta Sah in partial fulfillment of the requirements for the degree of Masters of Science in Renewable Energy Engineering.

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ABSTRACT

Floating Solar photovoltaic system is one of the fast growing PV technology in Asia. It is fairly new technology with development of less than 10 years. This system helps in cooling down of solar PV modules which ultimately increases the efficiency and energy production of the solar PV system. This research includes experimental technical and financial analysis of a floating solar PV system and its comparison with the land based Solar PV system. A solar panel was installed on the pond behind center of energy studies (CES) which is inside Pulchowk Campus. Another Solar panel of same capacity was installed on land on the same site. For their comparison, measurements of temperature, open circuit voltage and short circuit current were taken for 10 days. The temperature around the floating solar photovoltaic system was always less in compared to the land-based photo voltaic system. The result shows increase in the power of floating solar PV system by approximately 12% in comparison to the land based solar PV system. The irradiance absorbed by floating solar PV system was nearly 1.5% more than the land based solar system. The structural stability of the floating structure of the floating solar photovoltaic system was analyzed to determine its feasibility. Financial analysis of a 1MW floating solar power plant was done on the basis of the obtained data and it was compared to the existing land based solar PV system. The IRR of the 1 MW plant was estimated as 13.282% which is just above discount rate of 12%. The project NPV was calculated as US$136,899 and the B/C ratio is 1.02 which is above 1. The cost benchmark analysis of floating solar photovoltaic systems of different capacities was also done.

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LIST OF ABBREVIATION

B/C	Benefit/cost ratio
DNI	Direct Normal Irradiance
FSPV	Floating Solar Photo Voltaic
GHI	Global Horizontal Irradiance
GW	Gigawatts
IRR	Internal Rate of Return
MPP	Maximum Power Point
NOCT	Nominal Operating Cell Temperature
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
PV	Photo Voltaic

CHAPTER ONE : INTRODUCTION

1.1 Background

One of the most effective and widely used renewable energy sources is solar energy. It is the most ample resources on earth that encourage the use of technical solutions efficiently convert this energy. Among the solar energy technologies are the fastest growing solutions solar power. The world's cumulative solar PV capacity was 773.2 GW, with 138 GW of new PV capacity installed in 2020 (Global cumulative installed solar PV capacity 2020 | Statista, 2022). This increase is mainly because of falling prices of PV modules, which make up the majority of investment in PV systems with helpful government incentives. Provides a utility-scale, low-cost, large-scale installation. Solar power systems are under the project investment umbrella without a doubt.

However, in order to construct a massive photovoltaic system, land is first of all highly available, and many countries are facing land shortages. However, in a sustainable economy, soil plays an massive role in agriculture and economic life. Similarly, the implementation of solar power projects often faces land issues such as land acquisition and substation capacity and availability. Subsequently, the investment cost of power transportation will increase as projects are planned in large remote areas. On the other hand, temperature has a significant impact on how well solar systems operate. The PV module's absorption increases as the temperature increases. As the temperature of the module rises, and the performance of the PV system decreases. Since then, there has been considerable interest in controlling such temperature changes. In fact, improving the efficiency of solar energy is the key to making these technologies more profitable.
A novel idea has been created that suggests placing a photovoltaic system underwater using a floating structure in order to solve these two key issues. Floating solar has grown from a small niche sector a few years ago to hundreds of MW of installations worldwide. Additionally, due to the cool water, natural convection affects solar modules mounted on floating structures. When beginning to examine sophisticated cooling systems, high water availability is a very helpful parameter. Therefore, floating solar applications have

enormous promise in hot, arid areas where it is necessary to alter the operating temperature to maximize system efficiency.

1.2 Problem Statement

The development of photovoltaic systems is difficult and the market is becoming more and more important for competitiveness. New innovations and processes must pave the way for economical solutions. In this industry, clever and novel solutions like floating solar arrays are ideal. It is promising in terms of strengthening renewable energy globally and can bring significant added value. Reduced land costs and new synergies among local stakeholders. Floating solar power systems offer many advantages due to strong convective water,

1.3 Objectives

1.3.1 Main objective

The main objective of the thesis is to perform the techno-economic Analysis of Floating Solar Photovoltaic system in Nepal.

1.3.2 Specific objectives

- To make the design of the floating solar PV system, fabricate and install it on the site.
- To analyze the effect on the performance of FSPV by changing the tilt angle to different values and applying manual tracking system.
- To compare the performance floating solar PV system with the land based PV system.
- To perform the techno-financial analysis of 1 MW floating solar PV system.

1.4 Scope of Work

Compared to onshore PV installations, the FSPV system has the following advantages: Land is becoming more and scarcer as a result of rising population. As a result, both the project's cost and the cost of land have increased significantly. Particularly in metropolitan settings, the space needed for solar systems cannot be used for any other purpose. FSPV systems that make advantage of water bodies can address these problems. Systems on land are also vulnerable to high temperatures. The photovoltaic power plant's efficiency and temperature are indirectly related. As a result, the solar array's ability to produce energy will decrease as its temperature rises. Because evaporation lowers the temperature near the system, floating systems maintain higher power generation efficiency than onshore systems.

1.5 Limitations

Lack of research on this topic in Nepal can be a limitation. Lack of funding was another limitation of this thesis.

CHAPTER TWO : LITERATURE REVIEW

2.1 Solar Energy

Solar energy is the radiation from the sun that can produce heat, cause chemical reactions, or produce electricity. The total amount of solar energy striking the earth far exceeds the world's current and projected energy needs. In the ensuing decades, it paves the way for a hopeful future of the production of clean, inexpensive, and sustainable energy. (IEA 2011). In fact, as figure 2.1 perfectly shows, the solar energy is far greater than the annual human consumption of energy. In relation to annual global energy consumption, the figure also depicts the potential for additional energy sources. The world's primary energy consumption is 1800 times greater than its solar irradiation, but hydropower can only supply the world's primary energy needs for one year.

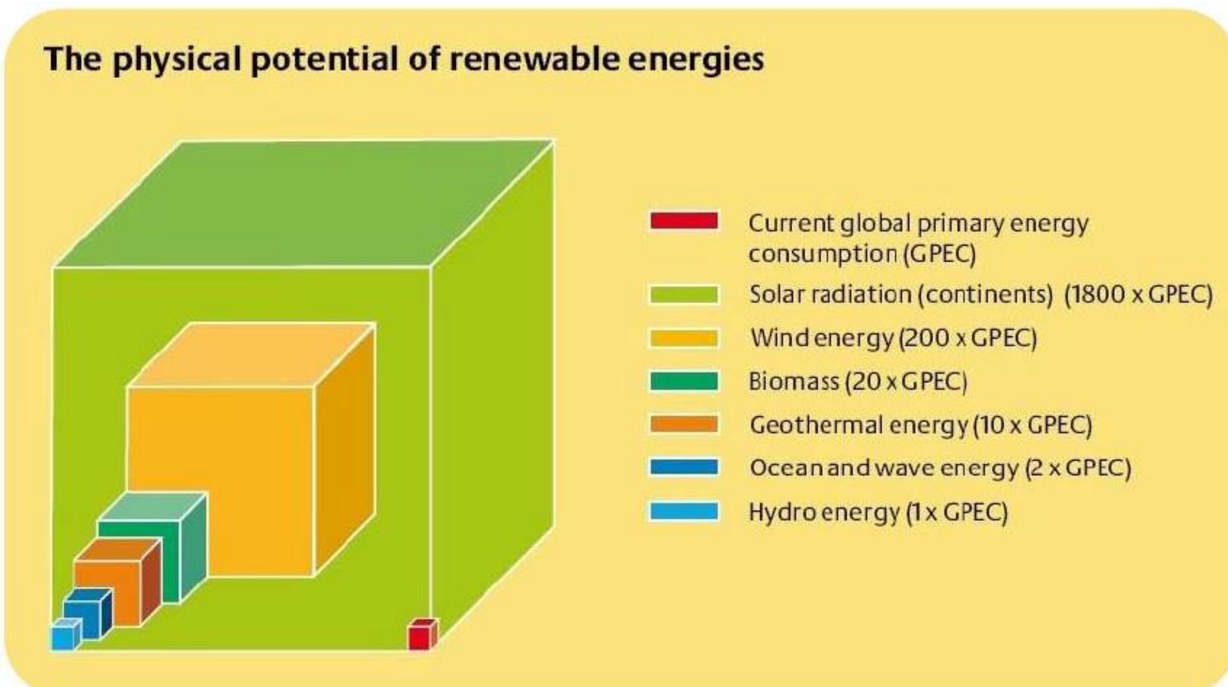

Figure 2.1 Global Energy Consumption

Source: Howels 2016

Direct Normal Irradiance

The quantity of direct sun radiation that a vertical plane receives from a small solid angle is known as direct normal irradiance, or DNI. The amount of solar radiation per area is used to measure it. The PV module receives the most solar radiation when its surface is perpendicular to the sun's rays. To maximize the absorption of solar energy, the tilt angle of PV modules is a crucial factor.

Diffuse Horizontal Irradiance

The amount of sunlight that reaches a horizontal earth's surface, plus ground reflection sunlight, is known as diffuse horizontal irradiance (DHI).

Global Horizontal Irradiance

The total of DNI and DHI is called global horizontal irradiance (GHI). It represents the total solar radiation that is available to an area. Despite its enormous potential, solar energy makes up a relatively modest portion of the global mix of electricity generation. As simply considering renewable energy used to produce electricity, solar energy is still underrepresented when compared to other energy sources like hydropower, wind power, and biomass. And in the ensuing decades, its share of the electrical mix is anticipated to climb tremendously. Investing costs and the necessity for big plant-friendly spaces are unquestionably the main challenges.

Figure 2.2 Solar module

2.2 Photovoltaic energy

One of the most widely used photovoltaic technologies in use today is photovoltaics (PV). Solar cells can produce electricity at any scale, function at temperatures close to ambient, and have no moving parts.

Theoretically, a 10 square kilometer (km^2) array and a 10 square meter (m^2) PV array are both equally efficient per unit area.

One or more PV modules that are electrically coupled together make up a photovoltaic system. Each module has a "BoS" or balance of system that is made up of numerous individual solar cells. Hardware elements including as housings, racks, cables, inverters, and transformers. Combiners, inverters, and transformers in a grid-tied system transform the low-voltage direct current (DC) energy produced by numerous individual PV modules into high-voltage alternating current (AC) energy that feeds the grid.

2.3 Photovoltaic Fundamentals

2.3.1 PV Effect

The PV effect is used by photovoltaic systems to turn solar energy into electrical power. The creation of an electric current in response to exposure to light is known as the PV effect. DNI and diffuse horizontal irradiance are absorbed by PV cells (DHI). When photons from sunlight come into contact with PV materials, they are transmitted, absorbed, or reflected. During absorption, if the photon's energy is higher than the semiconductor's bandgap, an electron can be emitted and removed. This physical effect is caused by the PV cell's P-N junction, which basically acts like a diode, producing a direct current when freely moving electrons flow between the N-type and P-type semiconductors.

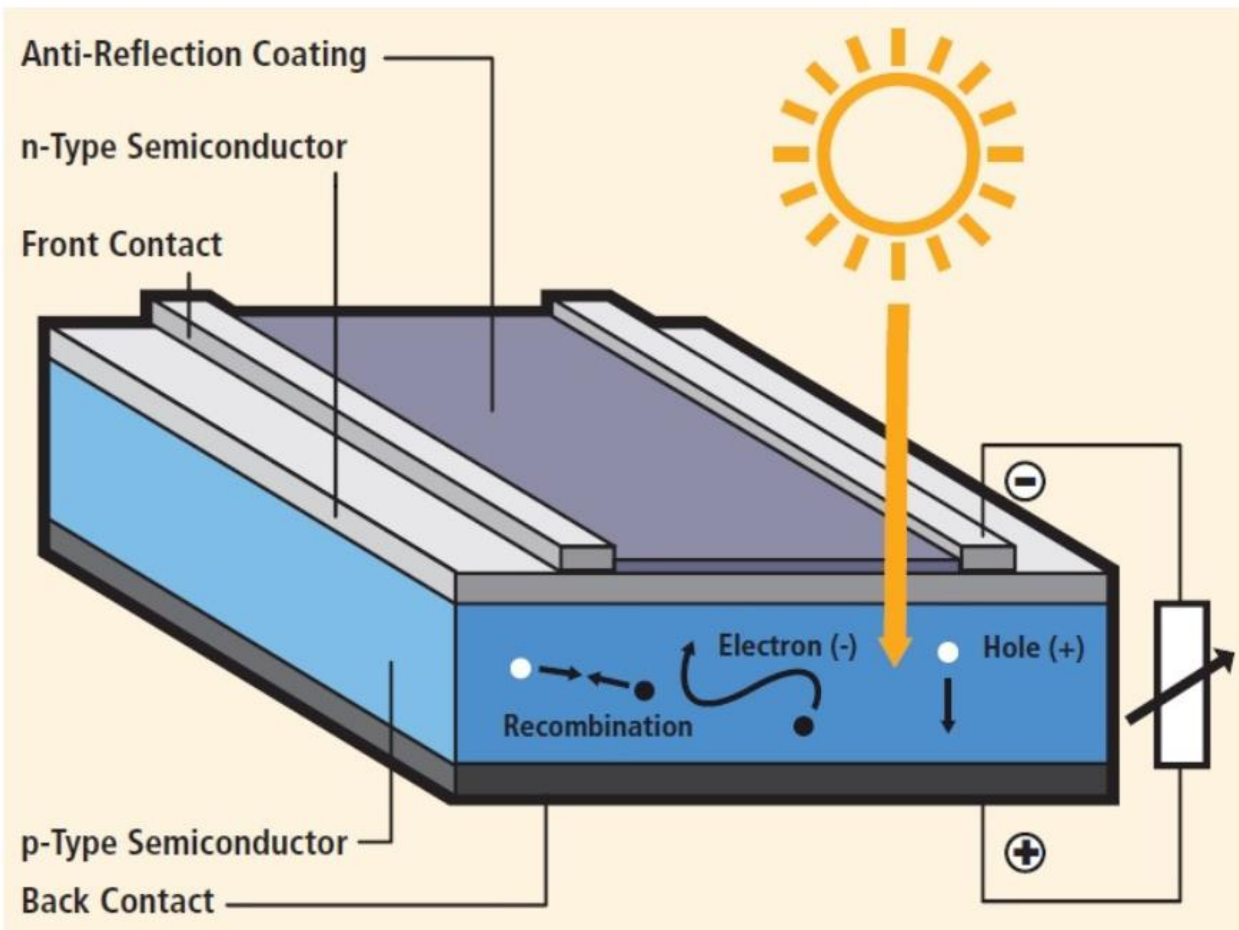

Figure 2.3 Photovoltaic Effect

2.3.2 PV Terminology

This section briefly defines and describes few of the most important PV specifications that manufacturers utilize. Since this term is common in the global PV market, it is also used extensively in this paper.

