Floating Photovoltaic Systems

Subjects: Energy & Fuels | Green & Sustainable Science & Technology
Contributor: Rafi Zahedi

Floating Photovoltaic (FPV) system is a solution which employ PV panels in a cooler environment, achieve higher efficiency, and reduce water evaporation. FPV systems open up new opportunities for scaling up solar generating capacity, especially in countries with high population density and valuable lands, as well as countries with high evaporation rates and water resources deficiency.

Keywords: dust accumulation ; Floating Photovoltaic (FPV) systems ; Floating Photovoltaic (FPV) cleaning techniques ; soiling ; water-based cleaning approaches ; water-free cleaning approaches

1. Introduction

The increased energy consumption and global warming concerns have encouraged governments to promote the installation of Renewable Energy Sources (RESs) [1][2][3]. Due to the sustainable development goals of the 2030 agenda about increasing the share of RESs in the global energy mix, their development is imperative [4][5]. Because it is abundant and free of fuel costs, solar energy is a promising energy source that has attracted wide attention, so that a variety of its applications, including Photovoltaic (PV) panels, has been developed [6][7][8][9]. PV panels are capable of converting solar irradiation into electricity [10][11][12]. One of the most prominent aspects of PV systems is that they are environmentally friendly and have near zero CO_2 emissions [13][14][15]. In addition, the long-term perspective of PV systems due to their ongoing quality improvement and cost reduction is promising [16][17][18][19].

2. FPV System Development Purposes

Land-based PV systems require a large area of vast land (about 8 m^2 per 1 kW). This can decrease the interest in many countries because the lands needed for PV systems installation may be expensive. Furthermore, the efficiency of PV panels is characterized by a specific maximum power thermal coefficient expressed in %/°C [20]. This coefficient is negative for commercial PV panels, which means that by increasing PV cells' temperature, the efficiency of cells is reduced. Based on the aforementioned reasons, FPV systems can offer a synthetic solution for the conservation of valuable lands and increasing energy generation [21]. In the countries where FPV systems are used for energy generation, companies have developed this technology in order to gain the maximum energy based on the power generation equation of PV panels [22].

Under normal conditions, two factors that limit the energy generation of PV systems are: (1) the high operating temperature of PV cells and (2) any reduction in the solar irradiation incidence on the PV panel due to soiling. Therefore, PV panels should be periodically cleaned, usually by water. The use of non-fresh water can increase the soiling. Consequently, an extra water source must be provided for cleaning FPV systems, which are usually placed on the surface of non-fresh water reservoirs. Due to water scarcity in some areas, cleaning becomes difficult, challenging, and subsequently costly.

Because of the low cost of fossil fuels in oil-rich countries, using RESs is not a preferred method for energy generation. In addition, access to the vast lands for the Middle East and North Africa (MENA) countries is not a problem. For most of these countries, which are located in arid and semi-arid regions, water security is an important priority. Some of the anticipated impacts of climate changes in these countries are droughts and amplified heat waves, which accelerate the evaporation of open water resources and reservoirs [23]. Therefore, the water stored in reservoirs can be better managed if surface evaporation losses can be reduced. Covering the surface of the water with FPV systems allows these countries to tackle their water deficiency. Depending on the covered surface, FPV systems can reduce water evaporation up to 80% [23]. Furthermore, this solution can provide other advantages as follows:

- The power generated by FPV systems can be used as an income source.

- The long-time warranty of solar equipment decreases the maintenance costs and if FPV systems are installed on dam lakes, the saved water can be utilized for load peak shaving.

Companies in these countries are developing such a technology to achieve maximum water loss reduction based on the Penman equation and its derivatives [24].

