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Design and Construction of A Test Bench to Investigate The Potential of Novel Partially Submerged PV System

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ABSTRACT

The floating photovoltaic (FPV) system has attracted wide attention due to its numerous advantages that out-performance the land-mounted photovoltaic (LPV) system. However, in the arid coastal area, the FPV surface temperature could reach a temperature that effects negatively the performance of the panel and its lifespan. So, in this paper, an experimental study investigating the performance of the new partially submerged photovoltaic system (PSPV) as a new modification to release the harmful thermal energy that elevates the panel temperature into the surrounding water. The developed system consists of a floating photovoltaic panel that has a segment of the panel's length submerged in the water. The experimental setup was constructed and tested under summer Egyptian conditions. A performance comparison between the PSPV system for various submerged lengths on the PSPV and LPV systems has been implemented to assess the significance of the modified system. The performance pattern with a minimum radiation deflection for detecting the optimal scenario was explored using three submerged lengths of 5,10, and 20 cm. The outcomes revealed that the PSPV module's average surface temperature was always lowered than the LPV module. It also noted that PSPV produces up to 18.2% more daily electricity than LPV by increasing the submerged length to 10 cm. An economic analysis has been performed on the proposed system that showed a reduction in the LCOE from 0.8 \$/kWh for the PSPV to 0.9 \$/kWh for the LPV while the potential of the PSPV in saving 51.92 $kgCO_2$ / summer season.

Keywords: Floating PV; Solar energy; Photovoltaic; Cooling; LCOE

1. INTRODUCTION

PV modules are one of the most promising energy generation systems; nevertheless, the high cost of PV power generation, as well as its lower performance, limit the PV cell industry's growth. Improving photovoltaic cell performance has become a global norm in order to focus on PV cells as a renewable, sustainable energy source. Around 13 - 20% of the solar radiation incident on the PV panel is converted into electrical energy while the remaining is transformed as thermal energy absorbed by the panel [1]. This leads to an increase in PV panel temperature [2]. The high temperature of the module, according to Koteswararaon et al. [3], will adversely affect the material used to produce the PV module, reducing the cell's life and conversion efficiency. it has also been found that thermal cycles speed up the aging of the PV panels in the long term and degrade their production [4]. Many cooling attempts have been employed on the PV to enhance its performance by decreasing the cell temperature [5].

Passive techniques are also particularly applicable to PV cooling systems. These methods do not necessitate the use of any external mechanical equipment. The greatest advantage of passive cooling systems is that they don't need an external power source to operate. As a result, the system is streamlined, and maintenance costs are reduced. Passive PV panel cooling is explored by Amr et. al. [6]. He investigated the passive PV panel cooling using fins attached to the module's back surface. The embedded fins also reduced the temperature of the cells by around 4-5ºC. The electrical efficiency of a PV module with fins is greatly improved by increasing the height and number of fins, but the thickness and thermal conductivity of the fins are barely affected.

Idoko et al. [7] investigated the multi-concept cooling approach, which entails three different methods of passive cooling: conductive cooling, air passive cooling, and water passive cooling. The trials led to an increase of 21 W in peak power as well as a more than 3% increase in efficiency, making the module more effective and profitable. Hernandez-Perez et al. [8] used CFD software to create a sequence of 3D heatsink models that simulate standard operating conditions. The prototypes of the models with the best results in terms of temperature level and distribution were constructed for experimental assessment. The experimental outcomes were in full conformity, reaching a reduction of around 10ºC at the highest irradiance. Abdollahi and Rahimi [9] tested a novel PCM-based water-cooler nano-enhanced PCM system for passive natural cooling of the PV module. Experiments discovered that the integration of nano-composed oil PCM resulted in the highest escalation in maximum produced power compared to the reference case, ranging between 44.74 and 48.23% at solar radiation intensities ranging from 410 to 690 W/m^2.