Open Circuit Voltage Voc

Open circuit voltage is the potential difference between two terminals of an electronic device when it is disconnected from the circuit. No external load is connected. No external current flows between the terminals. Alternatively, open circuit voltage can be thought of as the voltage that must be applied to a solar cell or battery to stop current flow.

Short Circuit Current Isc

Short-circuit current is the current that flows through a solar cell when the voltage across the solar cell is zero (that is, when the solar cell is short-circuited). The short-circuit current is due to the generation and collection of photo generated charge carriers. For an ideal solar cell with a moderate resistive loss mechanism, the short circuit current and luminous flux are the same. The short circuit current is therefore the maximum current that can be drawn from the solar cell.

Maximum Power Point MPP

On a solar module's current-voltage (I-V) curve when it is illuminated, the maximum power point (MPP) is the location where the product of current and voltage is at its highest (Pmax, measured in watts). MPP actually plays an important role in the performance analysis of PV modules and systems.

2.3.3 PV Cell Types

PV cells are often designed to accentuate the power generated as well as the amount of light received and absorbed. Therefore, a metal grid is used for conduction and an antireflection coating is applied on top of the cell. Similarly, the efficiency of PV cells is strongly related to cell production, which often leads to high research and production costs when considering material costs (for example, in the case of silicon Si). Resistive losses (series and shunt resistors) and optical losses (reflections or high-energy photons) have a significant impact on PV cell efficiency and are unaffected by the particular operating ambient circumstances.

2.3.4 PV Cell Performance

An IV curve, as seen in Figure 2.4, can be used to visualize the performance of PV cells. The curve displays the cell's maximum power point (MPP) at specific operating and meteorological conditions.

Standard Test Circumstances (STC) and Normal Operating Conditions (NOC) are commonly used to deliver the specified conditions (NOCT). An air mass of 1.5, a temperature of 25 °C, and a radiation of 1000 W/m2.are the requirements for STC (Guedez 2017). To more accurately reflect actual situations, a NOCT condition is applied. Irradiance is 800 W/m2, ambient temperature is 20°C, and the average wind speed is 1 m/s. We may determine the performance of an actual PV cell using the two given circumstances. This considers regional weather patterns as well as temperature correction variables supplied by the manufacturer.

The sum of Impp and Vmpp determines a PV cell's maximum output power under particular operating conditions.

The PV module should be paired with an MPP tracker to receive MPP continuously (MPPT). To increase module current, MPPT modifies and improves the working voltage of the module. Since MPPTs are frequently mounted directly on inverters, they function at the array level. For potential performance advantages, it can also be applied at the module or string level, though at a higher cost.

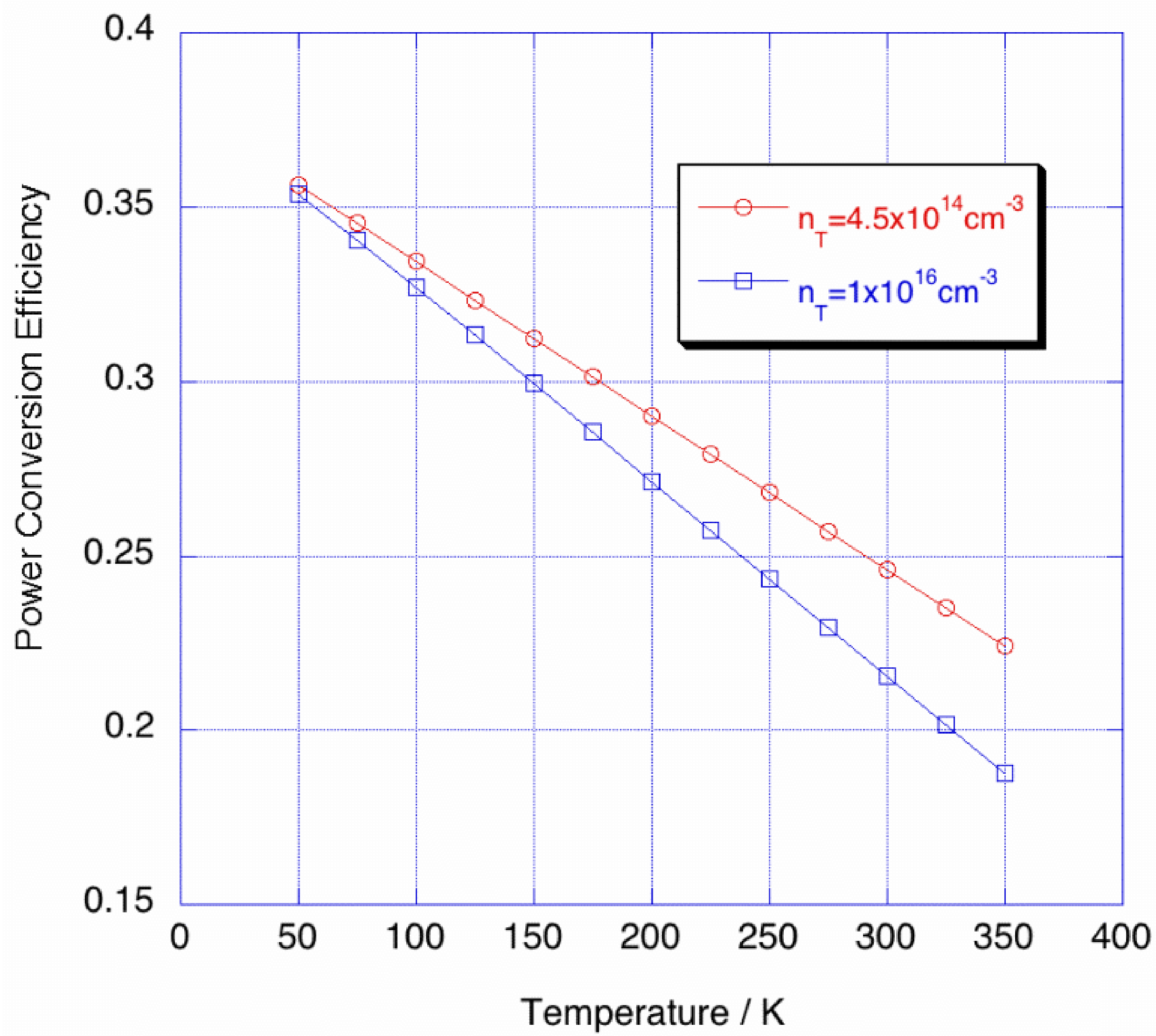

Figure 2.4 Effect of temperature on solar module efficiency

The efficiency of a PV generator depends on the module cell temperature. Data for PV modules are measured at a standard temperature of 25°C. The actual temperature of the cell is about 20°C above the ambient temperature, which is called the rated operating temperature of the PV cell and is given by the formula:

$$\Delta T = T_p - T_a = \frac{NOCT - 20°}{0.8} X\ I$$

$$V_{ocv'} = V_{ocv} - \Delta T\ X\ 0.0842$$

$$I_{scc'} = I_{scc} - \ \Delta T\ X\ 0.0086$$

Where T_p = Panel temperature (˚C),

T_a = Ambient temperature (˚C),

V_{ocv} = Open-circuit voltage (V),

I_{scc} = Short circuit current (A)

The efficiency of photovoltaic array (η_{PV}) can be determined by following equation:

$$\eta_{pv} = (V_{ocv'} X I_{scc'})/(V_{ocv} \mathrm{X} I_{scc})$$

Solar generator efficiency is further reduced by module shading and dirt. Therefore, the installation site has no shade and PV generators should be cleaned regularly to avoid efficiency loss due to dirt. Shading and dirt can reduce the performance of your PV system by up to 3%

2.4 Technical difference

Floating solar power plants, both on the roof and above ground, have some differences from conventional solar power systems. These are represented by floating structures, mooring systems, floating substations, and submarine cables. All this depends on the type of pool in which the equipment is installed.
Recent studies on floating devices have identified mainly his four types of structures.
• A unique aircraft consisting of a cubic (or similar) buoy that forms a floating base on which PV panels can be placed.

•Modular with PV panels.
• Slope resistance. It usually consists of a plastic buoy with a metal structure that supports the board at an angle of inclination.
• Water (usually a thin film) or semi-submersible modules placed directly in water, or floating structures with only a thin layer of conductive material (eg aluminum) between the module and the water

2.5 Floating Installations

Figure 2.5 Floating Solar PV system

Around the world, examples of PV arrays mounted on floating constructions have been suggested and constructed. A solution like this has many of benefits. The first is the rise in energy demand in agriculture as a result of decades-long modernization initiatives. Installing more efficient irrigation systems has made agriculture more water efficient, but has greatly increased power demand. The entire energy system and markets have changed significantly in recent years/decades. Decades ago, the main concern was universal access to electricity, but today there is a heightened awareness of greenhouse gas emissions from fossil fuels, the fear of nuclear dangers, and a resolute awareness increase. There are many factors, including decreasing carbon availability and increasing demand. Local governments seeking energy self-sufficiency see renewable energy as the energy source of the new age. These factors make attaining energy independence and concerns about land usage the primary forces behind the development of floating PV systems. Farmers who lack the space for PV arrays on their land can now attain energy independence or at the very least satisfy a portion of their rising electricity needs by installing floating PV arrays in irrigation tanks. The rate of water evaporation in these agricultural reservoirs, especially in hot and remote places, is another benefit of floating irrigation tank installations.

2.6 Financial Analysis

The profitability of investing in photovoltaic systems depends on electricity prices and income
source. Investment analysis changes based on economic parameters characterize the profitability of the PV system. The methods used for financial analysis are as follows:

2.6.1 Internal Rate of Return (IRR)

The discount rate for the net present value with no investment is known as the internal rate of return (IRR). One of the most used methods for capital budgeting is IRR. Companies invest in a variety of initiatives to raise shareholder wealth and build value, but this is only achievable if the projects they invest in provide income beyond the minimum required by the provider equity (i.e. shareholders and creditors). The hurdle rate is the lowest necessary return. An example of a discounted cash flow (DCF) technique is IRR. That is, the project's initial expenditure or investment must be covered by net cash flow that is either much more than the initial investment or the time value of money is considered. This endeavor is a worthwhile investment. The linear interpolation or hit-and-trial method is most frequently used to determine IRR. Spreadsheets, financial calculators, and formulas as the IRR is characterized as the discount rate at NPV = 0, we can write

PV of future cash flows − Initial Investment = 0; or

$$\left(\frac{CF1}{(1+r)^1}+\frac{CF2}{(1+r)^2}+\frac{CF3}{(1+r)^3}+\cdots\right)-Initial\ Investment=0$$

Where,

r is the internal rate of return;

CF1 is the period one net cash inflow;

CF2 is the period two net cash inflow,

CF3 is the period three net cash inflow, and so on

2.6.2 Net Present Value (NPV)

The difference between the current value of cash inflows and withdrawals over a period of time is known as net present value (NPV). The profitability of a proposed investment or project is examined using NPV in capital budgeting and investment planning. The outcome of a computation to ascertain the present value of potential future cash flows is NPV. The following formula is used to determine the NPV (Chun, 2013):

$$NPV = -C_0 + \sum_{0}^{N} \left(\frac{c}{(1+d)^N}\right)$$

Where,

C is the total cash flow in the analysis period after tax,

$C0$ is the capital investment,

d is the nominal discount rate and N is the project analysis period

CHAPTER THREE : METHODOLOGY

Methodology is an approach towards proper affair with project exquisite for the completion of a well-balanced project. The conceptual framework of the project is given below:

