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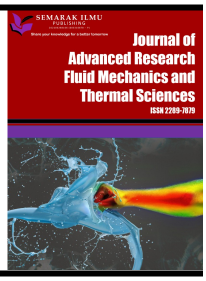

Feasibility Study of a Grid-Connected Floating Photovoltaic System (GCFPV) in Segari Shrimp Farm

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ABSTRACT

The primary expenses in shrimp farming operations conducted in man-made ponds are related to energy consumption. Pond water must possess an enough oxygen level in order to support the healthy growth of cattle, in addition to requiring cleanliness. Utilizing high-capacity electric pumps, aerators, and other equipment such as fish feeders, UV lights, and others is an essential prerequisite for the functioning of a shrimp pond. The purpose of this research was to assess the efficacy of implementing a floating solar system in a water reservoir as a means of generating alternative energy, with the aim of decreasing reliance on grid-based energy supply. The research demonstrates that the grid-connected floating PV system (FPV) is more viable than ground and rooftop grid-connected PV systems in terms of energy production efficiency for SE Aquatech shrimp farm. Agrivoltaics, besides reducing energy bills, may also decrease costs related to algae management in agriculture.

1. Introduction

The aquaculture sector has seen substantial growth during the last several decades. Agricultural systems have a crucial role in guaranteeing food security and supplying nourishment to the global population [1]. Moreover, Asia accounts for 89% of the global aquaculture output, including the agricultural sector [2]. The increase of aquaculture activities has significantly contributed to rural and national income by promoting employment and commercial opportunities [3]. Shrimp is considered a globally traded commodity, along with other popular seafood commodities such as salmon, pangasius, tuna, and tilapia [4].

Energy is a crucial need for the aquaculture industry, along with water and land resources. Farms mostly use a significant amount of energy via the utilization of pond aerators and water pumps [5]. Approximately 80% of the energy used in agriculture is allocated to electric aerators, while 10% is used for water pumping, and the other 10% is dedicated to various other applications [6]. Furthermore, when compared to other prominent aquaculture systems, marine shrimp aquaculture

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systems exhibit a notably high level of energy efficiency. This is determined by calculating the ratio between the energy intake from industrial sources and the protein output from the food produced [5]. The inefficient systems are mostly caused by the high-power consumption of machines and aerators, which typically have an efficiency of around 90% [7].

Mechanical aeration is the predominant technique used to enhance the level of dissolved oxygen (DO) in aquaculture ponds and to circulate the oxygen throughout the water column, including the pond's bottom. Aeration systems enable increased animal numbers and feed inputs. Furthermore, a comprehensive understanding of dissolved oxygen is crucial in order to prevent low concentrations of this critical indication of water quality in aquaculture ponds [8]. Within the smart farming system, the automatic aeration devices will promptly activate when the dissolved oxygen content in ponds drops below the acceptable threshold of 3 mg/l [9]. In the practice of intensive shrimp farming, aerators are often used more frequently during nighttime hours compared to daytime hours. This is done to avoid the occurrence of low levels of dissolved oxygen, which might lead to the stress or death of the shrimp.

The research site is situated at the coordinates 4.3659˚N, 100.5845˚E, in Segari village, Ipoh district, Perak. SE Aquatech is engaged in shrimp farming in ponds located on two parcels of land, totalling around 25 acres in size. The corporation strategically chose a place around 200 meters from the coastline to capitalize on the availability of saltwater resources for the purpose of using them in cattle ponds. The livestock business relies on a range of electrical equipment that demands a substantial energy supply and is the primary source of expenses for the operation. Hence, solar energy systems are seen as the optimal long-term answer for alternative energy sources. Prior to deployment, it is crucial to do thorough study on efficient system design. Nevertheless, other crucial factors contributed to the determination that the installation of the FPV system would be the most optimal choice.

1.1 Utilization of Normally Redundant Areas

A FPV system utilizes pre-existing water reservoirs in shrimp farms where there is no conflicting use. The water reservoir is a crucial infrastructure for this shrimp farm. It stored water specifically for the purpose of cultivating shrimp in ponds. A permanent pipeline has been built over the coastal range and out into the sea to pump seawater into the reservoir at high tide. Prior to being channeled to the shrimp pond plots, the water undergoes treatment at the reservoir to ensure it's free from contamination. Installing an FPV system has the advantage of not requiring land use and not causing any disruption to the reservoir's primary function.

