Performance of Photovoltaics in Ground Mount-Floating-Submerged Installation Methods

Nallapaneni Manoj Kumar, A. Ajitha, Aneesh A. Chand, and Sonali Goel

Abstract The use of ground-mounted photovoltaic (GMPV) systems for power generation is becoming popular these days. The GMPV systems demand vast land areas for their installations, and this has resulted in land-use conflicts. As a result, for mitigating the land-use issues, few novel ways of photovoltaic (PV) installations have emerged that include floating photovoltaic (FPV) and submerged photovoltaics (SPV). However, in literature, many have raised concerns over the FPV and SPV performance. In this paper, an experimental study is carried out to understand the performance of GMPV, FPV, and SPV systems. Three different prototypes of PV systems with data collection units in GMPV, FPV, and SPV installation methods are designed. An outdoor experimental study is carried at the same time, and performance assessment is carried out. Results observed from this study include weather parameters and electrical parameters. The analysis shows that FPV produces higher energy outputs when compared to the GMPV and SPV systems. From this investigation, we recommend the use of PV installation in FPV mode for solar power generation. The large-scale deployment of and the promotion of FPV systems would overcome the land-use conflicts between solar power and agriculture sectors. Also,

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the enhanced power outputs from FPV can help in overcoming the growing energy crisis.

Keywords Photovoltaics · PV installation · Power conversion efficiency · PV performance · Floating solar · Submerged PV · Ground-mounted PV

1 Introduction

Photovoltaics (PV) are playing a prime role in the modern-day power sector. Combined efforts on promoting renewables use and the activities that reduce greenhouse gas emissions accelerated the use of PV systems for power generation. Also, various initiatives are taken by the public and private organizations also supported the PV installations [1]. At present, most of the PV installations seen across the globe are ground-mounted photovoltaics (GMPV). The installed GMPV systems were performing within their designed limits and help in meeting the power demands. Recent literature on the GMPV systems suggested that their performance is varied from location to location as they experience different weather conditions [2, 3]. Besides, studies have also highlighted the negative impacts of these weather conditions on the power generation outputs of GMPV systems [4]. For example, the rise in PV module temperature and its impact on performance degradation is becoming a serious challenge [5]. On the other side, many activists claim that PV installation occupies vast amounts of land areas (approximately 2.5 to 5 acres of land for 1 MW of solar PV installation), and this has significantly affected the land-use decisions [6]. To be more specific, due to the solar movement, in many places, most of the agricultural land areas are converted into a solar power generating stations. This has resulted in a severe problem creating the land-use conflicts between the agriculture sector and the power sector [7]. Keeping the negative effects of PV module temperature and land-use conflicts in mind, few novel methods of PV installation were identified. These methods include the floating photovoltaic (FPV), and submerged photovoltaics (SPV). In the FPV installation method, the PV modules are installed on the water surface with the help of floating devices. The FPV method seems to be a reliable solution for avoiding land-use. Besides, the FPV systems act as barriers or water covers that would limit the evaporation of water from the water bodies. At the same, the PV module temperature tends to reduce due to the cooling effect caused by the water [8].

Similarly, the concept of SPV systems has also become popular these days, and here the PV modules are immersed in the water at different depths for harnessing the power that would be needed for marine applications [9]. Theoretically, the FPV and SPV systems seem to provide solutions, but many have questioned their functional performance related to the power outputs and power conversion efficiencies. For example, the incoming solar radiations that hit the PV module in the deep waters would be different when compared to the GMPV and FPV. At the same time, the thermal regulation of the PV module would be different in FPV and SPV systems.

The above-highlighted concerns question the power generation capability of each system. This has led to a severe challenge and doubts on the selection of installation methods among the GMPV, FPV, and SPV. Hence, conducting a study that reveals the comparative performance of GMPV, FPV, and SPV is needed.

The objectives of this paper are as follows:

- To conduct an experimental study on three different PV installation methods (GMPV—Ground Mount Photovoltaics, FPV—Floating Photovoltaics, and SPV—Submerged Photovoltaics) and to understand the deviation in their performance.
- To monitor and analyze the weather (global radiation, wind speeds, ambient temperature, and PV module temperatures) and basic electrical (voltage, current) parameters.
- To evaluate and compare the power parameters such as power input, power output, and power conversion efficiency of GMPV, FPV, and SPV.