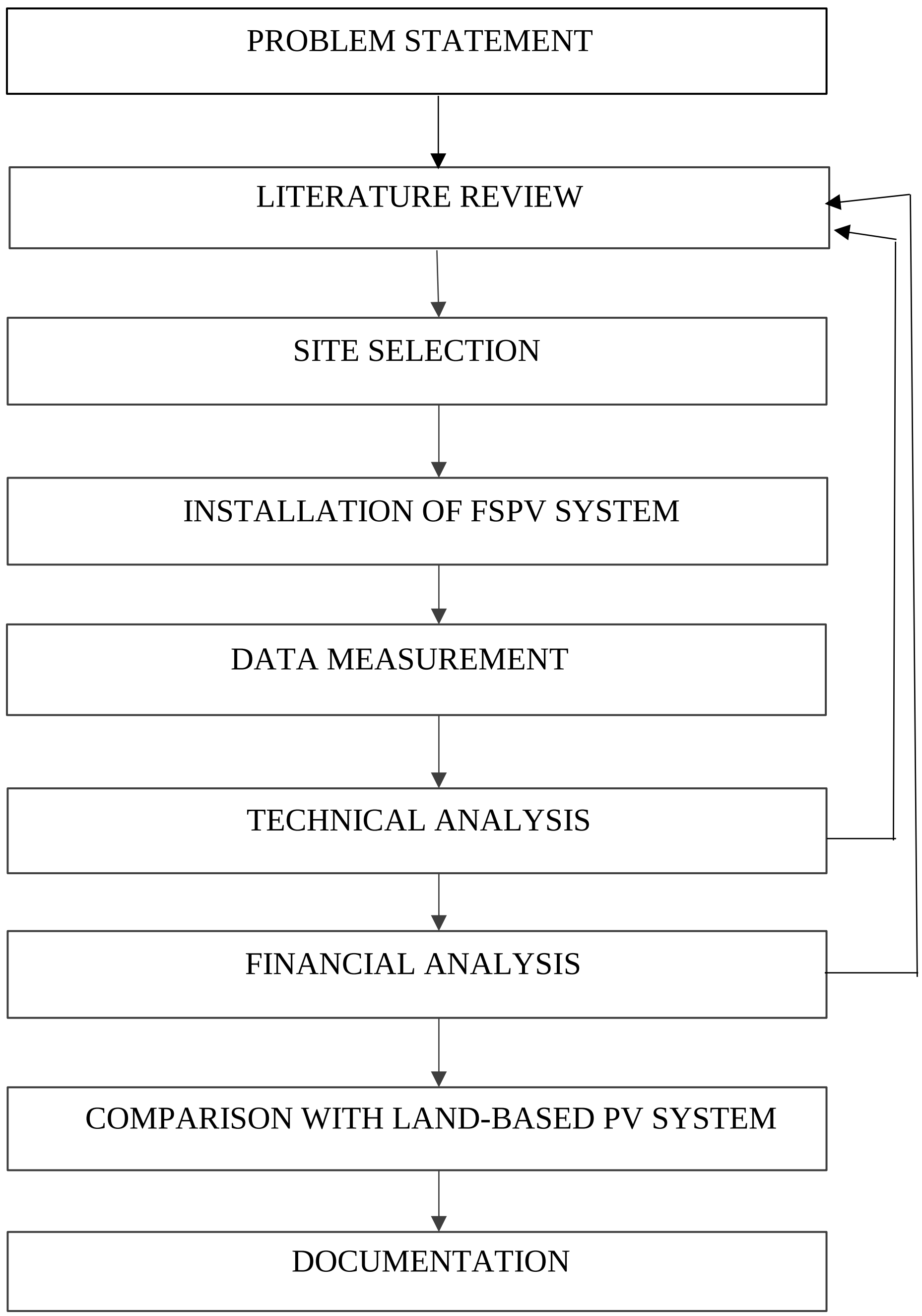

Figure 3.1 Timeframe

3.1 Literature review

The foremost step in conducting a project is its literature review. As a part of the literature review, the study about the different FSPV system was done. For literature review, related journals, research articles, textbooks was consulted. Since detailed study is most important in each and every stage of design phase, literature review will be done throughout the project period.

3.2 Site Selection

The pond behind Center for Energy Studies (CES) is used as a site for the experiment. The pond is about 1.5 m deep. Due to the presence of trees and CES building, there is shading problem but on a sunny day, enough sunlight falls on the pond.

3.3 Installation of FSPV

Different parameters required for the design was studied. Then, A floating solar panel was installed at the site selected. A financially convenient model was designed to be used on the site. An onshore Solar PV module was installed nearby for the comparison.

The floating structure of the FSPV system is designed as shown in the figure It consists of a frame mounting structure which is made of L-shaped angular iron The mounting structure floats on a tube of a truck tyre.

A monocrystalline solar panel of rated power 120 watts is used. It has 36 Solar cells. The specifications of the solar module are as follows:

Area: 0.98901 sq. meter

Rated Power: 120 Watts

Open circuit voltage: 21 Volts

Short circuit Current: 7.7 Amperes

(The above values are rated at 1000Watt/m^2 solar irradiance and 25° cell temperature.)

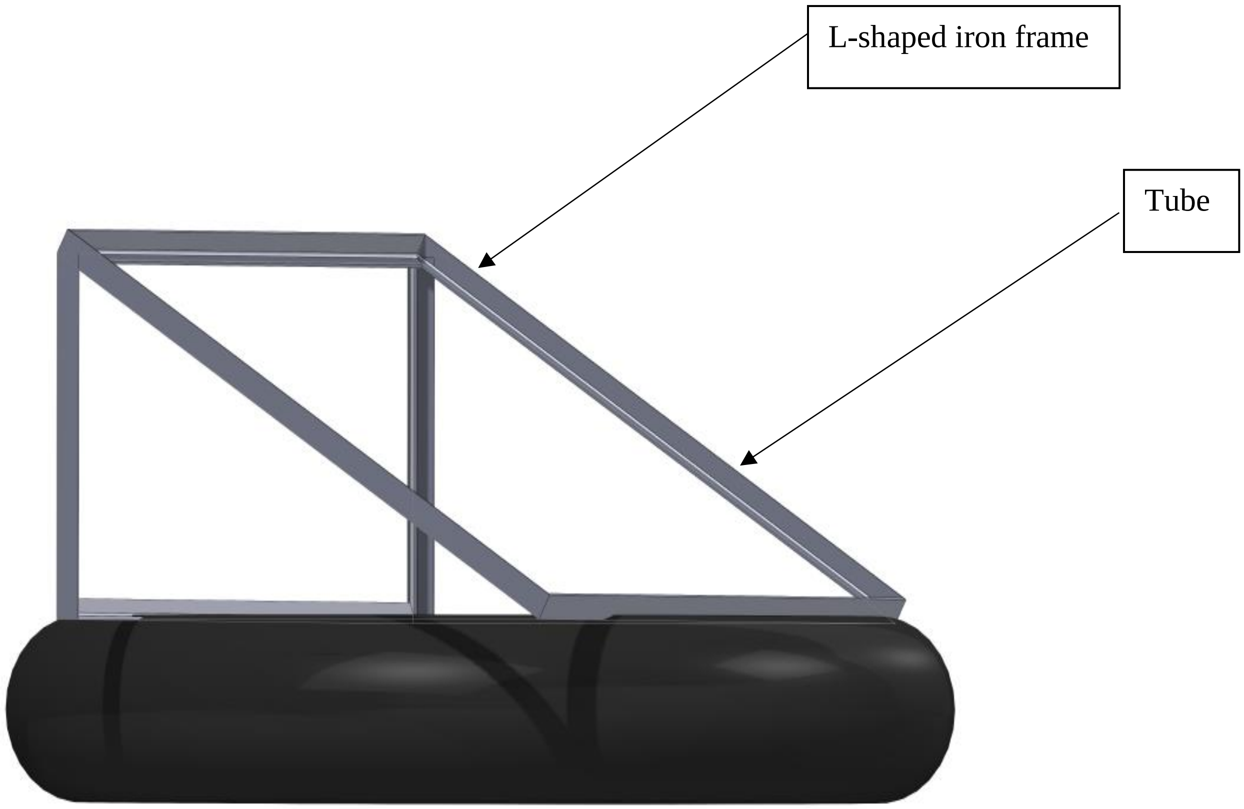

Figure 3.2 Floating structure for Solar PV

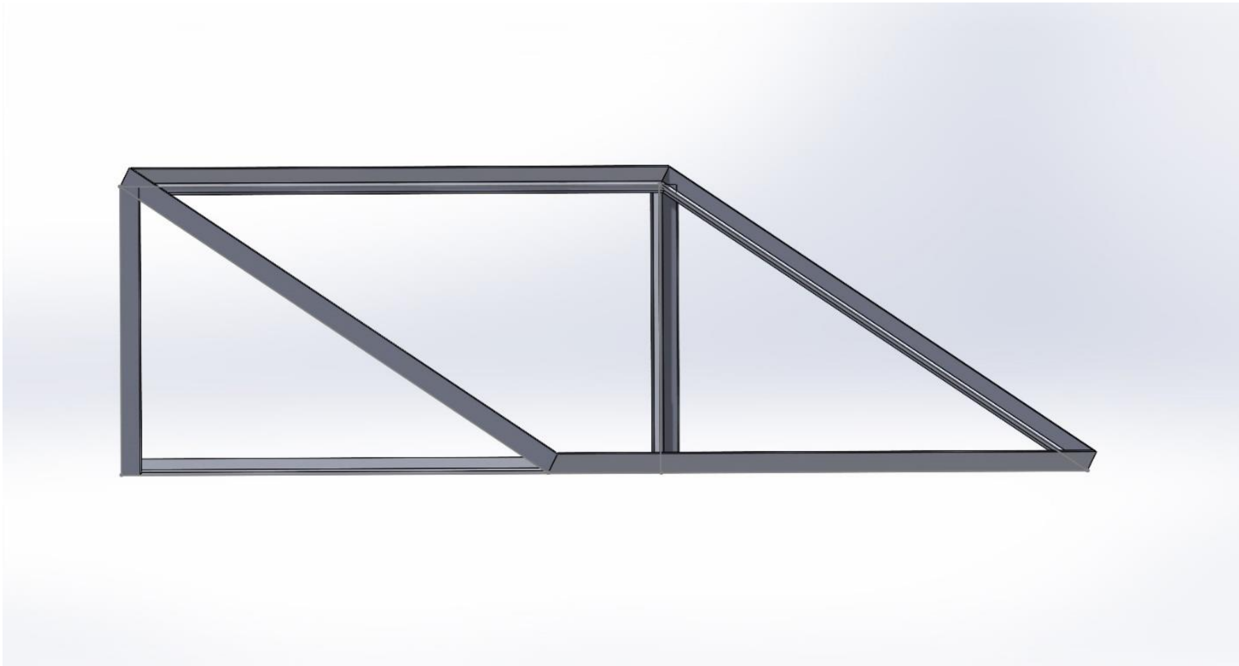

Figure 3.3 Angular iron structure for mounting Solar PV

Figure 3.4 Tube

The specifications of the floating structure are as follows:

Weight of frame = 10 Kg

Weight of the Solar module = 12 Kg

Dimensions of iron frame = 1496 mm x 666 mm (with adjustable hinge support for change in tilt angle)

The structure is pretty much stable. The frame is provide with hinge support so that the tilt angle can be adjusted for taking various data

3.5 Technical Analysis

After installation of the FSPV system on the site, the parameters like temperature, open circuit voltage and short circuit current were measured. The power was calculated from open circuit voltage and short circuit current.

Pyranometer was not available for the measurement of solar irradiance. The solar irradiance data was provided by Department of Hydrology and Meteorology, Ministry of Energy, Water Resources and Irrigation. From the data provided, the solar irradiance converted into electrical energy by both land based PV system and FSPV system was calculated.

The data were taken for two weeks. For the first five days, the tilt angle was fixed at 30°. After that, the tilt angle was changed from 25° to 28° with a degree change each day to analyze the effect of change in tilt angle. Then the effect of manual tracking system was observed by changing the azimuth angle of the solar module according to the direction of sun.

After the data were taken, the technical analysis was done on the basis of power and solar irradiance converted into electrical energy.

3.6 Financial Analysis

The financial analysis of the system was done using various methods. IRR, payback period and B/C ratio of 1MW FSPV system were calculated. The cost benchmark analysis was also done for FSPV system of different capacity.

3.7 Comparison with Land-based PV System

The technical and financial efficiency was compared against land based solar PV system.

3.8 Documentation

As the final step of the thesis, documentation was done.

CHAPTER FOUR : RESULTS AND DISCUSSION

4.1 Technical analysis of the FSPV system

After the FSPV system of 120 Watts and a solar module of same capacity was installed on the site, the data was taken for two weeks. The parameters measured were open circuit voltage, short circuit current and temperature. These data were used for analyzing the technical performance of the FSPV system and comparing it with the land based solar PV system. According to the objective of the thesis, the tilt angle was fixed at 30° for first five days for both FSPV and land based solar PV system. The analysis was done on that basis. For analyzing the effect of change in tilt angle on the FSPV system, the tilt angle was changed to 25° to 28° changing a degree per day for four days. Then, for analyzing the effect of manual tracking system, the azimuth angle of the solar panel was changed manually and then parameters were measured.

4.1.1 Data measured

The tilt angle of both the system was fixed at 30° 11th, 14th, 15th, 16th and 17th of August. The parameters measured are tabulated below for both land based and FSPV system.