In contrast to passive techniques, active thermal control techniques require external energy supply, such as pumps or fans, to disperse the cooling medium. These methods necessitate more power consumption and extra facilities, but they are more effective in terms of heat transfer cooling rate. Sargunanathan et al. [10] reviewed the experimental and numerical studies on the performance enhancement of PV cells by utilizing effective cooling methods. Sajjad et al. [11] carried out an experimental investigation on the back surface air-cooled PV module and compared the outcomes to the PV module without cooling. The cooled module showed 7.2% and 6% higher electrical efficiency and output ratios, respectively. Bayrak et al. [12] conducted experiments on various cooling mechanisms used in photovoltaic applications. The cooling techniques employ PCM, thermoelectric (TE), and aluminum heat sinks. The PV integrated with the fin system produced the most power of 47.88W while PV integrated with PCM and TEM produced the energy of 44.26 W.

Floating photovoltaic systems (FPV) are another approach to enhancing the efficiency of photovoltaic systems that indicate a great potential since 2006 with even bigger plans for the future that have been developed. FPV makes it possible to achieve higher performance of PV modules and better land-resource management to ensure energy efficiency. This technology eliminates the need to build photovoltaic power plants on precious land. The floating PV plant is usually made of a pontoon or individual floats in enclosed waters, such as rivers, pools, or small lakes, a mooring mechanism, solar panels, and wires for electric connections [13].

The floating solar systems have revealed many benefits over the traditional ground-based system by Cazzaniga et al. [14]. The offshore air temperature is observed to be less than the onshore air temperature of around 1°C to 3°C, thereby lowering the temperature of the PV module. Moreover, the difference could be larger for more urban locations [15]. Choi [16] has stated that the floating photovoltaic systems have a self-regulating effect and as the temperature rises, the evaporation rate rises, which cools the panels, increasing performance by 11% over land-based PV systems. the impacts of wind speed on a 100 kW FPV plant's power generation potential was investigated and discovered that as the wind speed increases, the FPV structure starts to rotate, reducing solar energy absorption and resulting in substantial power generation reductions. Mittal et al. [17] investigated the potential of the FPV system in power generation and water evaporation decrement when the FPV system covers 5%, 10%, 15%, and 20% of the lake's surface area.

According to a study done by Liu et al. [18]. Hasan and Dincer [19] simulated a photovoltaic bifacial module mounted on an aluminium sheet-covered floater. It was assessed in Australia 2012 by Helfer et al. [20] that 40% of the reservoir water storage capacity is lost by evaporation and weather change predictions on rising temperatures could be led to 15% higher evaporation losses. Sahu et al. [13] concluded that FPV systems could decrease water storage capacity losses of up to 33% in natural lakes and ponds and up to 50% in human storage facilities. Clot et al. [21] experimented with the usage of the PV modules submerged in water for Swimming Pools. Cazzaniga et al. [22] proposed the idea of the pontoons that carry the floating PV system as reservoirs of compressed air for energy storage purposes with a high storage system. The behaviour of a horizontal submerged photovoltaic solar panel in a water pool under a depth from 4 to 40 cm is explored by Rosa-Clot et al. [23]. The result revealed a considerable improvement in electric power output for shallow water with respect to a standard position PV panel outside the pool. Results were discussed and the water absorption of solar radiation for the completely submerged panel was investigated and understood.

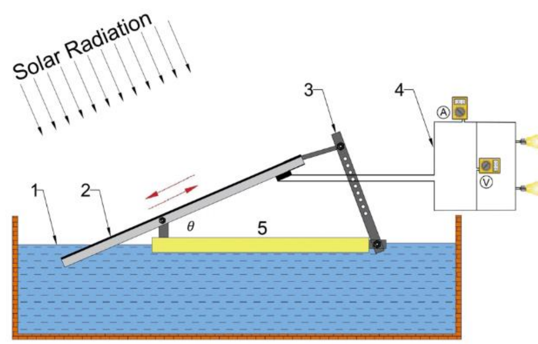
El Hammoumi et al. [24] performed an experimental investigation of a small-scale floating photovoltaic system (FPVS) and compared the electrical and thermal performance of an FPVS with those of an overland PV system (OPVS) with similar power. The test results show that FPVS will benefit from the normal water-cooling effect and outperform OPVS with up to 2.74ºC reductions in the PV temperature. Furthermore, the FPVS generates up to 2.33 % of regular electric capacity than the OPVS. A thorough study of the performance stability of FPV systems from the world's largest FPV testbeds, located on Singapore's Tengeh reservoir from April 2017 to March 2020 [25]. Rodrigues et al. [26] investigated the feasibility of a floating PV system in the Gavio reservoir in northeast Brazil. According to a payback analysis, the investment in the system's construction is fully recovered in 8 years, and water losses due to evaporation may be reduced by approximately 2.6 x 10^6 m^3/year, enough to serve around 5×10^5 people.