3. Frequency of Cleaning

As mentioned before, dust and soils have negative impacts on the efficiency of PV panels. Therefore, the importance of cleaning PV panels is considerable from both economic and performance points of view [25]. A key factor to maximizing the economic advantage is the determination of cleaning times. There is no specified cleaning cycle for PV panels, and the soiling rate of the region mostly determines the cleaning frequency [26]. The optimal cleaning frequency mainly depends on the environmental conditions of the installation place, such as precipitation and humidity, wind velocity, particle type, source of particles, and soiling rate [26][27]. In this regard, it has been suggested in [28] that PV panels should be cleaned weekly in moderately dusty places. Furthermore, it has strongly been recommended that all equipment should immediately be cleaned after a dust storm to maintain nominal operating efficiency. The soiling rate for 20° sloped PV systems installed in Mesa (near Phoenix, AZ, USA) has been determined in [29]. It has been demonstrated that the daily soiling rate (average loss of full power energy in each day because of soiling) of this site is −0.061% during the highest soiling period. In [30], using a novel model, the cleaning frequency of PV panels in desert regions has been determined to be 20 days, considering the output power reduction and particle concentration equal to 5% and 100 μg/m^3, respectively. A method to calculate the dynamic cleaning frequency of grid-connected PV systems by achieving a coefficient of cleaning tolerance has been presented in [31]. In [32], the cleaning interval of two different manual cleaning techniques, handwashing using water and application of washing tractor, have been determined in central Saudi Arabia. The results have demonstrated that the optimal average cleaning frequency of manual cleaning has been about 20 days, whereas this period is approximately 9 days for a washing tractor. The daily soiling rate in bifacial PV systems has been calculated in Santiago (Chile) and it has been compared with the conventional mono facial minimodules [33]. It has been illustrated that the soiling rate in the mono facial minimodule is 0.301% per day, whereas a rate of 0.236% per day has been measured for the bifacial system. Moreover, the soiling rate for the rear side of bifacial PV panels has been determined as 0.0394% per day. The dust accumulation effect on PV panels in the MENA region has been assessed in [25], and it has been noted that the cleaning interval can be 12–15 days. Using an endogenous method, the soiling rate in three utility-scale PV systems located in the Middle East has been calculated to be about 0.1% per day [34]. In [35], the optimal cleaning frequency of PV panels in a hot desert climate has been recommended to be weekly, especially during summers. Different aspects of dust deposition on the PV system installed in the Hashemite University (Jordan) have been assessed in [36]. Considering the environmental conditions, it has been suggested that PV panels should be cleaned every two weeks.

The assessment of the research studies has demonstrated that the cleaning interval of PV panels depends on the environmental conditions including the soiling rate. Note that the amount of soil that is cleaned in each cleaning time can be another factor that affects the cleaning frequency. In Table 2, a summary of the reviewed research studies has been presented.

Table 2. Classified summary of papers on cleaning frequency.

Reference	Location	Cleaning Frequency
[28]	**Minia region, middle of Egypt (moderately dusty places)**	**Weekly cleaning recommended.**
[29]	**Mesa (near Phoenix), AZ, USA**	**The daily soiling rate is determined to be −0.061%.**
[30]	**Desert areas**	**The frequency of cleaning is specified to be 20 days.**
[32]	**Central Saudi Arabia**	**The optimal cleaning interval for handwashing was 20 days and for tractor, washing was 9 days.**
[33]	**Santiago, Chile**	**The soiling rate in the mono facial minimodule is 0.301% per day, and in the bifacial module is 0.236% per day.**
[25]	**The MENA region**	**The cleaning interval is calculated to be 12–15 days.**
[34]	**The Middle East**	**It is demonstrated that the average soiling rate is 0.1% per day.**
[35]	**Desert areas**	**The panels should be cleaned weekly, especially in summers.**

Reference	Location	Cleaning Frequency
[36]	**Jordan**	**The cleaning interval is better to be 14 days.**