1.2 Improved Yield Performance

A solar module's efficiency is compromised in hot weather. The temperature of a FPV system may be reduced by up to 10% - 20% due to factors such as location, climate, and the kind of float structure used [2]. The reduced operating temperatures of a floating system, in conjunction with advantages such as less shading and soiling, enhance its capacity for energy generation compared to a land-based installation.

1.3 Evaporation Control

The presence of an FPV array causes shading on the water's surface, resulting in a decrease in the temperature of the surrounding water. The reduction in water loss due to evaporation is beneficial when applied to reservoirs, despite the fact that the rate of evaporation is directly proportional to the surface area covered by the floating platform. Furthermore, FPV systems have attracted significant attention in several research because of their capacity for water saving and versatility. According to Santafe *et al*., [10] these systems have the potential to save up to 5000 m³ of water per year, with an average performance ratio of 78%. Gozalvez *et al*., [11] emphasized the flexibility of FPV systems, noting that the floating PV cover can easily accommodate changes in water levels in the reservoir.

1.4 Restricting Algae Growth

The water ecology can benefit from algae, but too many algae might be problematic. High quantities of algae prevent light from penetrating the water, which inhibits the growth of plants, the creation of oxygen that shrimps need, and the breakdown of organic substances in the water. As a result, the water ecosystem cannot continue to function normally, jeopardizing the aquatic life that exists in the water body.

1.5 Less Prone to External Shading

Additionally, placing the array in the middle of a body of water places it farther away from anything that provides shade, including trees and buildings. As a result, the array spends less time in the shade and receives more sunshine, resulting in increased energy yields.

1.6 A Reduction in Panel Soiling

The system experiences less soiling since the solar array is located on the water's surface, furthest from sources of dust and dirt. The increased distance from the land means that dust and grime are not as easily trapped by the panel, especially in dry and dusty places, which decreases the need for surface cleaning. In fact, for such installations, there should always be a ready supply of water nearby to clean the panel surface.

2. Floating PV System Components

FPV system is composed of floating system, mooring system, PV system, cables, and connectors.

2.1 Floating System

An FPV system relies on the floater or pontoon. Durable and buoyant, the design can support solar panels and other equipment while floating on water. Durable, lightweight, and UV-resistant materials are used to make buoyant constructions. The buoyant structure must withstand wind, waves, and sea level changes; thus, its design is vital. Photovoltaic modules are firmly attached to the floating frame to ensure structural integrity and best performance. The FPV system's performance and longevity depend on the floating structure's design and materials.

2.2 Mooring System

The mooring system is a vital element of a FPV system. The purpose of this design is to secure the FPV array with little motion and ensure there is enough space between adjacent arrays or other assets. The mooring mechanism used in the FPV system may be classified into three categories - submerged mooring, shore mooring, and a hybrid combination of submerged and shore mooring. The underwater mooring is subdivided into two types: catenary mooring and taut leg mooring [12].

2.3 PV System

A PV system is an electrical power system that utilizes PV modules and other power conditioning equipment to efficiently transform solar energy into electrical energy. Crystalline solar cells, renowned for their efficiency, are often used to construct PV modules.

2.4 Cables and Connectors

Underground cables and connectors are used to transfer electricity from FPV system to the land. This power can then be fed to the grid or stored in the form of batteries. Fig. 1 shows the components of FPV system.

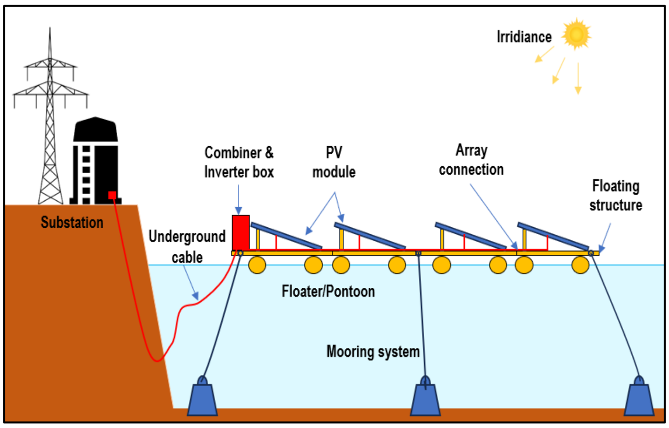

Fig. 1. Floating PV system components

3. Floating PV System Category

Three categories of FPV systems exist: modular raft-based pontoons in the first instance, flexible FPV or membrane FPV systems in the second, and submerged FPV systems in the third.