According to the previous literature survey, most of the research has been conducted on land-based PV modules that have been implemented with a variety of active or passive cooling methods, some of which have been tested in real outdoor settings, and some have seen experimental research supported by computer software design simulation for optimum performance. However, by a deep insight into these systems, the percentage improvement in the performance of the enhanced PV system doesn't compensate for the economic value of the huge flatted smooth land area for large-scale PV installation. Through their evaporation cooling and evaporation elimination, floating PV systems predominate on land worldwide. It is also apparent that FPV systems have grown in popularity over the last decade. There has been no recorded work on the FPV system in the middle east area, which is known for high steady solar radiation and clear skies, especially in Egypt. Many studies have been conducted about the economic and environmental impact of the FPV system and compare it with the ground land-based system [27]. The majority of FPV studies seldom focused on performance improvement of the FPV system. So, the author has attempted to cover this gap.

In the current study, an experimental study of a newly passive cooling approach for the floating PV system. In this work, a partially submerged photovoltaic system (PSPV) in water is considered. PSPV is a floating PV platform that has a portion of the PV module submerged in a body of water to release some of the thermal energy by using the water as a heat sink. The electrical and thermal efficiency of different submerged ratios will be analyzed to ascertain the significance of the cooling effect due to submerging in enhancing the performance of the PV module.

2. EXPERIMENTAL SETUP

Experiments were at a reference state without cooling overland (LPV) to compare the performance of the partially submerged photovoltaic PSPV module with that of the conventional, LPV module. Experiments were conducted at the Faculty of Engineering in Port Said, Egypt (31°16´N, 32°18´E) in August 2020. For the present study, two similar photovoltaic modules (PV) were used, one placed inside a water basin of eight-meter diameter for simulating a water body while the other was installed over land. Due to Egypt's position in the northern hemisphere, panels were oriented to the south. To retain the specified orientation for the floating system, the entire PSPV system was anchored with a mooring mechanism. Both panels were installed close together in the same outdoor conditions and tilted at an angle to the horizontal plane that was θ=15° for optimum use of solar radiation in the summer season in Egypt as proven by Elminir et al. [28]. So, the tilt angle was set with a control mechanism. A sliding frame with a holder system was used to facilitate our investigation of the impact of a change in the length of the submerged segment of the PV panel in the water as seen in Figure 1 and Figure 2.



1-Water Basin, 2- PSPV panel, 3-Tilt holder, 4-Electric load circuit, 5-Floating unit

Figure 1- Schematic of the PSPV system

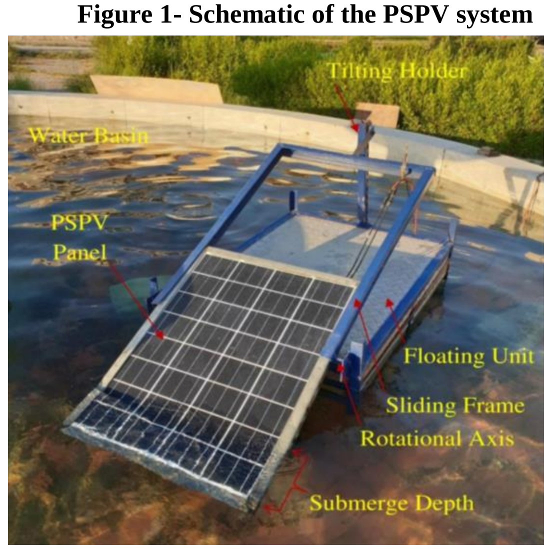


Figure 2 Photograph of the arrangement of the PSPV system.

The experiments set up as shown in Figure 3 were performed using two identical polycrystalline PV panels with a rated capacity of 83 W each. The PV solar panel specifications under normal STC test conditions are listed in table 1. During the test days from 8 am to 6 pm, multiple measuring instruments were used to determine the impacts of the variables examined on the electrical and thermal performance of the PV system. Table 2 depicts the main measurement instruments used in the experimental setup its accuracy range and standard uncertainty.