2 Materials and Methods

2.1 Power Conversion Efficiency

In the performance assessment of solar photovoltaic modules, power conversion efficiency is one of the most critical parameters. It generally refers to the amount of electricity that is produced out of photovoltaic cells when photon energy from the sun in the form of sunlight is incident on the surface of the photovoltaic cells. Mathematically it is represented as a ratio of output electricity produced by the PV module to the input energy that is available at the module area level.

Equation (1) is used to evaluate the power conversion efficiency of the photovoltaic module that is installed in three different configurations, i.e., (ground mount, floating, and submerged) [9].

$$\eta_{\text{pce}} = \frac{P_{\text{out}}}{P_{\text{in}}} \tag{1}$$

where η_{pce} is the power conversion efficiency in %; P_{out} is output electrical energy generated by the PV module in W; and P_{in} is the power input available at the PV module in W.

P_{in} is estimated by using Eq. (2), where it is the product of the solar irradiance incident on the PV module to its area [9].

$$P_{\text{in}} = S_r \times A_{\text{PV}} \tag{2}$$

where S_{r} is the solar irradiance in w/m^2; and A_{PV} is the area of the PV module in m^2.

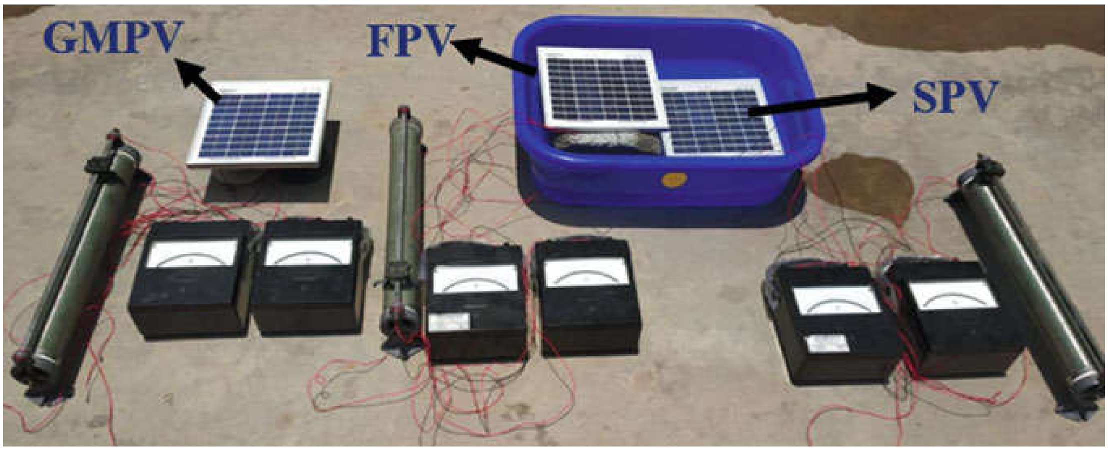

Fig. 1 Experimental setup showing three different ways of photovoltaic module installation

Table 1 Table captions should be placed above the tables

Description	Parameter/Specification/Values		
Installation method	Ground-mounted	Floating	Submerged
PV technology	Thin-film (a-Si)		
PV module electrical parameter	Open circuit voltage: 21.9 V, Short circuit current: 0.32 A, Maximum power: 10 W, Maximum voltage: 12 V		
PV module dimension and area	Dimension: 0.215 m * 0.191 m, Area: 0.041065 m^2		
Instruments used	Voltmeter: 0–30 V, Ammeter: 0–2 A, Rheostat 300 Ohms/2 A		

2.2 Experimental Setup

An experimental setup, as shown in Fig. 1, is designed. Three different thin-film PV modules made with a-Si material are used for experimentation. A provision is made to differentiate three installation methods such as ground mount, floating, and submerged. For monitoring the voltage, the current output from the three different experimental setups, voltmeter and ammeter are used. A rheostat is used to adjust the load. By setting the rheostat value, the experiment is performed by noting the currents and voltages from each setup for every 15 min from morning to evening. Table 1 gives a detailed specification and components used for experimentation.