3.1 Pontoon based FPV System

A pontoon is a type of floating device that has enough buoyancy to support itself and a heavy load. Many of the existing FPV systems are based on pontoons. The primary function of a pontoon in these systems is to ensure stability and buoyancy. Pontoons are typically made from Medium Density Polyethylene (MDPE) using a process called rotational moulding. However, using pontoons has some drawbacks. They limit the size of the plant and cannot withstand harsh environmental conditions. The pontoon structure is shown in Fig. 2.

Fig. 2. Pontoon based floating PV system [14]

3.2 Flexible FPV System

The concept of a thin film flexible FPV system has been proposed to enhance the reliability of the FPV system without significantly impacting its electrical performance. A thin film flexible FPV array was designed by Trapani and colleagues, and its performance was compared with that of a ground-mounted PV system. Their findings indicated an average improvement in electrical yield of 5% due to the cooling effect of water. The flexible FPV system, as shown in Fig. 3, offers several advantages. Firstly, it can easily adapt to wave motion. Secondly, it allows solar radiation to hit the surface at various incident angles. Thirdly, it requires less infrastructure. Lastly, the array remains in close contact with the water surface due to surface tension.

Fig. 3. Flexible floating PV system [15]

3.3 Submerged PV System

Within this setup, the PV panels are immersed in a somewhat shallow body of water as shown in Fig. 4. The efficiency of the PV panel in this system is influenced by the decrease in the module's operating temperature and the alteration of the solar radiation spectrum. The performance of a submerged PV system is influenced by several elements, including climatic conditions, the kind of PV technology used, and the depth of the water.

However, these systems are not without their challenges. Gisbert et al. found that the cost of FPV systems was 30% higher than that of conventional grid-connected PV installations [13]. Additionally, the entire structure of FPV systems can rotate or move due to wind or waves, leading to errors in the azimuth angle. This necessitates the use of an error compensator and careful consideration of various factors during site selection. Despite these challenges, FRP material for the rotary structure has proven to be more durable and reliable than aluminium and steel. The FTCC faced specific problems such as the warming of PV cells due to increased irradiance and the presence of uneven radiation in a wrongly connected array. The latter can nullify the advantages derived from the augmentation of radiation.

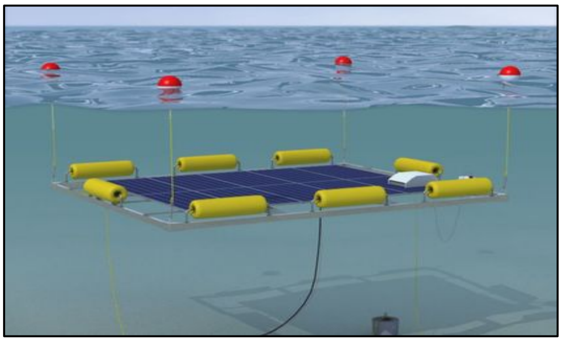

Fig. 4. Submerged floating PV system [16]

4. Methodology

The efficiency of PV modules is greatly influenced by the operating temperature. Lowering the operating temperature tends to result in an improvement in module efficiency. Thus, as compared to rooftop PV (RFV) and ground PV (GPV) systems, a floating PV (FPV) system may take use of the water's cooling effect and achieve better efficiency due to its proximity to the water surface. To investigate the cooling impact of water on PV modules, several testbeds were established, including the RPV system testbed, GPV system testbed, and FPV system testbed. In order to achieve parity in energy generating capacity, all testbeds are constructed using components of identical specifications. Additionally, photovoltaic (PV) modules are only sourced from tier-1 suppliers. The obtained data were then used to compute the alterations in the efficiency of power generating.