Table 1
PV module specification.

brand	S-ENERGY
Panel type	Polycrystalline
Dimensions in mm	920 × 680 × 38
[I_{sc}] (Amp.)	5.78
[V_{oc}] (Voltage)	19.7
[P_{max}] (W)	83
[V_{mp}] (Voltage)	16.5
[I_{pm}] (Amp.)	5.07
[Pmax] $_{NOCT*}$ (W)	60

NOCT*: Nominal Operating Cell Temperature: 47°C

A Hukse LP02 pyranometer was used to gauge the solar irradiance received by both LPV and PSPV surfaces with 0.025 W/m^2 accuracy. An infrared thermometer has been employed to detect the surface temperature in different positions in addition to the surface temperature of the submerged segment of the panel, in order to measure the average working surface temperature of both panels on an hourly basis. A digital thermometer is used to measure the bulk temperature of the water basin in which a part of PSPV was immersed.

Experimental measurements were taken at 1-hour intervals by recording the measured parameter using the numerous devices described. The electrical output power P and efficiency η_{elec} of both modules were then calculated with the following formulas:

$$P = V \times I \quad (1)$$

$$\eta_{elec} = \frac{P}{GA_s} \times 100 \quad \% \quad (2)$$

where P is the instantons maximum electrical power generated in W by connecting the output from each panel to the variable load circuit in order to draw the I-V characteristic curve to determine the maximum power point MPP and hence the maximum voltage and current [29]. G is the solar radiation intensity measured in W/m^2, and A_s is the solar harvesting surface area of the panel in m^2. The temperature of both modules has been captured using a digital infrared thermometer. Several fixed points have been measured hourly on each module and the average temperature of the PV panels T_{av} was calculated according to the following equation:

$$T_{av} = \frac{\sum_{i=1}^{n} T_i}{n} \quad (3)$$

The uncertainty of the instruments during the experimental measurements was investigated in order to determine the precision of the experimental data, which may have been affected by possible errors in the parameter measurement tests [24,25]. The uncertainties in the

Figure 3 Photographic view of the experimental setup

independent variables via the evaluation procedure are denoted as U_1, U_2, ………and U_n, with the uncertainty in the W_R result being obtained from the following equation, where x is the accuracy of the experimental.

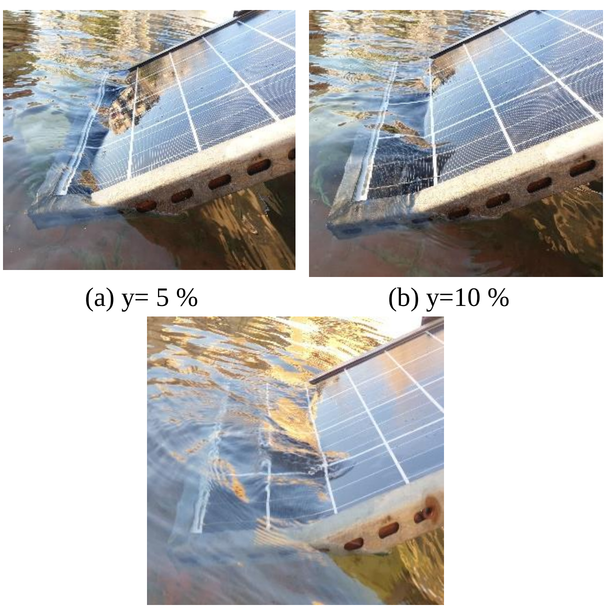
$$U_R = \left[\left(\frac{\delta R}{\delta x_1} U_1 \right)^2 + \left(\frac{\delta R}{\delta x_2} U_2 + ... + \left(\frac{\delta R}{\delta x_n} \right)^2 U_n \right] ^{1/2} \quad (4)$$

The maximum expected error in calculating P and η_{elec} are found to be 0.64W and 0.22%, respectively.

3. RESULTS AND DISCUSSION

The experiment was conducted under traditional metrological conditions to investigate the influence of submerged ratio (y) on the performance of the PSPV system for six test days, from August 10th to August 18th, 2020, and to compare it to the LPV system. Each submerged ratio of 5%, 10%, and 20% was assessed, as seen in Figure 4, and the findings were compared for analysis.