Table 4.1 Data measured for Land based Solar PV on 11th August 2022

Time	**Temperature(°C)**	**Irradiance Watt/m²**	**Open circuit voltage(V)**	**Short circuit Current(A)**	**Power (watts)**	**Percentage of irradiance absorbed**
10:45	27.2	910.5	17.75	6.03	107.03	11.89
11:45	28.1	1019.5	18.2	6.59	119.94	11.89
12:45	25	848.6	17.23	6.96	119.92	14.28
13:45	23.8	488.7	14.25	6.25	89.06	18.43

14:45	26.1	894.4	17.56	6.89	120.98	13.67
15:45	24	542.6	16.9	6.23	105.28	19.61

The day was quite sunny on 11th August. The irradiance was irregular throughout the day. For the land based PV system, the power ranged from 89-121 watts. The maximum irradiance converted into electrical energy was 19.61 %.

Table 4.2 Data measured for FSPV on 11th August 2022

Time	**Temperature(°C)**	**Irradiance Watt/m^2**	**Open circuit voltage(V)**	**Short circuit Current(A)**	**Power (watts)**	**Percentage of irradiance absorbed**
10:45	22.3	910.5	18.78	6.33	118.88	13.21
11:45	22.5	1019.5	18.96	7.01	132.91	13.18
12:45	21.8	848.6	18.53	6.26	116	13.81
13:45	21.2	488.7	16.05	6.05	97.10	20.06
14:45	22	894.4	18.96	6.29	119.26	13.48
15:45	21.5	542.6	17.83	6.32	112.68	21.00

For the FSPV system, the power ranged from 97-133 watts. The maximum irradiance converted into electrical energy was 21 %. We can clearly see the increase in power in FSPV system.

Table 4.3 Data measured for Land based Solar PV on 14th August 2022

Time	**Temperature(°C)**	**Irradiance Watt/m^2**	**Open circuit voltage(V)**	**Short circuit Current(A)**	**Power (watts)**	**Percentage of irradiance absorbed**
10:45	26.1	552.3	14.25	6.23	88.78	16.25
11:45	26.1	525.1	14.23	5.90	83.96	16.16
12:45	25	333.1	12.10	3.27	39.57	12.01
13:45	25	481.6	14.36	5.13	73.67	15.46
14:45	22.8	696.4	15.29	6.25	95.56	13.87
15:45	22.2	304.4	14.25	3.39	48.31	16.41

The day was cloudy on 14th August. The values of irradiance was very low. So the power output was also low. The maximum irradiance was in the range of 550 watt/m^2.For the land based PV system, the power ranged from 39-96 watts. The maximum irradiance converted into electrical energy was 16.16 %.

Table 4.4 Data measured for FSPV on 14th August 2022

Time	**Temperature(°C)**	**Irradiance Watt/m^2**	**Open circuit voltage(V)**	**Short circuit Current(A)**	**Power (watts)**	**Percentage of irradiance absorbed**
10:45	22	552.3	14.35	6.34	90.98	16.65
11:45	21.8	525.1	14.23	6.85	97.47	18.76
12:45	21.2	333.1	12.30	3.71	45.63	13.85
13:45	21.1	481.6	14.59	5.02	87.83	18.43
14:45	22	696.4	15.35	6.05	95.94	13.93
15:45	21.3	304.4	14.23	3.87	55.07	18.29

For the land FSPV system, the power ranged from 45-97 watts. The maximum irradiance converted into electrical energy was 18.76 %. Even on cloudy day, we can see the increase in power of the FSPV system.

Table 4.5 Data measured for Land based Solar PV on 15th August 2022

Time	Temperature(°C)	Irradiance Watt/m^2	Open circuit voltage(V)	Short circuit Current(A)	Power (watts)	Percentage of irradiance absorbed
10:45	27.8	969.1	17.78	6.39	113.61	11.85
11:45	27.2	1078.6	18.14	6.02	109.20	10.24
12:45	27	1049.2	18.25	6.75	123.19	11.87
13:45	24	527.4	15.32	6.32	96.82	18.56
14:45	24	497.3	16.2	6.22	100.76	20.48
15:45	22.8	584.1	16.32	6.31	102.98	17.83

The day was quite sunny on 15th August. The maximum irradiance was in the range of 1075 watt/m^2 which is optimum for the performance of solar module. For the land based PV system, the power ranged from 96-123 watts. The maximum irradiance converted into electrical energy was 20.48 %.

Table 4.6 Data measured for FSPV on 15th August 2022

Time	**Temperature(°C)**	**Irradiance Watt/m²**	**Open circuit voltage(V)**	**Short circuit Current(A)**	**Power (watts)**	**Percentage of irradiance absorbed**
10:45 AM	23.2	969.1	18.23	6.96	126.88	13.24
11:45 AM	23.3	1078.6	20.40	6.23	127.09	11.91
12:45 PM	23	1049.2	19.25	6.89	132.63	12.75
1:45 PM	22.1	527.4	15.98	5.26	84.05	16.11
2:45 PM	22.2	497.3	16.15	6.85	110.63	22.49
3:45 PM	22.1	584.1	16.27	6.12	99.57	17.23

For the land FSPV system, the power ranged from 115-133 watts. The maximum irradiance converted into electrical energy was 22.49 %. The difference in power output and the irradiance converted into electrical output is clearly visible.

Table 4.7 Data measured for Land based Solar PV on 16th August 2022

Time	**Temperature(°C)**	**Irradiance Watt/m^2**	**Open circuit voltage(V)**	**Short circuit Current(A)**	**Power (watts)**	**Percentage of irradiance absorbed**
10:45	27.8	955.9	17.56	6.23	109.40	11.57
11:45	27.2	923.7	17.23	6.58	113.37	12.41
12:45	27	674.9	17.01	6.47	110.05	16.48
13:45	24	970.7	17.86	6.96	124.30	12.95
14:45	24	615.3	14.85	5.58	82.86	13.61
15:45	24	154.1	2.36(cloudy)	3.21	7.57	4.97

The day was both sunny and cloudy on 16th August. For the land based PV system, the power ranged from 7-124 watts. The maximum irradiance converted into electrical energy was 16.48 %.

Table 4.8 Data measured for FSPV on 16th August 2022

Time	Temperature(°C)	Irradiance Watt/m^2	Open circuit voltage(V)	Short circuit Current(A)	Power (watts)	Percentage of irradiance absorbed
10:45	23.8	955.9	18.96	6.08	115.27	12.19
11:45	24.2	923.7	19.02	6.36	120.97	13.24
12:45	23	674.9	17.41	6.35	110.55	16.56
13:45	23.2	970.7	18.06	6.89	124.43	12.96
14:45	22	615.3	14.03	5.08	71.27	11.71
15:45	21.2	154.1	2.32(cloudy)	1.52	3.53	2.31

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For the FSPV system, the power ranged from 3-124 watts. The maximum irradiance converted into electrical energy was 16.56 %. The difference in power output and the irradiance converted into electrical output is clearly visible

Table 4.9 Data measured for Land based Solar PV on 17th August 2022

Time	Temperature(°C)	Irradiance Watt/m^2	Open circuit voltage(V)	Short circuit Current(A)	Power (watts)	Percentage of irradiance absorbed
10:45	27.2	521.8	14.25	5.03	71.68	13.89
11:45	26.1	969.2	17.96	6.08	109.20	11.39
12:45	25	633.1	15.56	5.28	82.16	13.12

13:45	25	515.8	14.25	4.23	60.28	11.81
14:45	24.2	345.5	8.65 (cloudy)	3.58	30.98	9.06
15:45	24.2	265.2	5.83 (cloudy)	2.35	13.70	5.22

The day was mostly cloudy on 17th August. For the land based PV system, the power ranged from 13-109 watts. The maximum irradiance converted into electrical energy was 13.89 %.

Table 4.10 Data measured for FSPV on 17th August 2022

Time	**Temperature(°C)**	**Irradiance Watt/m²**	**Open circuit voltage(V)**	**Short circuit Current(A)**	**Power (watts)**	**Percentage of irradiance absorbed**
10:45	23.2	521.8	15.82	5.26	83.21	16.12
11:45	23.2	969.2	18.69	6.01	112.33	11.71
12:45	23	633.1	16.56	5.36	88.76	14.17
13:45	22.8	515.8	14.28	4.35	62.12	12.17
14:45	22.2	345.5	8.25 (cloudy)	3.6	29.7	8.69
15:45	21.6	265.2	5.98 (cloudy)	2.25	13.45	5.12

For the FSPV system, the power ranged from 13-112 watts. The maximum irradiance converted into electrical energy was 16.12 %. The difference in power output and the irradiance converted into electrical output is clearly visible.

The tilt angle was changed from 30° to 25° on 18th August to analyze the effect of change in the tilt angle. It was changed both for land-based PV system and FSPV system and the parameters measured are given in the table below:

Table 4.11 Data measured for Land based Solar PV on 18th August 2022

Time	**Temperature(°C)**	**Irradiance Watt/m²**	**Open circuit voltage(V)**	**Short circuit Current(A)**	**Power (watts)**	**Percentage of irradiance absorbed**
10:45	27.8	863.2	16.98	6.05	102.73	12.03
11:45	27.2	990.2	17.89	7.03	125.77	12.84
12:45	26.1	775.4	16.58	6.25	103.63	13.51
13:45	25	790.7	17.89	6.01	107.52	13.74
14:45	24	592.3	15.32	5.96	91.31	15.59
15:45	22.2	432.3	13.12	4.85	63.63	14.88

For 25° tilt angle, there is no major change as in comparison to the 30°. For the land based PV system, the power ranged from 63-125 watts. The maximum irradiance converted into electrical energy was 15.59 %.

Table 4.12 Data measured for FSPV on 18th August 2022

Time	Temperature(°C)	Irradiance Watt/m^2	Open circuit voltage(V)	Short circuit Current(A)	Power (watts)	Percentage of irradiance absorbed
10:45	23.8	863.2	17.58	6.27	110.23	12.91
11:45	23.2	990.2	18.57	6.23	115.69	11.81
12:45	22.1	775.4	16.88	6.05	102.12	13.31
13:45	22.5	790.7	18.28	6.03	110.23	14.09
14:45	22.5	592.3	15.22	4.96	75.49	12.89
15:45	21.9	432.3	13.20	3.58	47.26	11.05

For the FSPV system, the power ranged from 47-115 watts. The maximum irradiance converted into electrical energy was 14.09 %. The difference in power output and the irradiance converted into electrical output is clearly visible

The tilt angle was changed from 25° to 26° on 19th August and the parameters measure are given in the table below:

Table 4.13 Data measured for Land based Solar PV on 19th August 2022

Time	Temperature(°C)	Irradiance Watt/m^2	Open circuit voltage(V)	Short circuit Current(A)	Power (watts)	Percentage of irradiance absorbed
10:45	22.8	818.2	15.25	6.03	91.98	11.37
11:45	22.8	978.7	15.23	6.03	91.84	9.49
12:45	22.8	714.7	15.89	5.02	79.77	11.28
13:45	22.8	845.7	15.68	5.05	79.18	9.47
14:45	22.8	728.3	15.48	5.04	78.02	10.83
15:45	22	273.1	10.23	6.22	32.94	12.19

For 26° tilt angle of the land based PV system, the power ranged from 32-91 watts. The maximum irradiance converted into electrical energy was 12.19 %.

Table 4.14 Data measured for FSPV on 19th August 2022

Time	Temperature(°C)	Irradiance Watt/m^2	Open circuit voltage(V)	Short circuit Current(A)	Power (watts)	Percentage of irradiance absorbed
10:45	22.1	818.2	15.27	6.03	92.08	11.37
11:45	21.8	978.7	16.22	6.03	97.81	10.10
12:45	21.6	714.7	15.79	5.02	79.26	11.21
13:45	21.8	845.7	15.82	5.05	79.89	9.55

14:45	21.8	728.3	15.81	5.04	79.68	11.06
15:45	20.5	273.1	10.03	3.22	32.30	11.96

For the FSPV system, the power ranged from 32-97 watts. The maximum irradiance converted into electrical energy was 11.96 %. The difference in power output and the irradiance converted into electrical output is clearly visible

The tilt angle was changed from 26° to 27° on 20th August and the parameters measure are given in the table below:

Table 4.15 Data measured for Land based Solar PV on 20th August 2022

Time	**Temperature(°C)**	**Irradiance Watt/m^2**	**Open circuit voltage(V)**	**Short circuit Current(A)**	**Power (watts)**	**Percentage of irradiance absorbed**
10:45	26.1	825.2	17.52	5.89	103.19	12.64
11:45	25	1006.9	18.23	6.96	126.88	12.74
12:45	22.8	850.8	13.23	5.12	67.74	8.05
13:45	22.8	691.3	12.56	4.96	62.30	9.11
14:45	22.8	609.4	10.52	3.89	40.93	6.79
15:45	22.5	215.6	5.32	2.21	11.76	5.51

For 27° tilt angle of the land based PV system, the power ranged from 11-126 watts. The maximum irradiance converted into electrical energy was 12.74 %.