4.1 Testbed Setup

Fig. 5 depicts the schematic representation of the experimental setup. Each testbed used a single PV module unit, specifically the Trina Solar model TSM-DE18M(II), with a capacity of 500Wp. Additionally, a 500Wp micro inverter, the ZHC solar company's model T-500, was employed. Each PV module is oriented with a tilt angle of 4.5 degrees and an azimuth of 0 degrees, facing south. In addition, the temperature of the PV module was measured using a DS18B20 temperature sensor connected to an Arduino based data logger. The research used the D52-2047 multi-function power meter produced by Vikye to record the output of the testbed. As this configuration is a grid-connected system, the power meter's output was linked to the socket outlet.

The testbeds are positioned within a 20-meter radius of each other to ensure uniformity inside characteristics including as irradiance, air humidity, wind, and ambient temperature. The rooftop testbed is positioned on the roof of the pump house, which is constructed with a metal deck roofing system. Meanwhile, the ground testbed is in a nearby open area. The floating testbed is deployed on the reservoir's surface using an appropriate pontoon. It is then controlled by a rope fastened to the pool's bank. A solar irradiance measurement was conducted at the same location using a CMP3 pyranometer, a device manufactured by Kipp & Zonen, a firm based in Delft, Netherlands. Data collection was conducted over a period of 30 days, commencing on April 1, 2023, and concluding on April 30, 2023. The analysis for this research focused only on the data for days without precipitation, which amounted to a total of 22 days.

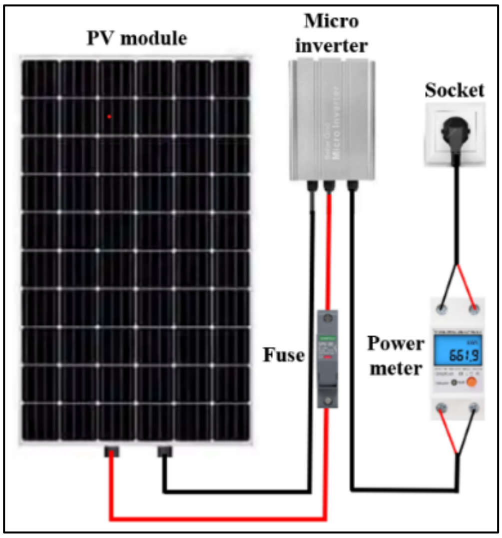

Fig. 5. PV system testbed

4.2 Testbed Modelling

The Formulating techniques serve the purpose of both extracting data insights and assessing the efficacy of the testbeds. This attribute is crucial as it allows for the evaluation of the performance of many testbeds under the same conditions. Moreover, the generation of data by computational methods necessitates the development of a model for the experimental system. This model is likely generated from the distinct physical and operational characteristics of the testbeds, as well as the surrounding conditions in which they operate.

According to Rus-Casa *et al.*, [17] a PV testbed may be constructed by using ambient characteristics and information found in the manufacturers' datasheets. The power output of a photovoltaic (PV) module, expressed in per-unit conversion, is determined by the module's temperature and the amount of solar irradiation under Standard Testing Condition (STC). The equation for calculating the modelled power in per-unit convention, denoted as P_{cal}, is given as follows [18]:

$$P_{cal} = P_{PV\_rated} * (G_S/G_{STC})[1 - \beta * (T_C - T_{STC})] \tag{1}$$

where G_S is the measured solar irradiance (hourly) and P_{PV_rated} is the rated PV power at STC. G_{STC} and T_{STC} is the solar irradiance (1000W/m^2) and PV module temperature (25°C) at STC, respectively. Besides that, β is the temperature correction based on measured polycrystalline silicon PV module temperatures with a power decrease in between 0.30%/°C and 0.5%/°C. Besides that, the P_{out} can be determined as follows:

$$P_{out} = P_{cal}/\eta_{inv} \tag{2}$$

where P_{out} is the rated AC output power of the proposed PV array in kWp and η_{inv} is the conversion efficiency from DC to AC according to inverter efficiency. The PV inverters we used in this study operate at 90% of conversion efficiency.