Over the duration of the days tested, solar radiation, atmospheric, and water temperatures were recorded as the climate parameter that varies throughout the day as a two-day sample is presented in Figure 5.



(a) y= 5 % (b) y=10 % (c) y= 20%

Figure 4 Photographs of the Submerged ratios of the PSPV system examined(a), (b), and (c)

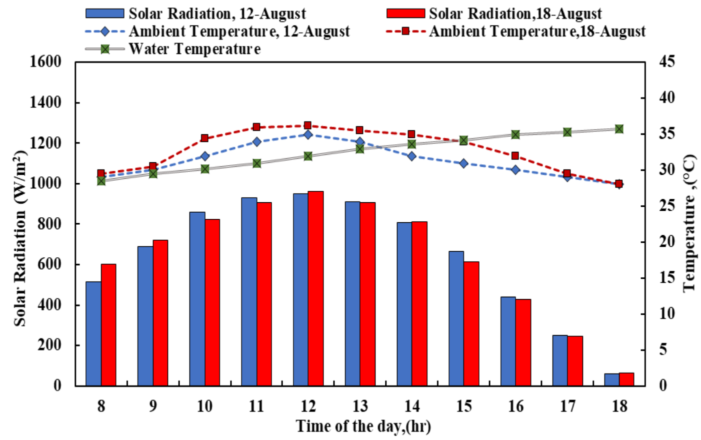


Figure 5 Sample of the climate recorded data

The solar intensity peak logged during the test days was about 950 W/m^2. It can be observed that, for the experimental days, a minimum variation in the average solar radiation and ambient temperature was noticed. Moreover, the water temperature had a nearly steady rate of increase and reached its maximum value by sunset from 28.5 ºC to 35.7 ºC.

3.1. The Submerged Ratio Effect on The Temperature of The PV Panel.

The effect of the submerged ratio on the performance of the PSPV system is reflected mainly in the surface temperature of the panel. Figure 6 presents the surface temperature of the PSPV module with the inspected submerged ratios of 5%, 10%, 20%, and compares them with the surface temperature of the land-based module.

It can be seen that in comparison with the reference module on the ground the temperatures of all PSPV modules with the submerged ratios were decreased. By increasing the submerged ratio, the surface temperature of the PSPV panel was observed to decrease. The average temperatures of the PSPV panel were, 38.67ºC, 37.77ºC, and 36.43ºC for the examined submerged ratios of 5%, 10%, and 20% respectively, compared to the LPV panel, with an average temperature of 42.43°C, whereas the maximum temperature reductions for the PSPV for the all examined submerged ratios compared to the LPV panel were respectively 7.90ºC, 9.20ºC, and 10.50ºC at noon.

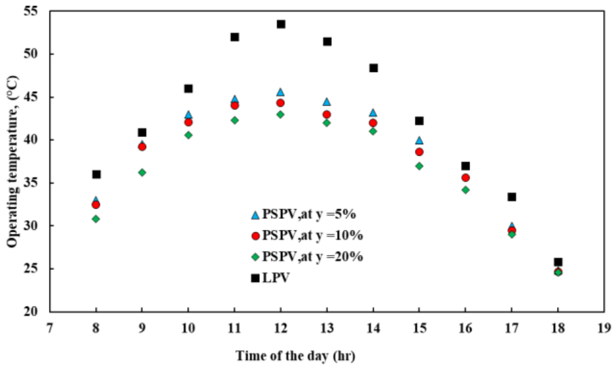


Figure 6 PV operating temperature for the examined submerged ratios

3.2. The Submerged Ratio Effect on The Electrical Behavior of The PV Panel

The most important parameter to examine in the PV system is electric efficiency, since this is high energy. The electrical efficiency may be determined by measuring the loaded voltage and current, as well as the electrical power output. Figure 7 depicted the variation of the current flow through the electrical circuit for all submerged ratios studied, while Figure 8 presented the PV module's hourly voltage readings for all submerged ratios studied during the day.