References

1. Sobri, S.; Koohi-Kamali, S.; Rahim, N.A. Solar photovoltaic generation forecasting methods: A review. Energy Convers. Manag. 2018, 156, 459–497.
2. Adefarati, T.; Bansal, R.C. Reliability, economic and environmental analysis of a microgrid system in the presence of re newable energy resources. Appl. Energy 2019, 236, 1089–1114.
3. Neagoe, M.; Burduhos, B.G.; Mohammadi, F.; Cretescu, N.R. A Comparative Analysis of the Solar Energy Receiving S hare Using Four Tracking System Types at Mid-Latitude Regions. In Solar Energy Conversion in Communities–Springe r Proceedings in Energy; Springer: Cham, Switzerland, 2020.
4. Mohammadi, F. Research in the Past, Present and Future Solar Electric Aircraft. J. Sol. Energy Res. 2018, 3, 237–248.
5. Johnston, R. Arsenic and the 2030 Agenda for Sustainable Development. In Arsenic Research and Global Sustainabilit y; CRC Press: Boca Raton, FL, USA, 2016; pp. 12–14.
6. Ghorbani, N.; Kasaeian, A.; Toopshekan, A.; Bahrami, L.; Maghami, A. Optimizing a hybrid wind-PV-battery system usin g GA-PSO and MOPSO for reducing cost and increasing reliability. Energy 2018, 154, 581–591.
7. Zahedi, R.; Gharehpetian, G.B.; Rastegar, H. Environment Compatible Management Strategy of Distributed Generation Based on Neural Network with a Power Capacity Index. In Proceedings of the Electrical Engineering (ICEE), Iranian Co nference on, Mashhad, Iran, 8–10 May 2018; pp. 1022–1026.
8. An, W.; Wu, J.; Zhu, T.; Zhu, Q. Experimental investigation of a concentrating PV / T collector with Cu 9 S 5 nanofluid s pectral splitting filter. Appl. Energy 2016, 184, 197–206.
9. Lee, J.; Bérard, J.-P.; Razeghi, G.; Samuelsen, S. Maximizing PV hosting capacity of distribution feeder microgrid. App l. Energy 2020, 261, 114400.
10. Mohammadi, F. Design, Analysis, and Electrification of a Solar-Powered Electric Vehicle. J. Sol. Energy Res. 2018, 3, 2 93–299.
11. Kasaeian, A.; Nouri, G.; Ranjbaran, P.; Wen, D. Solar collectors and photovoltaics as combined heat and power system s: A critical review. Energy Convers. Manag. 2018, 156, 688–705.
12. Mehdipour, C.; Mohammadi, F. Design and analysis of a stand-alone photovoltaic system for footbridge lighting. J. Sol. Energy Res. 2019, 4, 85–91.
13. Bakkar, M.; Aboelhassan, A.; Abdelgeliel, M.; Galea, M. PV Systems Control Using Fuzzy Logic Controller Employing S hading Conditions. Energies 2021, 14, 841.
14. Kumari, P.A.; Geethanjali, P. Parameter estimation for photovoltaic system under normal and partial shading conditions: A survey. Renew. Sustain. Energy Rev. 2018, 84, 1–11.
15. Syafiq, A.; Pandey, A.K.; Adzman, N.N.; Rahim, N.A. Advances in approaches and methods for self-cleaning of solar ph otovoltaic panels. Sol. Energy 2018, 162, 597–619.
16. Zubi, G.; Dufo-lópez, R.; Pasaoglu, G.; Pardo, N. Techno-economic assessment of an off-grid PV system for developin g regions to provide electricity for basic domestic needs: A 2020–2040 scenario. Appl. Energy 2020, 176, 309–319.
17. Zolfaghari, M.; Hosseinian, S.H.; Fathi, S.H.; Abedi, M.; Gharehpetian, G.B. A new power management scheme for par allel-connected PV systems in microgrids. IEEE Trans. Sustain. Energy 2018, 9, 1605–1617.
18. Baghaee, H.R.; Mirsalim, M.; Gharehpetian, G.B. Multi-objective optimal power management and sizing of a reliable wi nd/PV microgrid with hydrogen energy storage using MOPSO. J. Intell. Fuzzy Syst. 2017, 32, 1753–1773.
19. Mohammadi, F.; Neagoe, M. Emerging Issues and Challenges with the Integration of Solar Power Plants into Power Sy stems. In Solar Energy Conversion in Communities–Springer Proceedings in Energy; Springer: Cham, Switzerland, 20 20.
20. Cazzaniga, R.; Cicu, M.; Rosa-Clot, M.; Rosa-Clot, P.; Tina, G.M.; Ventura, C. Floating photovoltaic plants: Performanc e analysis and design solutions. Renew. Sustain. Energy Rev. 2018, 81, 1730–1741.