3 Results and Discussion

Using the designed experimental setup, data related to weather parameters, and PV module electrical parameters are recorded in three different installation methods (GMPV, FPV, and SPV). Later the data is analyzed and presented in the graphical representation. The global radiation, which is measured for each installation type, is given in Fig. 2a. The solar radiation that is incident on GMPV and FPV is observed to the same, and it varied between 650 and 982 W/m^2. In the case of the SPV module, the incident solar radiation varied between 293.91 and 686.49 W/m^2. Overall, the incident solar radiation on the SPV module is observed to be lesser than that of GMPV and FPV. Wind speed is another critical parameter that generally influences the efficiency of PV modules. The variation in wind speed is observed to be in between 1.6 and 4 m/s for the monitored local time and the same is graphically represented in Fig. 2b.

Temperature is another critical parameter to be considered while analyzing the performance of the PV module in any installation configuration. In Fig. 3, the monitored temperatures are shown, and these include the temperatures at standard testing condition (STC), ambient, water surface, water at 12 cm depth. In SPV, water is the medium where the PV modules are immersed; hence, the water temperature is considered while analyzing the performance. Besides, the PV module temperatures in GMPV, FPV, and SPV installation methods are also shown in Fig. 3. In GMPV installation method, the recorded PV module temperatures range in between 44.19 and 50.90°C for local time between 11:00 a.m. and 4:00 p.m., whereas the for the same monitored period the recorded PV module temperatures for FPV and SPV are in the range of 41.33–46.31 and 33.77–42.34 °C, respectively. The recorded maximum PV module temperatures are 58.5, 52.42, and 49.09 °C for GMPV, FPV, and SPV installation methods, respectively. The recorded minimum PV module temperatures are 44.19, 41.33, and 33.77 °C for GMPV, FPV, and SPV installation methods, respectively. When compared to GMPV, the observed module temperatures in FPV and SPV methods are lesser. In FPV, the cooling effect of water on the PV module resulted in temperatures reductions.

The recorded PV module electrical parameters that include voltage and current for three different installation methods (GMPV, FPV, and SPV) are represented graphically in Fig. 4a and b. The voltage and current are monitored every 15 min starting from morning 11:00 a.m. to evening 4:00 p.m., and their variation seems to be

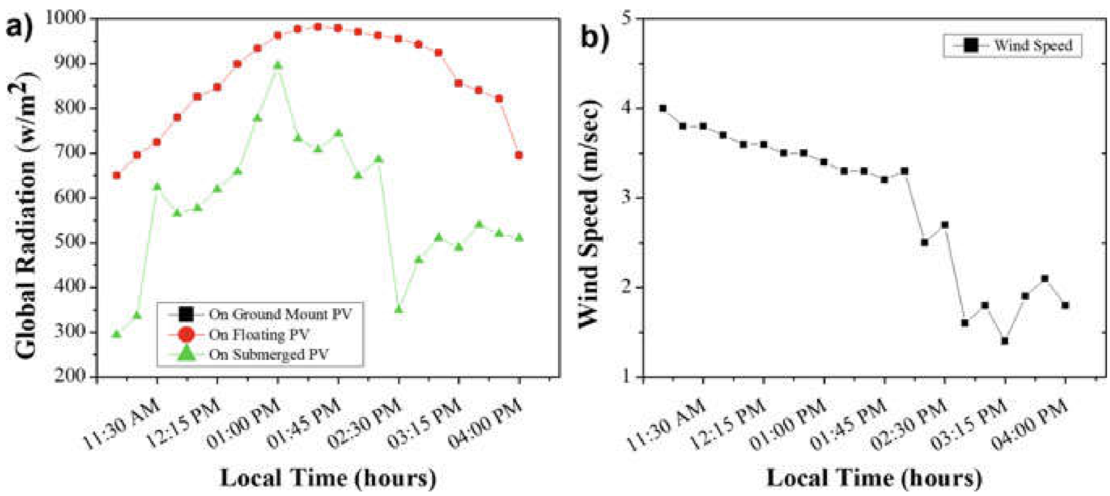

Fig. 2 Weather parameters. **a** Global radiation in w/m^2, **b** Wind speed in m/s