The results show that the electric voltage and current parameters follow the solar radiation pattern from sunrise until the solar peak, and then worsen until sunset. It can be seen that the voltage and current have been predominated for all of the PSPV modules from the morning until 03:00 pm. The daily averaged voltages of the PSPV module were about 12.61 V, 12.96 V, and 12.32 V for the submerged ratios of 5%, 10%, and 20%, respectively. When comparing this to the LPV system, the daily averaged voltage was 12.13 V. Moreover, the averaged currents of the PSPV module were 3.02 A, 3.22 A, and 2.86 A for the submerged ratios of 5%, 10%, and 20%, respectively while the average current of the LPV system was 2.85 A. Figure 9 shows the hourly power curves for the different submerged ratios investigated.

The power supremacy was for all the PSPV systems, such as in the voltage results, with all the submerged ratios tested before 03:00 pm. The daily average generated power reached 40.84 W, 44.20 W, and 38.51 W for the submerged ratios 5%, 15%, and 20%, respectively. Meanwhile, the electrical power generated from the LPV panel had an average power generation of 37.38 W, with a peak of 60.20 W at noon. The peak power of 62.17 W, 63.6W, and 61.61 W was recorded at noon for the submerged ratios of 5 to 20%. A power enhancement of 9.3% to 18.2% has been achieved in the PSPV module by increasing the submerged ratio from 5% to 10% respectively.

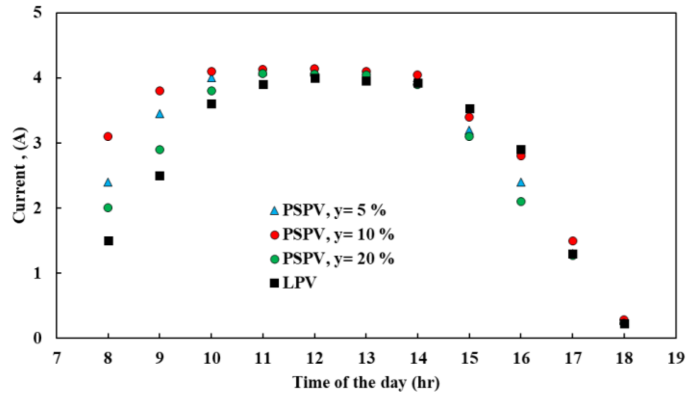


Figure 7 Current of the PV module for the examined submerged ratios

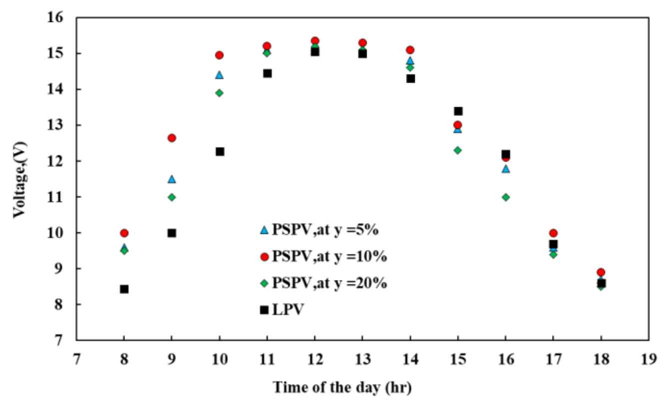


Figure 8 Voltage variations of the PV module for the examined submerged ratios.

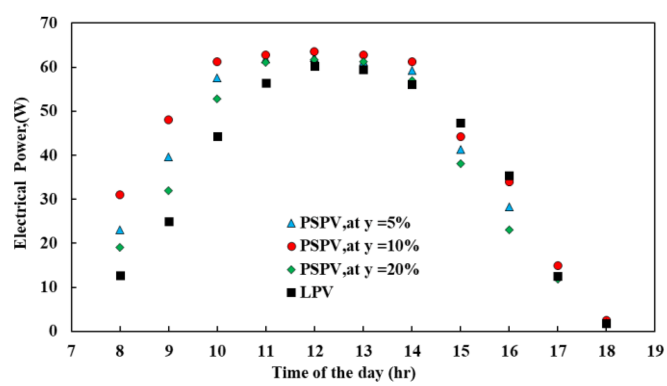


Figure 9 Electrical power of the PV module for the examined submerged ratios

It was observed that the PSPV module with the submerged ratio of 10% had the highest power generation over the other studied ratios. By increasing the submerged ratio, declining its operating surface temperature, which could, in turn, optimize the productivity of the panel, as discussed above, more thermal energy drained away from the PV module. However, once the solar radiation reaches the water's surface, a small portion of it will be reflected, dispersed, and absorbed by the water medium due to the radiation properties of the latter [32]. The remnant radiation would be passed through the water until it reached the PV panel's underwater segment. The reduced temperature of the PV panel compensates for the diffused radiation and improves the panel's efficiency, as shown by the experimental results.