21. Campana, P.E.; Wästhage, L.; Nookuea, W.; Tan, Y.; Yan, J. Optimization and assessment of floating and floating-tracking PV systems integrated in on- and off-grid hybrid energy systems. Sol. Energy 2019, 177, 782–795.
22. Skoplaki, E.; Palyvos, J.A. On the temperature dependence of photovoltaic module electrical performance: A review of efficiency / power correlations. Sol. Energy 2009, 83, 614–624.
23. Pouran, H.M. From collapsed coal mines to floating solar farms, why China’s new power stations matter. Energy Policy 2018, 123, 414–420.
24. Leuning, R.; Zhang, Y.Q.; Rajaud, A.; Cleugh, H.; Tu, K. A simple surface conductance model to estimate regional evaporation using MODIS leaf area index and the Penman-Monteith equation. Water Resour. Res. 2008, 44.
25. Hammad, B.; Al-Abed, M.; Al-Ghandoor, A.; Al-Sardeah, A.; Al-Bashir, A. Modeling and analysis of dust and temperature effects on photovoltaic systems’ performance and optimal cleaning frequency: Jordan case study. Renew. Sustain. Energy Rev. 2018, 82, 2218–2234.
26. Said, S.A.M.; Hassan, G.; Walwil, H.M.; Al-Aqeeli, N. The effect of environmental factors and dust accumulation on photovoltaic modules and dust-accumulation mitigation strategies. Renew. Sustain. Energy Rev. 2018, 82, 743–760.
27. Dolan, D.; Prodanov, V.; Taufik, T. Energy and economic losses due to soiling on utility scale PV system to guide timing of cost effective cleaning. In Proceedings of the 2015 IEEE 42nd Photovoltaic Specialist Conference (PVSC), New Orleans, LA, USA, 14–19 June 2015.
28. Hegazy, A.A. Effect of dust accumulation on solar transmittance through glass covers of plate-type collectors. Renew. Energy 2001, 22, 525–540.
29. Naeem, M.; TamizhMani, G. Cleaning frequency optimization for soiled photovoltaic modules. In Proceedings of the 2015 IEEE 42nd Photovoltaic Specialist Conference (PVSC), New Orleans, LA, USA, 14–19 June 2015; pp. 1–5.
30. Jiang, Y.; Lu, L.; Lu, H. A novel model to estimate the cleaning frequency for dirty solar photovoltaic (PV) modules in desert environment. Sol. Energy 2016, 140, 236–240.
31. Mei, M.H.; Shen, Z.; Zeng, C. Study on cleaning frequency of grid-connected PV modules based on related data. In Proceedings of the 2016 IEEE International Conference on Power and Renewable Energy (ICPRE), Shanghai, China, 21–23 October 2016; pp. 621–624.
32. Jones, R.K.; Baras, A.; Al Saeeri, A.; Al Qahtani, A.; Al Amoudi, A.O.; Al Shaya, Y.; Alodan, M.; Al-Hsaien, S.A. Optimized Cleaning Cost and Schedule Based on Observed Soiling Conditions for Photovoltaic Plants in Central Saudi Arabia. IEEE J. Photovolt. 2016, 6, 730–738.
33. Luque, E.G.; Antonanzas-Torres, F.; Escobar, R. Effect of soiling in bifacial PV modules and cleaning schedule optimization. Energy Convers. Manag. 2018, 174, 615–625.
34. Skomedal, Å.; Haug, H.; Marstein, E.S. Endogenous Soiling Rate Determination and Detection of Cleaning Events in Utility-Scale PV Plants. IEEE J. Photovolt. 2019, 9, 858–863.
35. Al-Housani, M.; Bicer, Y.; Koç, M. Experimental investigations on PV cleaning of large-scale solar power plants in desert climates: Comparison of cleaning techniques for drone retrofitting. Energy Convers. Manag. 2019, 185, 800–815.
36. Al-Kouz, W.; Al-Dahidi, S.; Hammad, B.; Al-Abed, M. Modeling and Analysis Framework for Investigating the Impact of Dust and Temperature on PV Systems’ Performance and Optimum Cleaning Frequency. Appl. Sci. 2019, 9, 1397.