5. Result and Discussion

In Table I, the key parameters that were utilized in the process of determining the total energy production of the planned system are presented. In Table II, the time series data for the energy generation of the photovoltaic (PV) system are displayed. These data were obtained through a combination of calculations and experimental measurements using the PV testbed system. Both tables provide information that indicates the average values that were gathered over a period of days 22 days.

Table 1
Key parameters data

Time	G_S (W/m^2)	G_{STC} (W/m^2)	β (0.5%/°C)	T_C (°C)	T_{STC} (°C)
7:00	0	1000	0.005	30	25
8:00	42	1000	0.005	48	25
9:00	227	1000	0.005	50	25
10:00	690	1000	0.005	60	25
11:00	736	1000	0.005	66	25
12:00	872	1000	0.005	69	25
13:00	1027	1000	0.005	73	25
14:00	755	1000	0.005	72	25
15:00	393	1000	0.005	70	25
16:00	204	1000	0.005	66	25
17:00	141	1000	0.005	60	25
18:00	19	1000	0.005	54	25
19:00	18	1000	0.005	48	25

Table 2
Calculated and actual output

Time	Calculated Power (W_p)			Actual Power (W_p)		
	Rooftop	Ground	Floating	Rooftop	Ground	Floating
7:00	0.00	0.00	0.00	0.00	0.00	0.00
8:00	16.73	17.48	18.05	9.40	10.00	10.50
9:00	89.38	91.94	95.00	70.50	75.00	78.75
10:00	256.16	271.69	288.77	216.20	230.00	241.50
11:00	263.30	286.49	291.46	253.80	270.00	283.50
12:00	306.07	325.69	335.50	296.10	315.00	330.75
13:00	351.23	381.27	395.14	336.52	358.00	375.90
14:00	259.91	280.29	290.49	286.70	305.00	320.25
15:00	137.06	145.90	151.21	156.98	167.00	175.35
16:00	72.98	78.03	80.78	93.06	99.00	103.95
17:00	52.35	55.52	57.42	62.04	66.00	69.30
18:00	7.31	7.70	7.95	6.58	7.00	7.35
19:00	7.17	7.49	7.74	5.64	6.00	6.30

5.1 Comparison of Testbed Output

Fig. 6 depicts the temperature fluctuation of the PV module throughout the three testbeds. The maximum recorded temperature of the PV module was seen on the RPV testbed, measuring 73°C. The GPV and FPV testbeds recorded temperatures of 60°C and 54°C, respectively. Nevertheless, the RPV testbed registered the lowest temperature of the PV module, whereas the GPV and FPV reported temperatures of 23°C, 26°C, and 27°C respectively. The temperature range of FPV modules is the lowest, whereas RPV modules have the largest temperature range, reaching up to 50°C.

The RPV module undergoes the most substantial variations in temperature, spanning a range of 50°C. This phenomenon may be attributed to direct solar radiation and insufficient cooling processes, resulting in elevated daytime temperatures and reduced nighttime temperatures. In addition, the GPV module has a significantly narrower temperature range compared to the RPV module. The earth may provide natural cooling, hence decreasing the maximum temperature. Nevertheless, it continues to undergo significant fluctuations in temperature. The temperature range of the FPV module is the lowest. The presence of the water body underneath it is likely to have a cooling effect, resulting in a decrease in the maximum temperature and ensuring a more consistent temperature overall.

Furthermore, Fig.6 illustrates that solar irradiance has a gradual rise from 8 am, followed by a significant surge beginning at 9 am. It reaches its peak between 1 and 2 pm, after which it gradually declines until 7 pm. The observed pattern is characteristic of solar irradiance since it aligns with the trajectory of the sun over the celestial dome. The temperature rise on the PV panels begins at around 6 am, before the increase in solar irradiation. This phenomenon may be attributed to the proximity of the testbed to the coastline, where ambient temperatures have the tendency to increase rapidly after sunrise. The increase and decrease in PV module temperature occur at a considerably slower rate than solar irradiation, perhaps because of the thermal inertia of the PV modules.