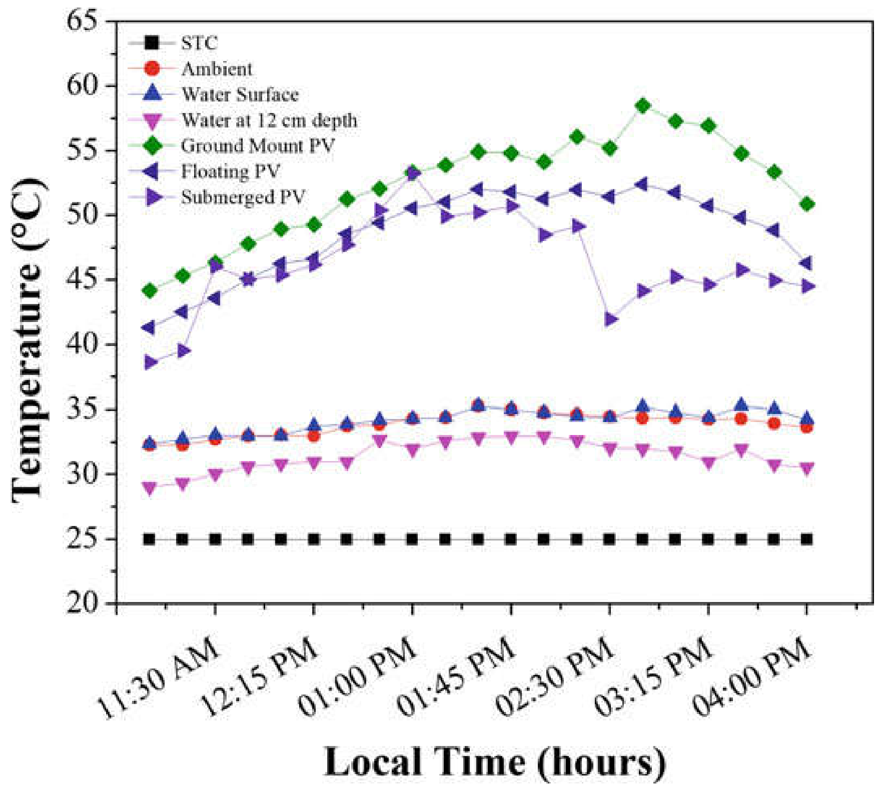

Fig. 3 Ambient temperatures and photovoltaic module temperatures in GMPV, FPV, and SPV installation methods

dynamic in each monitored installation method. In GMPV and FPV installation methods, the recorded voltages for the monitored period are between 10 and 5 V, whereas in the case of SPV, the recorded voltage is in between 8 and 3.6 V. The recorded maximum voltages are 11, 12 and 11.5 V for GMPV, FPV, and SPV installation methods, respectively. The recorded minimum voltages are 5 and 3.6 V for GMPV, FPV, and SPV installation methods, respectively.

In the GMPV installation method, the recorded current for the monitored period is in between 0.2 and 0.1 A, whereas in the case of FPV and SPV, the recorded currents are in between 0.23 to 0.1 A and 0.13 A to 0.12 A. The recorded maximum currents are 0.24, 0.26 and 0.25 A for GMPV, FPV, and SPV installation methods, respectively. The recorded minimum currents are 0.1, 0.1 and 0.12 A for GMPV, FPV, and SPV installation methods, respectively.