The effect of the submerged ratio on the PSPV module's efficiency was investigated and compared with the LPV system. In the morning, when the low solar radiation intensity was increasing, the efficiencies increased until noon, and then decreased as the radiation diminished. Figure 10 depicts the hourly electrical efficiencies of the PSPV module at the various submerged ratios investigated. The recorded data revealed that the performance enhancement of the PSPV module was higher than the LPV module almost throughout all day except for the last two hours, as noted. the average electrical efficiencies of the PSPV panel tilted with an angle of 15° for the three submerged ratios were 11.68%, 12.98%, and 10.93%, respectively with efficiency gains of 15.60%, 28.40%, and 8.20% respectively compared to the LPV 10.11 %. The PSPV module with a submerged ratio of 10% achieved the best efficiency, and hence the best performance, as it gathered between the boost from the cooling effect and the minimum radiation losses.

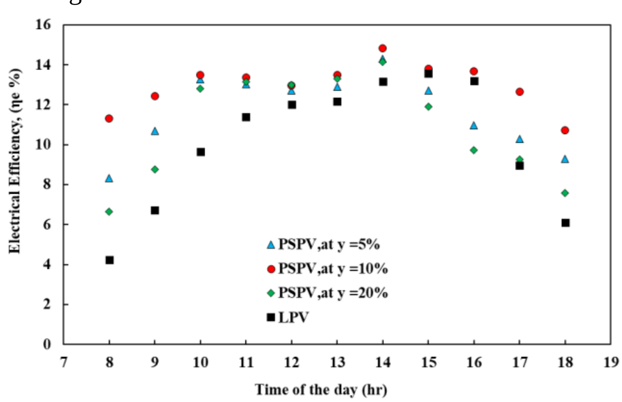


Figure 9 electrical efficiency for the PV panel for the examined submerged ratios.

4. MITIGATION OF ENVIRONMENTAL EMISSIONS

In the last few decades, an increase in the concentration of carbon dioxide CO_2 has caused global warming and climate change which pose a threat to environmental sustainability. Power production on a global scale is mainly based on fossil fuels. However, fossil fuels are diminishing because of the rising population and rate of growth, which leads to widespread and persistent usage. Furthermore, the main source of CO_2 emissions that contribute to air pollution and environmental destruction is the use of fossil fuels. As a result, fossil fuels must be conserved, and alternative methods of extracting electricity must be investigated. The trend of encouraging the decarbonizing electricity generation from the use of renewable energy and their production at the global level has been undertaken to mitigate emissions from fossil fuels and greenhouse gases while also preserving natural ecosystems for future generations. The suggested PSPV system, which uses available lakes and water bodies to reduce evaporation, reduce water body temperature, and improve efficiency, would permit greater CO_2 emissions savings. The amount of CO_2 emissions reduction has been estimated in the following formula: [33]

The average carbon dioxide (CO_2) emission for coal-fired thermal power plants has been determined to be 890. (g/kWh) [34]. It can be noticed from the calculations that, at a tilt angle of 15°, the daily CO_2 emissions saving is about 399.92 g, 432.72 g, and 373.48 g for daily accumulated clean electric power generated of 449.26 W, 486.15 W, and 419.62 W for the submerged ratio of 5%, 10%, and 20%, respectively, as a result of employing the proposed PSPV system. As there is a slightly minor difference in the summer solar radiation of Egypt, gross accused carbon dioxide is predicted by the average daily power output in summer (June to September). For the optimum conditions of y = 10% and a tilt angle of 15°, a cumulative CO_2 emission reduction of 51.92 kg per summer season was estimated.