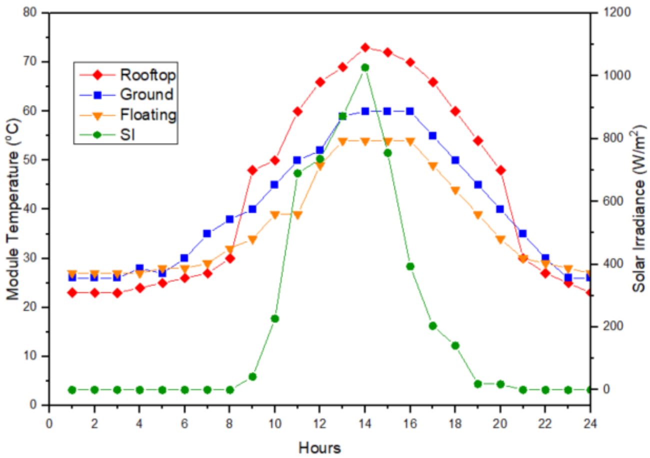

Fig. 6. Variation of irradiance & PV module temperature

Fig. 7 depicts the variation in energy generated by the testbeds. The energy generation process begins at around 8 am and continues until 7 pm, with the peak amount of energy production occurring between 12 noon and 2 pm. This pattern aligns with the typical length of daylight and is anticipated for solar energy installations. Moreover, solar radiation is the main component that affects the energy production pattern in each testbed. This is consistent with the notion of solar energy conversion, where more solar irradiation leads to higher energy generation.

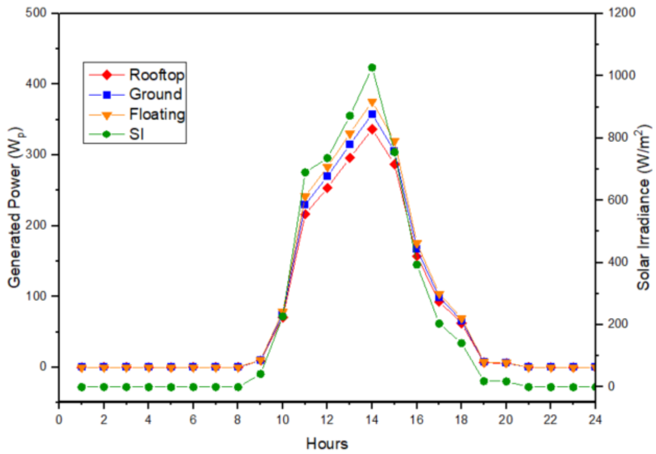

Fig. 7. Tesbed output power (kWp)

The temperature has a substantial influence on the efficiency of the photovoltaic (PV) module. An increase in temperature leads to a decrease in the efficiency of the PV module, which in turn reduces energy output. This is evident in the RPV testbed, which recorded the highest temperatures and the lowest energy output (1794 kW).

5.2 Accuracy of Testbed Systems

Fig. 8 illustrates the variation in energy generated by the computational method. The observed energy production pattern corresponds to the predicted energy generation fluctuation. These findings demonstrate the testbed's accuracy and reliability in collecting energy generating data. It is customary in scientific research and engineering projects to use this method to guarantee the dependability and precision of the system. The computed outcomes are higher than the real energy production, however the disparity is below 2.5%. This small variation may arise from several sources, including measurement inaccuracies, unaccounted environmental variables, or assumptions inherent in the computation.

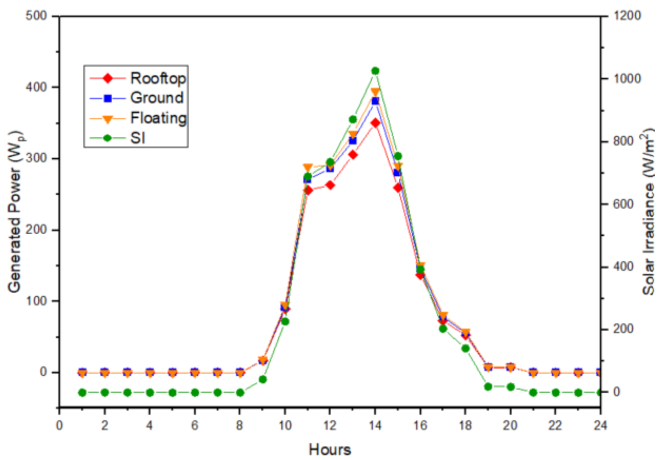

Fig. 8. Calculated output power (kWp)

5.3 Efficiency Improvement

Based on Fig. 7, the FPV system has achieved a 10.48% improvement in energy production efficiency compared to the RPV system, and a 4.76% increase compared to the GPV system. However, it's noteworthy to mention that the computed of energy efficiency was discovered to be 0.5 - 1.5% lower than the actual generating efficiency.