Table 4.16 Data measured for FSPV on 20th August 2022

Time	Temperature(°C)	Irradiance Watt/m^2	Open circuit voltage(V)	Short circuit Current(A)	Power (watts)	Percentage of irradiance absorbed
10:45	22.1	825.2	18.20	6.69	121.76	14.91
11:45	23	1006.9	18.57	6.23	115.69	11.62
12:45	22.8	850.8	13.15	5.58	73.38	8.72
13:45	21.9	691.3	12.45	3.56	44.32	6.48
14:45	21.8	609.4	10.62	3.89	41.31	6.85
15:45	20.3	215.6	5.05	2.30	11.62	5.45

For the FSPV system, the power ranged from 11-121 watts. The maximum irradiance converted into electrical energy was 14.91 %. The difference in power output and the irradiance converted into electrical output is clearly visible

The tilt angle was changed from 27° to 28° on 21st August and the parameters measured are given in the table below:

Table 4.17 Data measured for Land based Solar PV on 21st August 2022

Time	Temperature(°C)	Irradiance Watt/m^2	Open circuit voltage(V)	Short circuit Current(A)	Power (watts)	Percentage of irradiance absorbed
10:45	28	947.5	17.25	6.85	118.16	12.61
11:45	27.8	1059.3	18.02	6.75	121.64	11.61
12:45	28.1	1088.5	18.85	6.89	129.87	12.06

13:45	26.1	879.3	17.56	6.58	115.55	13.29
14:45	26.2	913.8	18.96	6.89	130.63	14.45
15:45	26.1	789.6	17.56	6.23	109.40	14.01

For 28° tilt angle of the land based PV system, the power ranged from 109-130 watts. The maximum irradiance converted into electrical energy was 14.45 %.

Table 4.18 Data measured for FSPV on 21st August 2022

Time	**Temperature(°C)**	**Irradiance Watt/m^2**	**Open circuit voltage(V)**	**Short circuit Current(A)**	**Power (watts)**	**Percentage of irradiance absorbed**
10:45	24	947.5	18.55	6.89	127.81	13.64
11:45	24.8	1059.3	18.96	6.58	124.76	11.91
12:45	25.2	1088.5	19.55	6.74	131.77	12.24
13:45	23.2	879.3	18.02	6.72	121.09	13.92
14:45	23.2	913.8	18.36	6.85	125.77	13.92
15:45	22.1	789.6	18.08	6.25	113	14.47

For the FSPV system, the power ranged from 113-131 watts. The maximum irradiance converted into electrical energy was 14.47 %. The difference in power output and the irradiance converted into electrical output is clearly visible.

For the next three days manual tracking system was introduced to both the land based and FSPV System and the parameters measured are given below:

Table 4.19 Data measured for Land based Solar PV on 22nd August 2022

Time	**Temperature(°C)**	**Irradiance Watt/m^2**	**Open circuit voltage(V)**	**Short circuit Current(A)**	**Power (watts)**	**Percentage of irradiance absorbed**	**Azimuth angle**
10:45	28	925.9	18.22	6.25	113.88	12.44	125
11:45	28	1019.6	18.96	6.98	132.34	13.12	160
12:45	27.3	884	17.25	6.25	107.81	12.33	210
13:45	27.8	1045.8	18.56	6.89	127.88	12.36	240
14:45	27	893.4	18.02	6.75	121.64	13.77	255
15:45	26.1	759	17.25	6.45	111.26	14.82	265

After introducing the manual tracking system, the consistency in the power of the module was observed. For the land based PV system, the power ranged from 107-127 watts. The maximum irradiance converted into electrical energy was 14.82 %.

Table 4.20 Data measured for FSPV on 22nd August 2022

Time	Temperature(°C)	Irradiance Watt/m^2	Open circuit voltage(V)	Short circuit Current(A)	Power (watts)	Percentage of irradiance absorbed	Azimuth angle
10:45	23	925.9	19.01	6.23	118.43	12.93	125
11:45	23.2	1019.6	18.98	6.86	130.21	12.91	160
12:45	23.3	884	18.22	6.89	125.53	14.36	210
13:45	24.8	1045.8	18.96	6.85	129.88	12.56	240
14:45	23.6	893.4	18.90	6.74	127.38	14.42	255
15:45	24.1	759	18.28	6.45	117.91	15.71	265

For the FSPV system, the power ranged from 117-130 watts. The maximum irradiance converted into electrical energy was 15.71 %. The difference in power output and the irradiance converted into electrical output is clearly visible.

Table 4.21 Data measured for Land based Solar PV on 23rd August

Time	Temperature(°C)	Irradiance Watt/m^2	Open circuit voltage(V)	Short circuit Current(A)	Power (watts)	Percentage of irradiance absorbed	Azimuth angle
10:45	22.8	881.2	17.25	6.23	107.47	12.33	125
11:45	22.6	1040.8	18.96	6.23	118.12	11.48	160

12:45	22.6	906.7	17.86	6.85	122.34	13.64	210
13:45	22.6	497.3	14.26	5.02	71.58	14.55	240
14:45	22.6	199	0.25 (raining)	_	_		255
15:45	22.6	492	(raining)	_	_		265

For the land based PV system, the power ranged from 71-122 watts. The maximum irradiance converted into electrical energy was 14.55 %.

Table 4.22 Data measured for FSPV on 23rd August 2022

Time	**Temperature(°C)**	**Irradiance Watt/m^2**	**Open circuit voltage(V)**	**Short circuit Current(A)**	**Power (watts)**	**Percentage of irradiance absorbed**	**Azimuth angle**
10:45	20.6	881.2	18.25	6.38	117.26	13.45	125
11:45	21.3	1040.8	19.02	6.03	114.69	11.14	160
12:45	21.3	906.7	18.6	6.25	116.25	12.96	210
13:45	21.6	497.3	14.24	4.90	69.78	14.19	240
14:45	20.8	199	(raining)	_	_		255
15:45	24.8	492	(raining)	_	_		265

For the FSPV system, the power ranged from 69-117 watts. The maximum irradiance converted into electrical energy was 14.19 %. The difference in power output and the irradiance converted into electrical output is clearly visible.

Table 4.23 Data measured for Land based Solar PV on 24th August 2022

Time	**Temperature(°C)**	**Irradiance Watt/m²**	**Open circuit voltage(V)**	**Short circuit Current(A)**	**Power (watts)**	**Percentage of irradiance absorbed**	**Azimuth angle**
10:45	26.8	885.9	18.23	6.02	109.74	12.53	125
11:45	27	948.3	18.62	6.85	127.55	13.60	160
12:45	26.2	724.2	16.96	6.79	115.16	16.08	210
13:45	26.8	910.8	17.75	7.01	124.43	13.81	240
14:45	26.1	715.4	18.02	6.25	112.63	15.92	255

For the land based PV system, the power ranged from 109-127 watts. The maximum irradiance converted into electrical energy was 16.08 %.

Table 4.24 Data measured for FSPV on 24th August 2022

Time	**Temperature(°C)**	**Irradiance Watt/m²**	**Open circuit voltage(V)**	**Short circuit Current(A)**	**Power (watts)**	**Percentage of irradiance absorbed**	**Azimuth angle**
10:45	22.8	885.9	18.31	6.36	116.45	13.29	125
11:45	23	948.3	18.96	6.55	124.19	13.24	160
12:45	22.2	724.2	18.52	6.22	115.19	16.08	210
13:45	22.7	910.8	18.96	7.03	133.29	14.80	240
14:45	23.1	715.4	18.58	6.20	115.20	16.28	255

For the FSPV system, the power ranged from 115-133 watts. The maximum irradiance converted into electrical energy was 16.28 %. The difference in power output and the irradiance converted into electrical output is clearly visible.

4.1.2 Comparison of the FSPV system with the land based solar PV system at tilt angle 30°

After taking the measurement of the parameters, it was observed that the temperature near FSPV system was less as compared to the land.

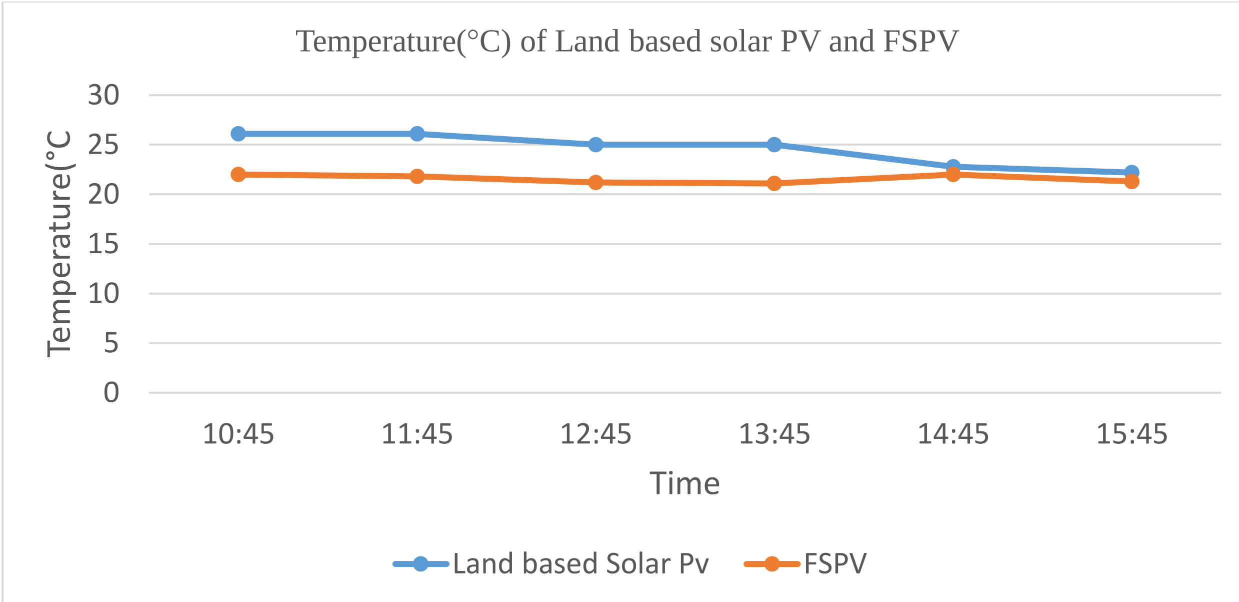


Figure 4.1 Temperature difference between Land-based Solar PV and FSPV

As we can see in the above graph, the temperature of the FSPV system is less than that of the land based FSPV System. The above graph is of one day but similar behavior was shown on all days.

The power measured from both system were also compared with one another which can be seen in the graph below:

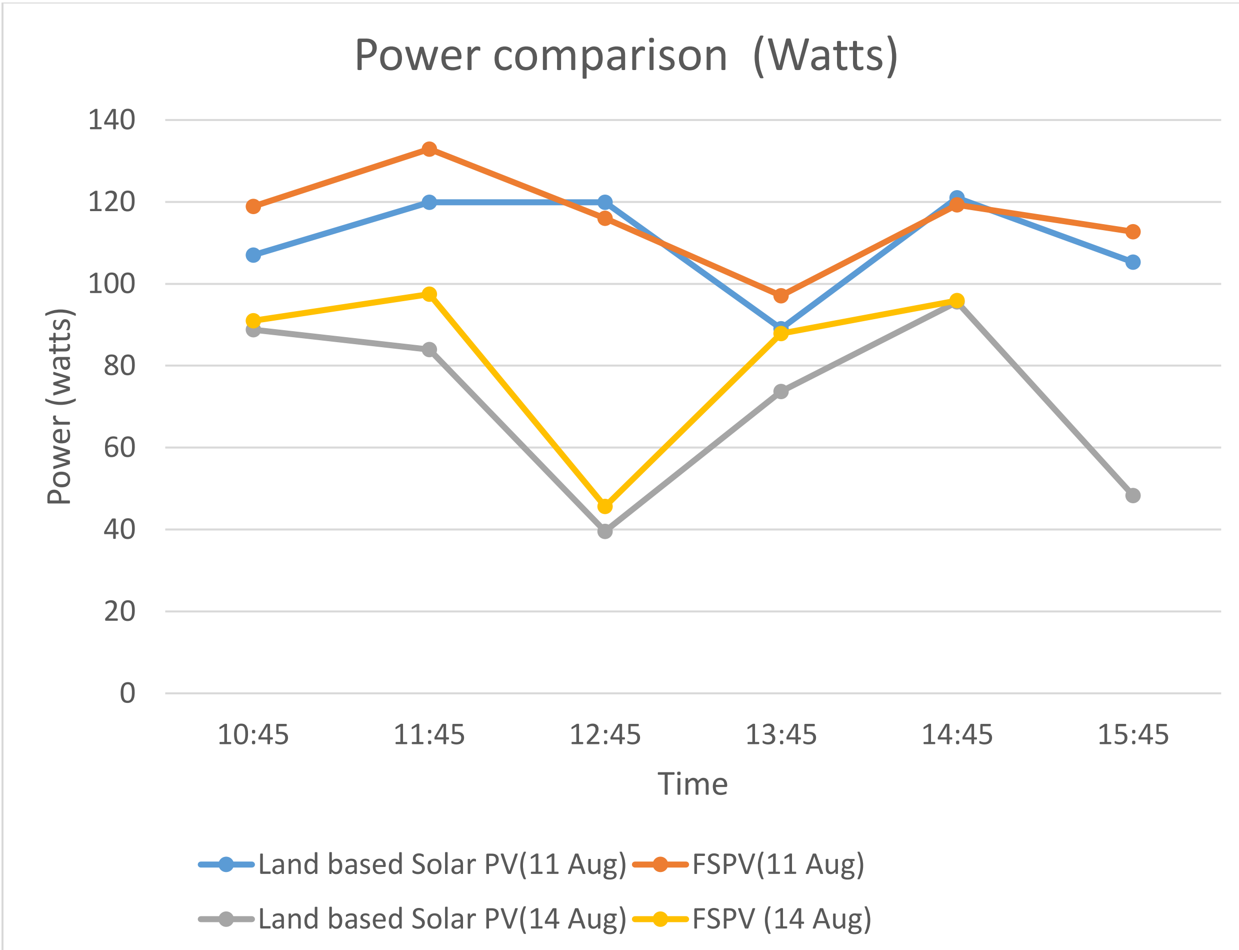


Figure 4.2 Power comparison of Land-based Solar PV and FSPV

The graph shows the power difference between land-based and FSPV system of two days. On both days, power produced by FSPV system was more than the land based system. On the average, FSPV system produced 12% more power than land based PV system. The power gain was 15.5 % according to an experiment conducted in Malaysia on 80 watt Solar panel. (Majid, 2014)

The solar irradiance absorbed by both system for electrical energy comparison were also calculated and the difference can be seen in the chart below.