Using the above-discussed PV module electrical parameters and based on methodology shown in Sect. 2, the performance of the PV module in GMPV, FPV, and SPV installation methods is studied. As a result, power inputs, power outputs, and power conversion efficiencies are calculated and these are presented in the graphical representation in Fig. 5a, b, c, respectively. The power input is calculated using Eq. (2) and is shown in Fig. 5a. The power input for GMPV and FPV installation methods is observed to be similar, and it is between 26.69 and 28.54 W for the local time between 11:00 AM and 4:00 PM. The recorded maximum input power is 40.32 W, and the minimum input power is 26.92 W. In the case, SPV, the observed input power

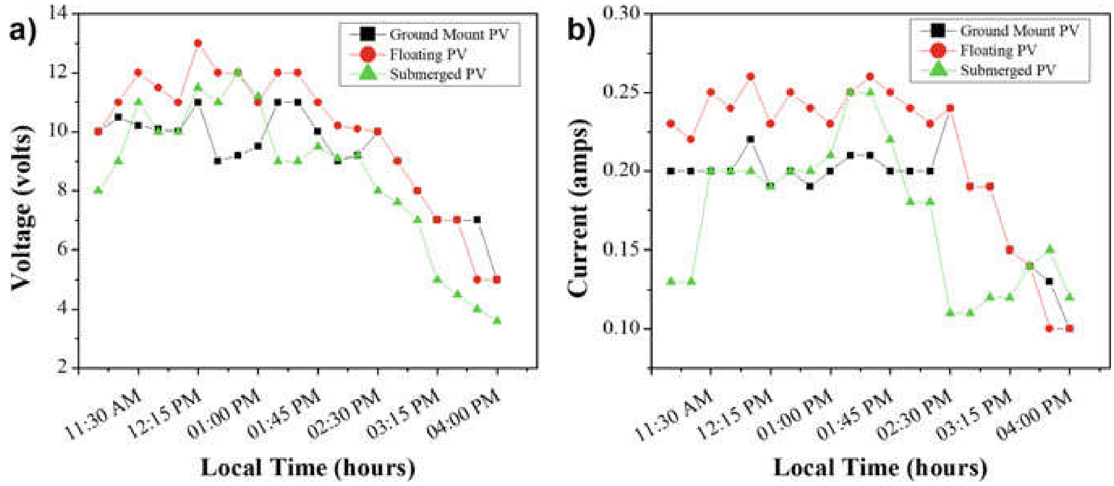

Fig. 4 Electrical parameters of GMPV, FPV, and SPV. **a** Voltage in volts, **b** current in amps