5.4 Potential of Floating PV Systems

SE Aquatech has built a total of 11 pounds in plot 1. These include 9 ponds specifically designed for livestock needs, as well as a wastewater pumping pond and a water reservoir. However, the FPV system project can only be executed in a saltwater reservoir with dimensions of 90m x 30m and a depth of 3m, as shown in Fig. 9. The execution of the project in the livestock pond would disturb the functioning of the pond and have an impact on the cattle.

Typically, PV system technology provides three approaches for implementation: grid-connected PV, standalone PV, and hybrid PV. Grid-connected photovoltaic (GCPV) systems are the most economically and efficiently viable alternative for properties situated within a 5 km radius of grid infrastructure. During periods of solar irradiance, the energy produced will be used to power the sites. However, during times of low solar irradiance and at night, electrical equipment will rely on the grid supply. Furthermore, for the low voltage specific agriculture tariff, the client has an option to augment the PV capacity to 70% of daily demand by enrolling in the Net Energy Metering (NEM) program. NEM enables users to export surplus energy to the national grid and utilize it as required. Furthermore, grid-connected PV systems exhibit the most economical installation and maintenance expenses in comparison to the PV systems.

Fig. 9. Plot-1 reservoir pool with 2700m^2 space

The monthly electricity usage for SE Aquatech Sdn Bhd in plot-1 averaged 13,368.5 kWh, with a daily use of around 439.7 kWh. Based on the PV output map, the Segari area experiences an average PV production of 4.0 hours per day, which is 4.8% lower than the highest PV output recorded in Peninsular Malaysia. In essence, the necessary photovoltaic (PV) array size is a mere 110 kWp. To meet the energy needs, 220 units of Trina solar PV modules with a power capacity of 500 Wp and dimensions of 2.187m x 1.102m (2.41m^2) are necessary. This will need a minimum area of 530.2m^2. The effective space should also consider the dimensions of the pontoon and the hallway. The water reservoir size of 2700m^2 is enough for the planned FPV system. Nevertheless, the maximum allowable capacity for installation in low voltage commercial clients is limited to 60% of the fuse rating [19].

6. Conclusion

The FPV system can efficiently utilize the existing water reservoirs, thus eliminating the need for additional land. Additionally, the system can control water evaporation from the reservoirs, thereby conserving water. It can also restrict the growth of algae, which helps maintain the health of the aquatic ecosystem. The system's central location on the water body minimizes external shading on the solar panels, and being located on the water surface, the system is less prone to dust and dirt accumulation, reducing maintenance needs.

FPV modules have the lowest maximum temperature and the smallest temperature range among the three types of PV testbeds. This is likely due to the cooling effect of the water body underneath the FPV system, which helps to maintain a more consistent temperature overall. While solar irradiation is the primary factor influencing energy production in all testbeds, the efficiency of PV modules decreases with rising temperatures, leading to reduced energy production. Given that FPV modules recorded the lowest temperatures, they can maintain higher efficiency levels and, consequently, higher energy production. The proximity of the FPV to the coastline and the rapid increase in ambient temperatures after sunrise can affect the temperature of the PV modules. However, the FPV system's location on the water may mitigate these effects due to the water's cooling properties.

Floating photovoltaic (FPV) grid-connected systems have shown high reliability since the actual energy production closely aligns with the estimated values, with a deviation of less than 2.5%. The energy production efficiency of FPV systems exceeds that of both RPV and GPV systems. The GCPV system is the optimal and economical option for premises that have access to grid infrastructure.

Based on the results, it seems that implementing the FPV system at SE Aquatech Sdn Bhd's shrimp farm might be a viable and advantageous option. However, other factors such as cost, maintenance, and environmental impact should also be considered before making a final decision.

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