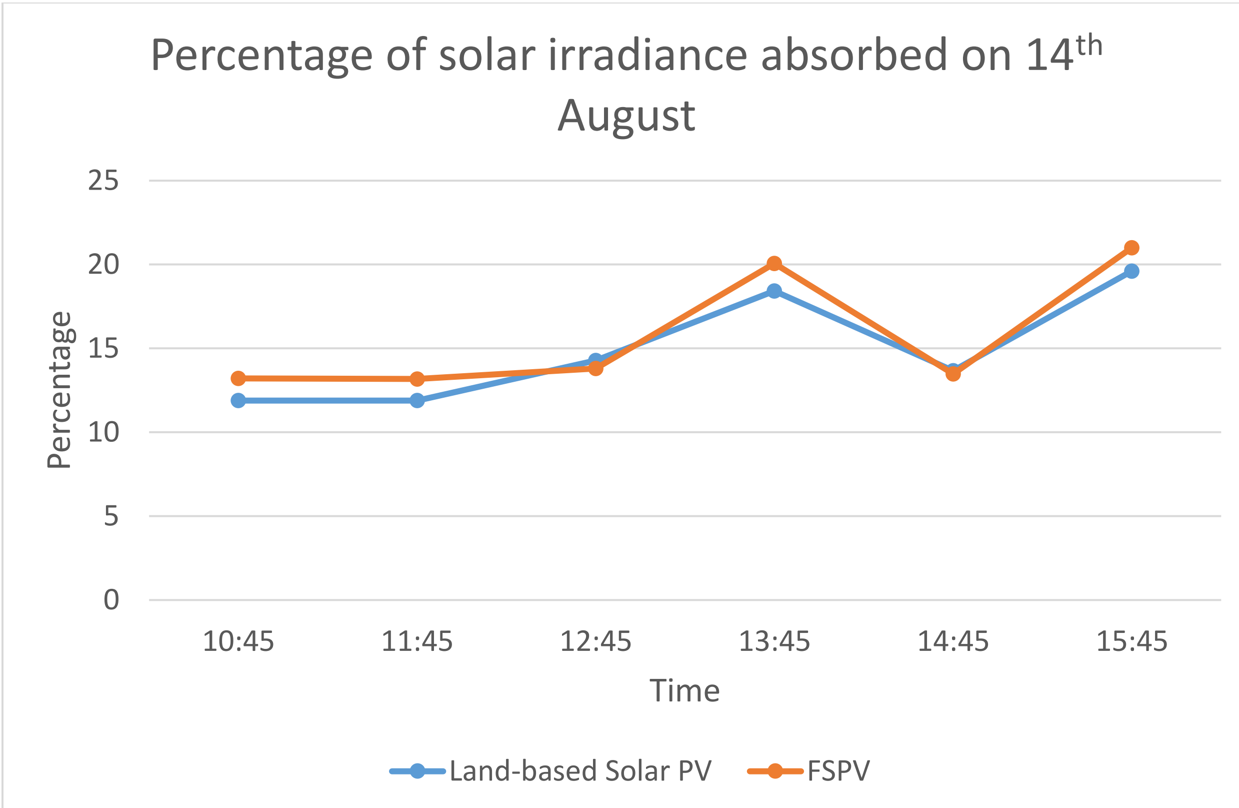


Figure 4.3 Comparison of solar radiation absorbed on 14th August

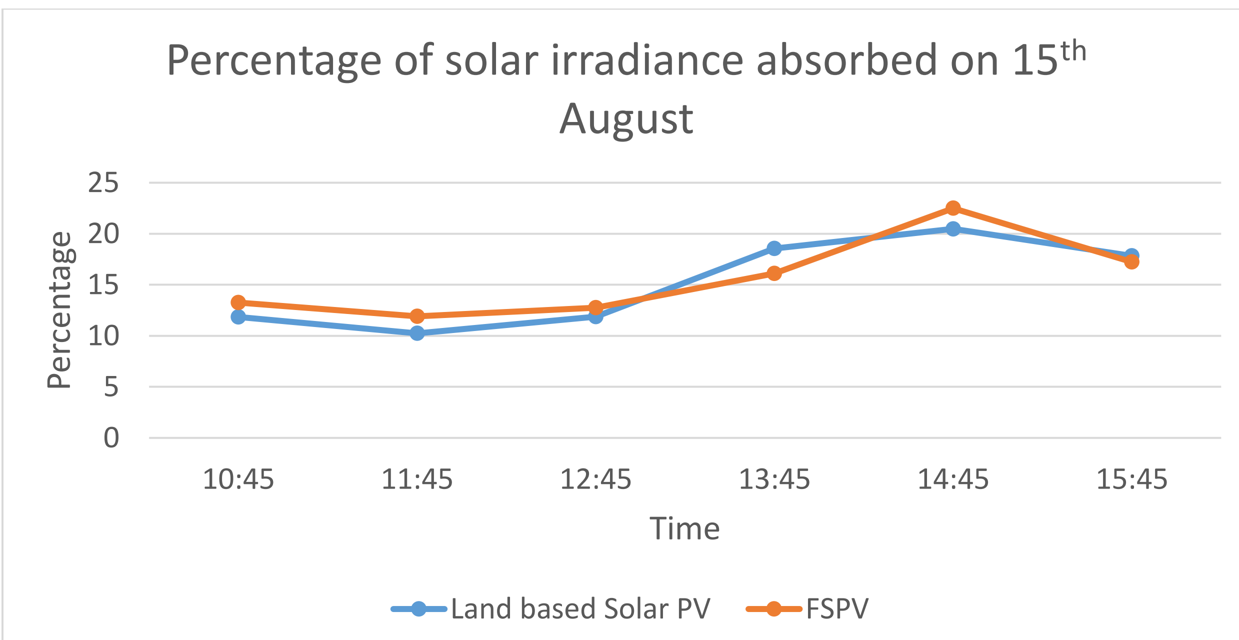


Figure 4.4 Percentage of solar radiation absorbed on 15th August

In the above two graphs, the irradiance absorbed by both land based PV system and FSPV system are shown. The irradiance absorbed by FSPV system that is converted into electrical energy is nearly 1.5% more than that of FSPV system.

4.1.3 Effect of change in the tilt angle on the FSPV system

The tilt angle was changed from 30°to 25°, 26°, 27°and 28°on 18, 19, 20 and 21 of August respectively. At tilt angle 25°, the percentage of irradiance converted to electrical output was in the range 11-14%. At tilt angle 26°, the percentage of irradiance converted to electrical output was in the range 9-11%. At tilt angle 27°, the percentage of irradiance converted to electrical output was in the range 5-15%. The weather was also very inconsistent which maybe a major factor in the wide range. At tilt angle 28°, the percentage of irradiance converted to electrical output was in the range 11-14.5%. From the above tables, we can observe that the change in tilt angle from 25° to 28° has little effect on the performance of the FSPV system.

The effect of change in tilt angle was more in land based system than in FSPV system.

4.1.4 Effect of manual tracking system on the FSPV system

The azimuth angle of the FSPV system was manually changed according to the position of the sun to analyze the effect of the manual tracking system. The weather was sunny 22nd August day. There was rain on 23 August on the later part of the day, so data could not be taken. But the power output was consistent when the sun was out. From the above tables, we can observe that by introducing tracking system, the performance of the FSPV system can be made consistent. Although it will be difficult to automate the automatic tracking system. The power output of FSPV was enhanced by 18% as compared to the on-ground PV system. But in this experimental study, it was enhanced by 11-12%.

The manual tracking system was positive for both land based and FSPV system.

4.1.5 Structural Analysis of the System

Floating structure dimensions are governed by buoyancy and stability considerations. Upper weight is more important to these structures than the lower substructure. The weight of the frame structure was 10 kg and the weight of the panel was around 12 kg. So the total weight was 22 kg which was to be made float on the tube. The centre of gravity is typically above the centre of buoyancy. So, the floating system was to be placed on the tube such that it does not sink.

If the same floating structure is to be designed for a larger system, the iron frame and tube are to be configured in such a way that the centre of gravity is typically above the centre of buoyancy so that the structure does not sink.

4.2 Financial Analysis of the FSPV system

4.2.1 Techno-financial analysis of 1MW FSPV system

Technical Analysis

FSPV system consists of floating system, mooring system, PV system, cables and connectors.

a) Floating system: A floating system consists of floating bodies (floats and structures) on which PV arrays are attached. Provides the buoyancy needed to float the entire system. Floats are typically made of high density polyethylene (HDPE) or medium density polyethylene (MDPE).

b) Mooring System: The mooring system uses anchors and cables to secure the floating system. It also prevents the module from floating or rotating, allowing it to adapt to disturbances caused by water level fluctuations while maintaining its south-facing position.

c) PV system: The PV system consists of PV modules.

One of the main reasons for decreased efficiency of PV system is an increased temperature of the PV cells. Since the FSPV system is in constant contact with water, the PV cells are cooled which increases the efficiency of the system. Basic approach of an FSPV system is to install PV system over floaters oriented to the south with a fixed azimuth angle (0º) and a fixed tilt angle (30º). Tracking the azimuth angle will result in an increased efficiency with less sophisticated mechanism and lower cost but that design is not considered in this paper since numerous papers on tracking PV system have been published previously. In this paper, 1 MWp plant is considered with PV modules of 250 wp and 2 inverters of 500 KW with the output of 400V 3-phase connected by approximately 1 km long cables to the substation on land.

Each array is securely anchored at four corners, thus preventing them from floating away or turning. The tilt angle of PV system is taken to be 30º only. Also, the increased efficiency due to decrease in temperature counteracts the effect of optimum tilt angle.

Simulation of the Floating PV system carried out in the PVSyst software. The solar irradiance and meteorological data were taken from NASA-SSE. In order to adapt the system for simulation in PVSyst, the operating temperature of PV modules was reduced by increasing the thermal loss factor due to the cooling effect of water. For land-based PV cells, the thermal loss factor is generally taken to be about 20 W/m2K. But for water, the thermal loss factor could be as high as 250-300 $W/m^2/K$. However, in this scenario, the thermal loss factor assumed to be 62 W/m^2K only.

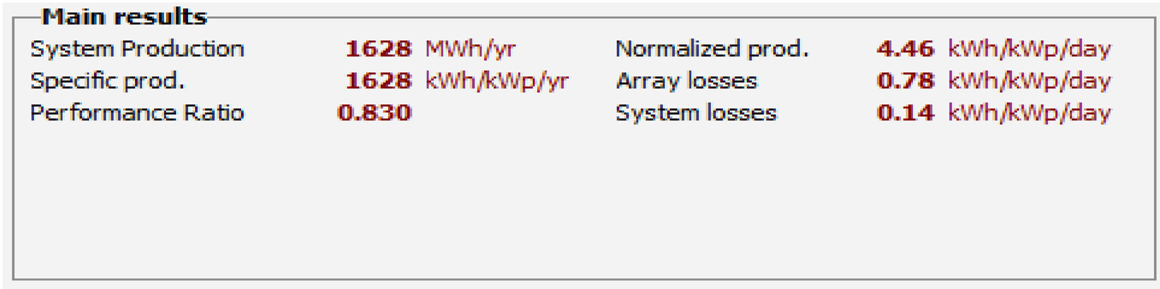
The result from PVSyst simulation is shown below:

PV Array

PV modules	Mono 250 Wp 60 cells	Inverter	500 kWac inverter
Nominal power	1000 kWp	Inv. unit power	500 kW
MPP voltage	30.7 V	Nb. of inv.	2
MPP current	8.1 A		

Figure 4.5 Solar PV System constituents

For both land based and FSPV system, 4000 modules of 250 Wp monocrystalline modules were taken which take the area of 6508 m^2. Two inverters of 500 KW were considered.



Main results

System Production	1628	MWh/yr	Normalized prod.	4.46	kWh/kWp/day
Specific prod.	1628	kWh/kWp/yr	Array losses	0.78	kWh/kWp/day
Performance Ratio	0.830		System losses	0.14	kWh/kWp/day

Figure 4.6 Main results for land-based PV system

For the land based PV system, the annual energy production was calculated to be 1628 MWh/yr with the performance ratio of 83 %.