5. ECONOMIC ASSESSMENT

Increased power supply systems in the future. A Levelized cost of electricity (LCOE) is defined and is generally agreed as the strategy of economic analysis of power production electricity in order to compare the costs among the various types of generation technologies [35]. This approach predicts the estimated overall cost of constructing and maintaining a power generation asset for its entire lifespan, divided by the overall power capacity of the asset for its lifetime. Inevitably, from an economic point of view, any enhancement approach should also be evaluated. The economic evaluation was carried out for the experimental setup by the cost per unit of electricity generated by the system (cost/kWh), represented by the (LCOE) on the basis of the cost analysis for evaluating the economic effectiveness of power produced from the cooled PSPV and LPV systems [36], [37]. LCOE can be defined as the ratio between the total cost represented in the Levelized cost of the capital investment L_{Cinv} ($), Levelized cost of operation & maintenance $L_{CO\&M}$ ($) of the system throughout the considered lifetime, and the summer electricity production by of the system Es (kWh) as expressed in eq. (5) [32,33].

$$LCOE = \frac{LC_{inv} + LC_{O\&M}}{E_S} \quad (5)$$

The cost of the capital investment includes the cost of the PV module, the floating assembly, construction modules, and structural structures hence, based on the above premise the following breakdown was proposed based on the author's experience in Table 3.

The operating and maintenance costs of either FPV or PSPV were not well reported, although the maintenance procedures are similar to the maintenance of the LPV system [40]. It is stated that the maintenance costs are constant throughout the life cycle and limited for the floating system and on average are higher for a ground system [41]. The on-site water bodies can be an advantage in comparison with those in PVs in the cleaning process of floating photovoltaic systems but even the cost of operation & maintenance can be equivalent or higher if the mooring systems and anchors exist. The cost of operations and repairs is assumed to be 8% of the original cost of investment [27]. Considering that the service period of both PSPV and LPV systems (n) is 25 years. The annual interest rate (i) is taken as 10%, and hence the capital recovery factor CRF of 11.01% was calculated using the footpath as those in eq.(6) [42].

$$CRF = \frac{i \times (1+i)^n}{(1+i)^n - 1} \quad (6)$$

The effective discount rate and the nominal escalation rate for the maintenance costs are considered to be 5% and 1% respectively. It can be spotted that the calculation of LCOE for the LPV system was 0.71 ($/kWh), while the LCOE for the PSPV system was slightly reduced to 0.63 ($/kWh) Therefore, the relative LCOE was improved by 9.61% due to the proposed cooling system. In comparison to the performance of an LPV, higher PV efficiency and lower cell temperature for PV with a cooling mechanism have resulted in lower LCOE

Table 3

Cost breakdown of both PSPV and LPV systems [13].

Components	PSPV	LPV
PV Module	70 $	70 $
Stand	--	20 $
Battery and Connection	50 $	50 $
Floating Unit (Including Stand for PSPV Unit)	25 $	--
Mooring System	5 $	--
Total cost of the investment	150 $	140 $

6. CONCLUSIONS

This paper shows the result of a newly partially submerged PV system that experimentally investigated to study the influence of the submerge length on the thermal and electric performance of the PSPV system and compare it with the reference LPV system Economical and environmental assessments have been made to evaluate the potential of the newly examined system. The results revels:

1. The submerged segment of the PV dissipates harmful heat to the surrounding water, which reduced the average temperature of the PSPV module to 36.3 ºC by increasing the submerged ratio to 20 % while 42.4ºC for the LPV system.
2. the temperature of the PSPV decreases as the submerged ratio increases as documented, the maximum temperature of the PSPV module decreases from 45.60°C to 43.00°C for submerged ratios from 5 % to 20 %, compared to 53.50°C for LPV at solar noon.
3. The rate of power generated from the PSPV boosts as the submerged ratio increases to 10% with an average generation rate of 44.20 W when it was 37.38 W compared with the LPV system.
4. The estimated LCOE for both systems also reveals that the least cost of electricity can be achieved using the PSPV system, LCOEs of 0.63 $/kWh, and 0.71 $/kWh were reached for the PSPV system and the LPV system, respectively.

Credit Authorship Contribution Statement

Amr Osama, Data Curation, Writing - Original Draft, Literature survey, Software, Analysis and interpretation of data, Running experiments.

Nabil A.S. Elminshawy: Conceptualization Supervision, Methodology, Validation, Review & Editing, Analysis and interpretation of data

Y. Elhenawy: Review & supervision.

Amany M. Saif: Editing, review & supervision, Analysis, and interpretation of data

Declaration of competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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