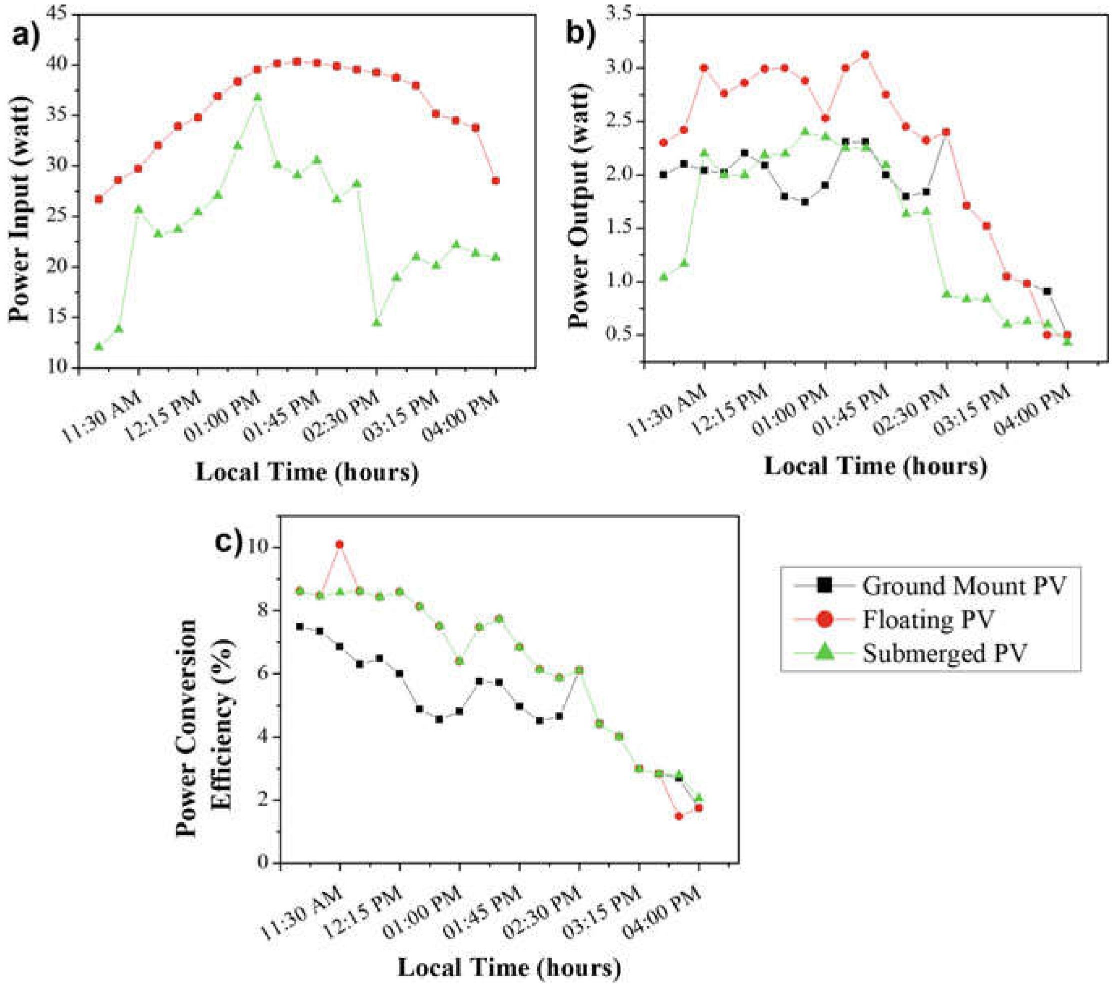

Fig. 5 Performance parameters of GMPV, FPV, and SPV. **a** Power input in watts, **b** power output in watts, and **c** power conversion efficiency in percentage

is lower than that of GMPV and FPV systems. This is due to the low incident radiation on the SPV module. The recorded maximum and minimum input powers in the case of SPV installation are 36.73 and 12.07 W respectively.

In Fig. 5b, the monitored power outputs of a PV module in the three installation methods are shown. The PV module in the GMPV installation method produced a power output that in the range from 2 to 0.5 W for the monitored between 11:00 a.m. and 4:00 p.m. The maximum power output of 2.31 W is observed in the peak sun hours from the GMPV, and the minimum power output is 0.5 W. Whereas in the case of FPV, the produced power outputs from the PV module is higher when compared to GMPV. The recorded power outputs in FPV are in the range between 2.3 and 0.5 with 3 W as maximum power output and 0.5 W as a minimum. The power outputs from a PV module in SPV are observed too much lesser when compared to GMPV and FPV. In the case of SPV, the maximum power produced is 2.3 W, and the minimum is 0.43 W.

In Fig. 5c, the power conversion efficiencies calculated using Eq. (1) are shown. The power conversion efficiency of the PV modules is observed to vary in three installation configurations, and on the other side, the efficiency tends to increase in the case of FPV and SPV.

4 Conclusion

In this paper, an experimental study of a thin-film amorphous silicon module is carried out in GMPV, FPV, and SPV installation methods.

From the experimental investigation, the following conclusions are made:

- It is observed that the PV module behave differently in each of the installations studied installation method.
- The temperature of the PV module is observed to be lower in the case of FPV, and SPV when compared to GMPV.
- Overall, the output power produced by a PV module in the FPV installation method is higher than the SPV and GMPV methods.
- Comparing the GMPV and FPV installation methods, it is observed that power outputs in FPV are higher, and the range varied between 15 and 66.66%.
- It is observed that the SPV systems produce less output power when compared to GMPV and FPV, and they are in the range of –0.99 to –63% and –7.03 to–63.33%.
- Overall it is observed that the temperature of the PV module and the incoming solar radiation are the most affecting parameters that affected the performance of FPV and GMPV.
- In the case of SPV, the incoming radiations are observed to be much lesser due to which the total produced power is lesser.

Based on the above conclusions, we recommend the use of PV modules in the FPV installation method if there is a limit land area. However, the decision on selecting the installation method is based on multiple criteria such as availability land, availability of water surface area, cost, and power demand. We believe this work would serve as a useful material for the readers.

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