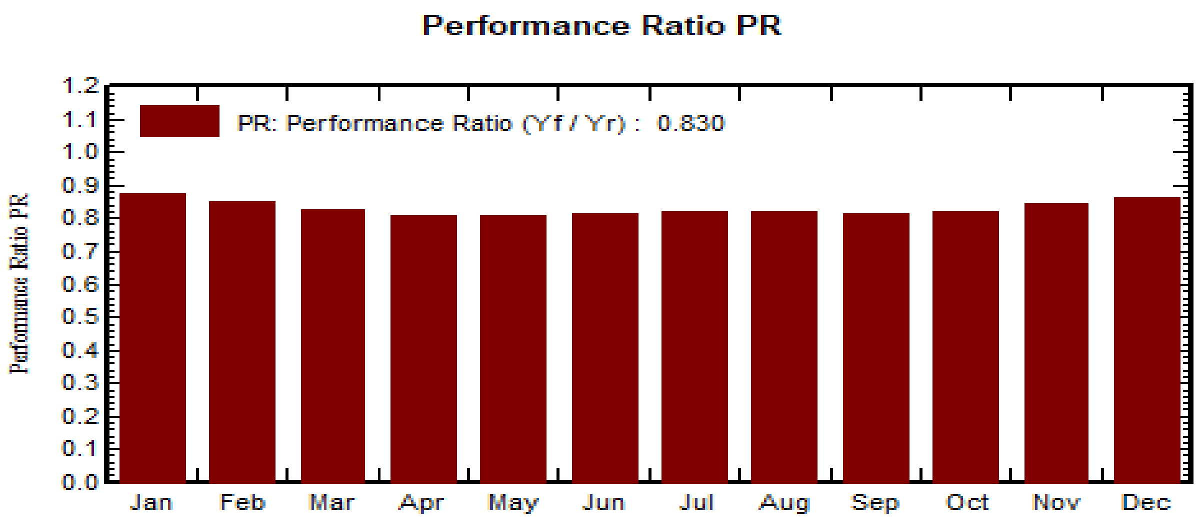


Figure 4.7 Performance ratio chart for Land based PV system

The performance ratio can be observed in the above figure for land-based PV system. It is consistent throughout the year.

New simulation variant
Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	118.4	40.23	8.08	169.3	165.6	151881	147658	0.872
February	114.2	46.69	13.11	144.3	141.2	126628	122837	0.851
March	165.2	65.90	18.89	187.5	182.9	158930	154314	0.823
April	161.3	75.49	23.68	162.7	157.9	135567	131501	0.808
May	181.6	86.28	25.22	168.9	163.5	140308	135930	0.805
June	160.0	86.76	25.01	144.9	139.9	121931	117909	0.813
July	147.4	86.05	23.72	134.7	129.8	114394	110587	0.821
August	157.1	81.34	23.54	151.6	146.6	128026	124075	0.819
September	136.7	64.86	22.61	144.2	139.6	121046	117221	0.813
October	149.6	50.82	20.38	182.2	178.2	153825	149279	0.819
November	128.3	35.13	15.21	180.6	177.0	156473	152154	0.842
December	123.6	26.07	9.99	190.5	186.7	168851	164190	0.862
Year	1743.4	745.64	19.14	1961.4	1909.0	1677861	1627654	0.830

Figure 4.8 Monthly values for land-based PV System

Same system was used for FSPV system. For the PVSyst simulation, the thermal loss factor was increased.

Main results

System Production	**1766**	MWh/yr	Normalized prod.	**4.84**	kWh/kWp/day
Specific prod.	**1766**	kWh/kWp/yr	Array losses	**0.39**	kWh/kWp/day
Performance Ratio	**0.900**		System losses	**0.15**	kWh/kWp/day

Figure 4.9 Main results for FSPV System

Annual electricity generation for proposed FSPV system amounts to 1764 MWh/year with Performance ratio of 90% which is significantly better result for a Solar PV system. This corroborates the feasibility and benefits of an FSPV system from technical perspective.

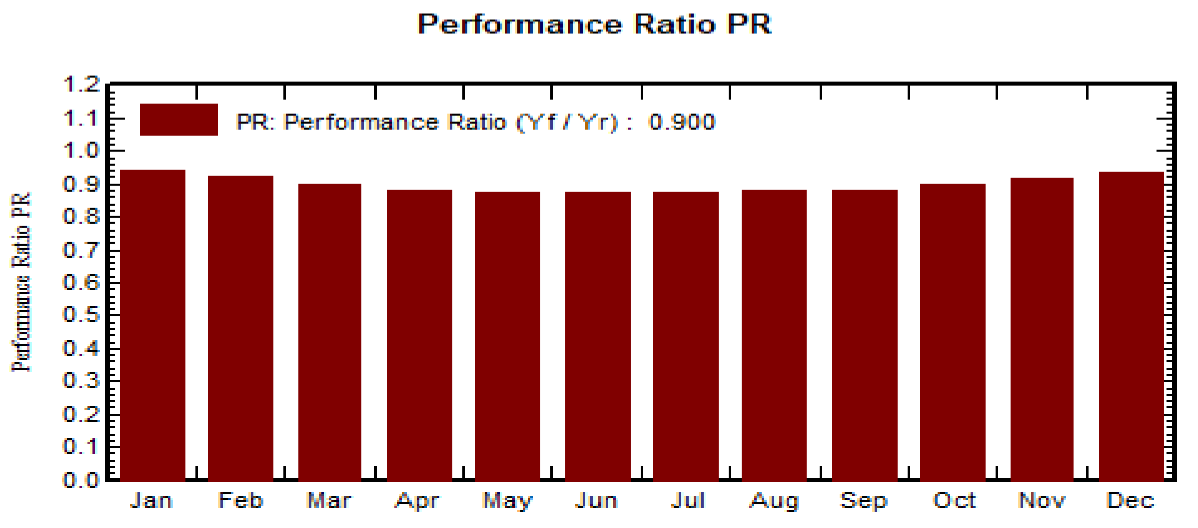


Figure 4.10 Performance ratio chart for FSPV System

New simulation variant
Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	118.4	40.23	8.08	171.7	168.2	166427	161732	0.942
February	114.2	46.69	13.11	145.4	142.4	138484	134304	0.923
March	165.2	65.90	18.89	187.8	183.2	173842	168734	0.899
April	161.3	75.49	23.68	161.6	156.9	146660	142230	0.880
May	181.6	86.28	25.22	166.8	161.3	150257	145556	0.872
June	160.0	86.76	25.01	142.9	137.8	128877	124640	0.872
July	147.4	86.05	23.72	132.9	128.0	120449	116457	0.876
August	157.1	81.34	23.54	150.2	145.2	136473	132255	0.881
September	136.7	64.86	22.61	143.8	139.2	130520	126389	0.879
October	149.6	50.82	20.38	183.3	179.3	169479	164418	0.897
November	128.3	35.13	15.21	183.1	179.6	172924	168057	0.918
December	123.6	26.07	9.99	193.9	190.3	186813	181546	0.936
Year	1743.4	745.64	19.14	1963.3	1911.4	1821206	1766317	0.900

Figure 4.11 Monthly values for FSPV System

Financial Analysis

Floating solar photovoltaic system are installed on various types of natural and artificial water bodies. The capital cost of FSPV system are higher than conventional land based solar Pv system as FSPV system cost depends on the site specifics, the floating structure and anchoring solution. The key cost items for FSPV system are site staging, floats, anchoring and mooring and other electrical components.

If FPV and hydropower plants are combined, hydropower has the ability to function as a real-time PV power compensation source because it is a form of instantaneously changeable energy source. The reservoirs behind hydroelectric dams can store water during times of high irradiance and release it at cloudier times or when demand surges; as a result, they function as a storage system for the operation of a hybrid solar and hydropower system. In order to account for the unpredictable nature of PV output, the hydropower plant might modify the reservoir's water level on a regular basis. The hydropower units can limit their output and store water in the reservoir during periods of high PV generation and low system demand. When system demand is high and PV generation is low, the hydropower plant releases water to improve output. The daily water balance of the reservoir should be kept at the same level as it was before to the installation of the hybrid system in order to satisfy the water needs of other reservoir services, such as irrigation, downstream environmental flows, and flood control.

For the financial analysis, a FSPV system of 1MW was assumed. Following assumptions are used in the model:

Total installed capacity: 1 MW

Project cost: US$1 million (US$1/Watt DC)

Debt: Equity ratio: 70:30

DC capacity factor: 21.6%

Annual Output for Year 1 (MWh): 1764

Degradation Factor: 0.60%

System lifetime: 25 years

Operation and Maintenance Cost (O& M): US$5/KW/year

OM Costs Escalator (%/year): 2.00%

Debt Interest rate: 12.00%

Debt period in years: 12

Discount Rate: 12.00%

Financial model results Compared to land based solar PV system, FSPV systems are expensive as the cost of floating structure constitute of 50% of the total cost of project. As compared to existing benchmark project cost of US$0.6-0.8 million/MW, floating solar almost costs US$1-1.2 million/MW. The Internal Rate of Return is calculated to be

13.282% which is just above discount rate of 102%. The project NPV was calculated as US$136,899 and the B/C ratio is 1.02 which is above 1.

If the tracking system is to be included in the FSPV system, the cost increases to $0.40 – $0.70/Watt which will increase the capital of the whole system.

4.2.2 Cost benchmark analysis

The key cost items for FSPV system are site staging, floats, anchoring and mooring and other electrical components.

Figure below shows that the cost per watt of the FSPV system in the baseline scenario decreases as the system size increases. Economies of scale are driven primarily by his Structure Balance of System (SBOS) costs. This represents 25% to 30% of the total cost, depending on the size of the system. Approximately 75% to 85% of SBOS costs can be attributed to float costs. The average cost of US-made floats is $0.20-$0.40/WDC, and the average cost of European-made floats is estimated at $0.22/WDC depending on type, including shipping to the US. Estimated WDC and $0.90/WDC floating construction and quantity purchased. As the float purchase volume increases, the unit price of the float decreases. For example, $0.40/WDC for 2MW FPV system, $0.36/WDC for 5MW FPV system, $0.30/WDC for 10MW FPV system, $0.20/WDC for 50MW FPV system. The float cost for a particular system size assumes the installer only orders floats for one system at a time. Developers large enough to run multiple systems in parallel can purchase float at a low cost to match their increased volume.

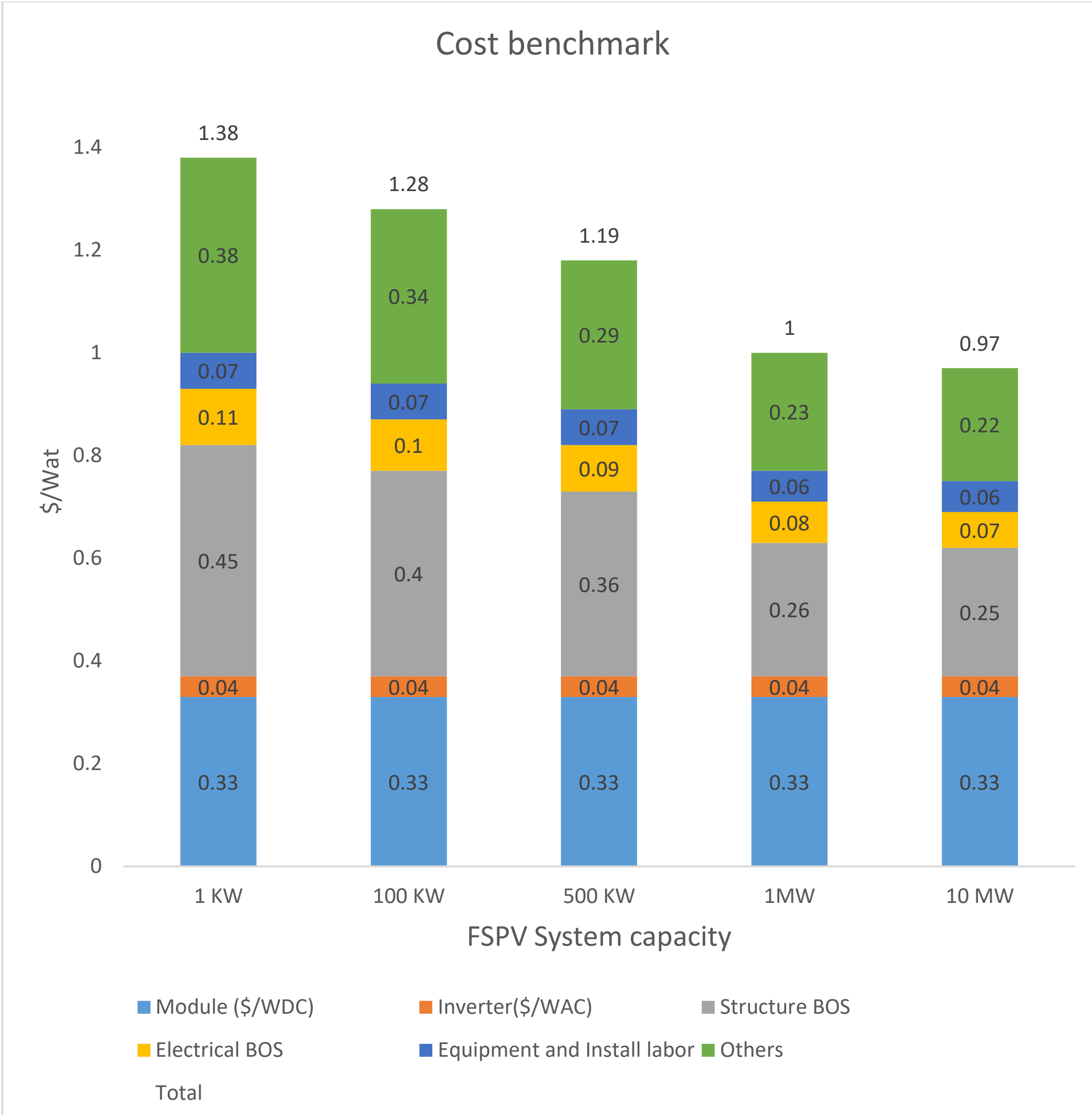


Figure 4.12 Cost benchmark analysis

4.3 Geographical effect on FSPV System

The performance of the FSPV system will differ according to the geographical locations in Nepal. As the temperature decreases, the performance will increase. FSPV system can be used in the Terai region of Nepal. The temperature is very high in terai region. FSPV system will help in the cooling and increasing the performance.

CHAPTER FIVE : CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

A solar panel was installed on the pond behind center of energy studies (CES) which is inside Pulchowk Campus. Another Solar panel of same capacity was installed on land on the same site. For their comparison, measurements of temperature, open circuit voltage and short circuit current were taken for 10 days. The following conclusions can be observed from the experiment:

a. The result shows increase in the power of floating solar PV system by 11-12% in comparison to the land based solar PV system. The power gain was 15.5 % according to an experiment conducted in Malaysia on 80 watt Solar panel.
b. The irradiance absorbed by floating solar PV system was nearly 1.5% more than the land based solar system.
c. There was little effect on the performance of the FSPV system in changing the tilt angle from 25° to 28°.
d. The power output of the FSPV system was consistent in introducing manual tracking system.
e. Financial analysis of a 1MW floating solar power plant was done on the basis of the obtained data and it was compared to the existing land based solar PV system. The capital cost is comparatively high for the FSPV system. The Internal Rate of Return is calculated to be 13.282% which is just above discount rate of 12%.

However, FSPV system are promising inside the photovoltaic region because of their better electricity manufacturing in comparison to terrestrial PV structures. In general, there are numerous problems that restrict the improvement of PV structures in Nepal and additionally have an effect on the increase of floating PV structures.

5.2 Recommendations

Following are the recommendations for future study of the FSPV system:

a. Experiment can be done on FSPV system of more capacity for better results.

b. Pyranometer can be used for accurate results.

c. Sprinkler system can be introduced to the system to analyze the better performance,

d. Automatic tracking system can be introduced.

e. The structure of the floating system can be studied in detail by considering the wave and wind characteristics of water,

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ANNEX

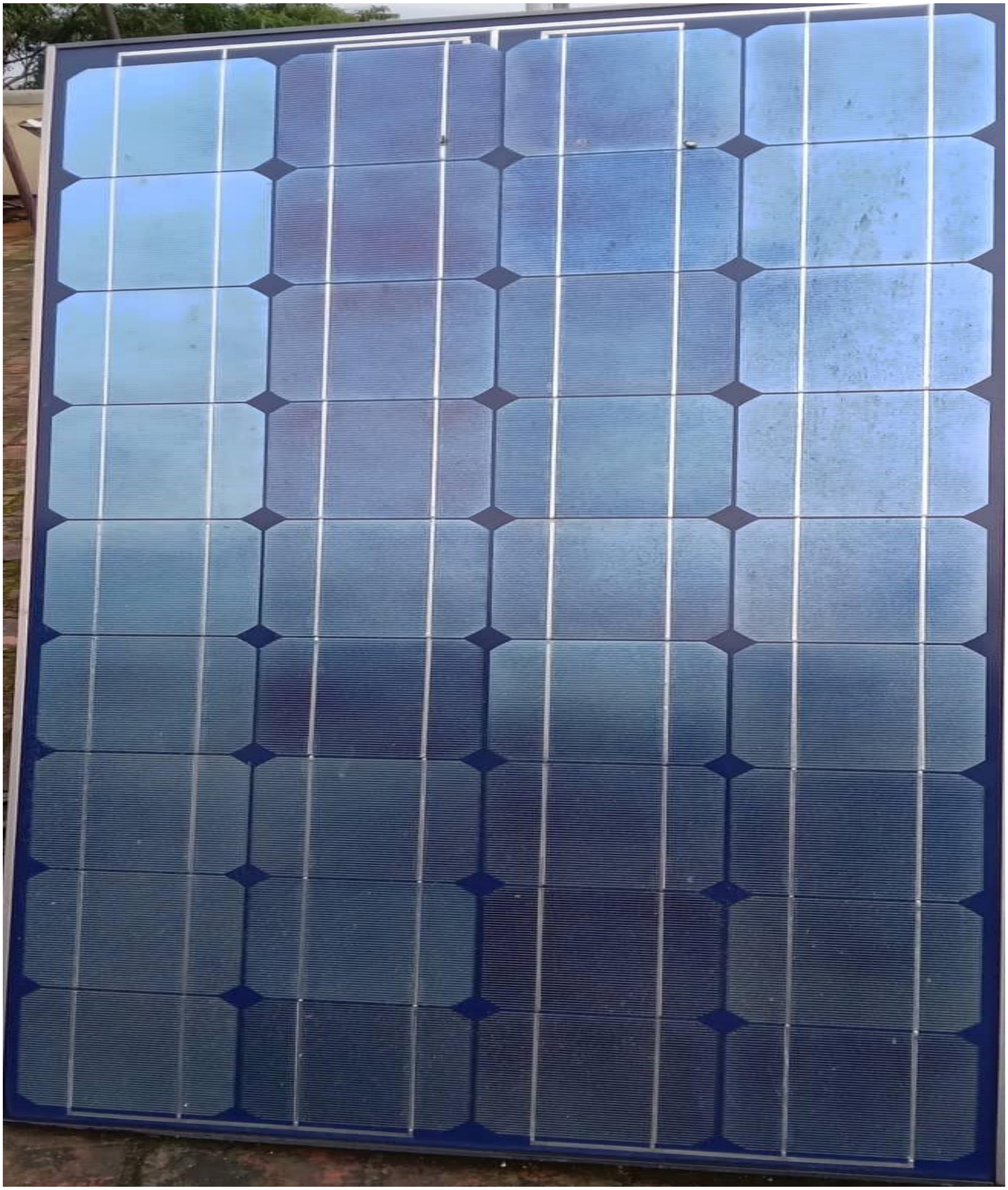

Figure A.1 Solar module used

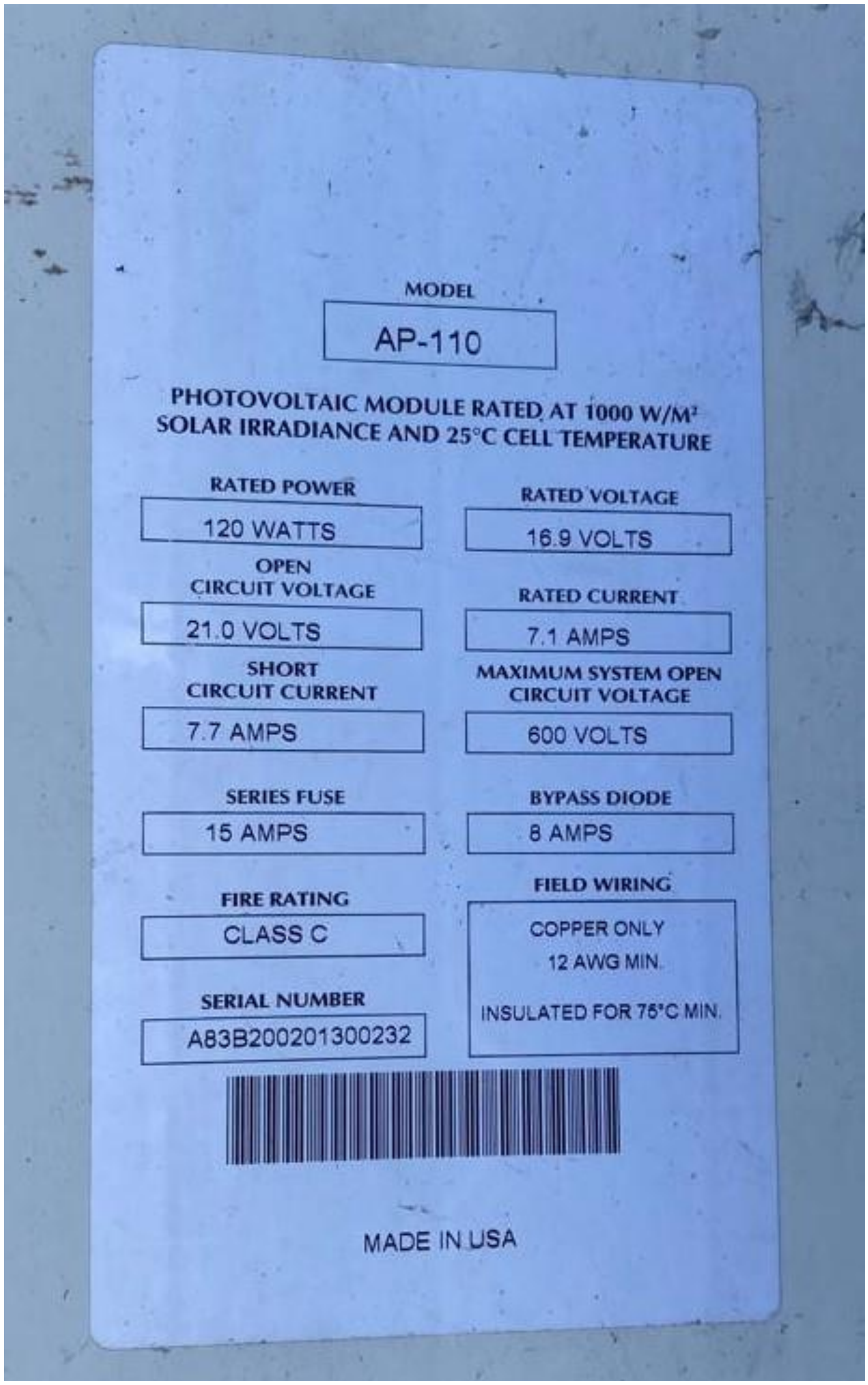

Figure A.2 Specifications of Solar module

Figure A.3 FSPV System on the site

Figure A.4 Experiment Site

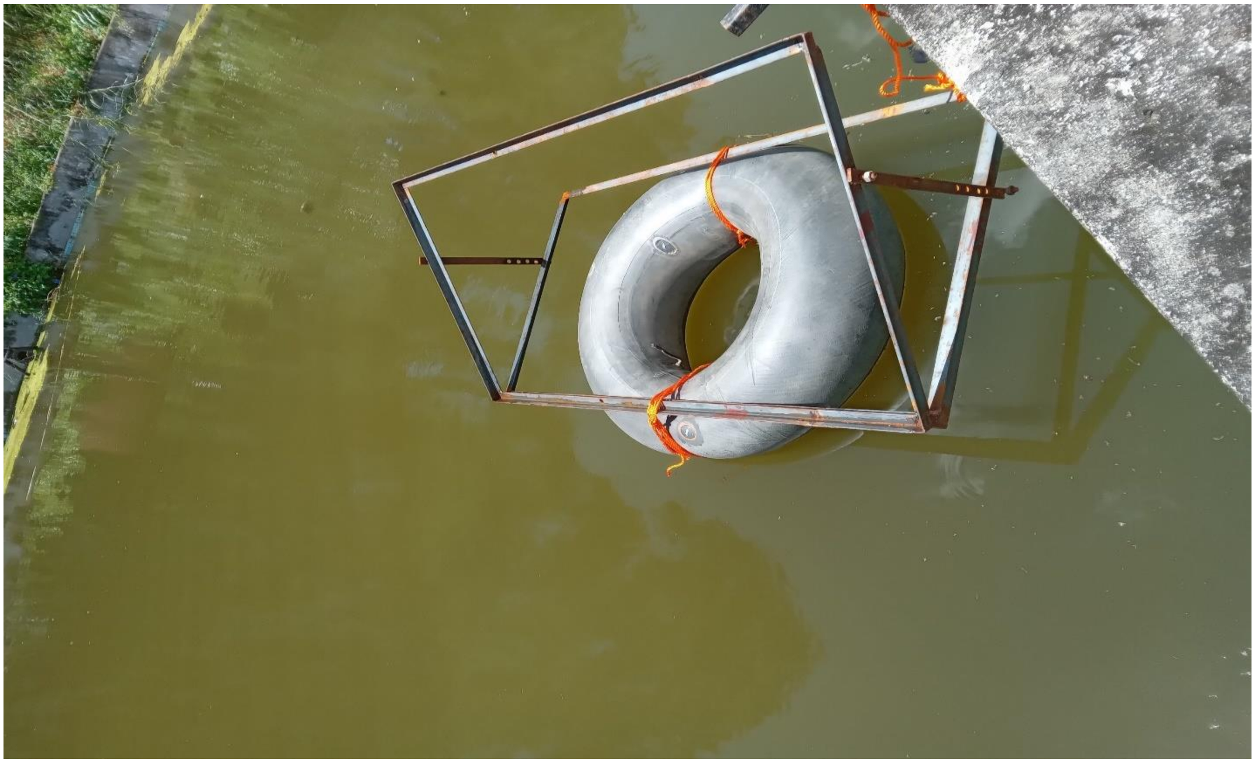

Figure A.5 Floating System

Figure A.6 Data measurement

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To Whom It May Concern

This is to confirm that the paper titled "*Techno-financial analysis of floating solar photovoltaic system in nepal*" submitted by **Shweta Sah** with Conference ID **12144** has been accepted for presentation at the 12th IOE Graduate Conference being held in October 19 – 22, 2022 at Thapathali Campus, Kathmandu.

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