International Scientific Conference 20 UNITECH 26

INTERNATIONAL SCIENTIFIC CONFERENCE
19-21 November 2026
GABROVO

EFFECT OF SEA SALT DEPOSITS ON THE POWER OUTPUT OF FLEXIBLE PHOTOVOLTAIC MODULES

Ivana Radonjic[1,2], Nemanja Pudar[3], Milutin Petronijevic[4], Tatijana Dlabac[3], Ilija Knezevic[3]

[1]Faculty of Sciences and Mathematics, University of Niš, Višegradska 33, 18000 Niš, Serbia
[2]Center of competence "Smart mechatronic, eco- and energy-saving systems and technologies", Gabrovo, Bulgaria
[3]Faculty of Maritime Studies Kotor, University of Montenegro, Put I Bokeljske brigade 44, 85330 Kotor, Montenegro
[4]Faculty of Electronic Engineering, University of Niš, Aleksandra Medvedeva 4, 18000 Niš, Serbia

……
**Corresponding author: ivana.radonjic-mitic@pmf.edu.rs*

Abstract
For the purpose of maritime sector decarbonisation and creation of environmentally responsible and sustainable marine systems (and environment), photovoltaic (PV) modules became a good solution to be applied on vessels. However, in such conditions PV modules are exposed to sea salt conditions (seawater and salt spray) that can decrease their electric output, whereby corrosion and coloring can also appear. In circumstances of increased utilization of PV modules in marine environments, research of sea salt influence on PV modules power output became a more frequent topic in scientific literature. Research in operational, but also in laboratory conditions can provide very valuable information about the influence of the marine environment on the electrical characteristics of dedicated PV modules used in these specific conditions. The experiment on sea salt effects on PV modules output was performed on the roof terrace of the Faculty of Maritime Studies Kotor, University of Montenegro. Two identical flexible monocrystalline silicon 330 Wp PV modules were used in order to compare electrical characteristics of clean and PV modules covered with sea water. After seawater evaporation, sea salt crystals remained on PV modules' front surface. The experiment demonstrated that repetitive spraying of seawater does not have considerable influence on a PV module's output.

Keywords: PV module, sea salt, seawater, electrical characteristics, output power.

INTRODUCTION

Due to traditional energy sources depletion and geopolitical uncertainty, countries around the world have started to diversify their energy portfolios increasing the share of renewable energy sources (RES) whereby photovoltaic (PV) technologies represent a great majority of renewable energy share [1].

In the era of worldwide general decarbonisation trends in all sectors, generating environmentally responsible and sustainable maritime transport is also of high importance [2].

With bringing in restrictive legislations by the International Maritime Organization (IMO) and European Union that require from vessels designers and owners to utilise non fossil fuels solutions for vessels' propulsion systems [3], interest for RES application is rising [4]. Among RES, PV technology came up as a convenient solution for maritime applications [5]. Beside the fact that the initial price of solar-powered vessels

This is an open access article licensed under Creative Commons Attribution 4.0 International
Print ISSN: 1313-230X, Online ISSN: 3033-1404

is higher in comparison to diesel-powered ships, solar-powered vessels have numerous advantages such as low operating costs, electricity production aligned with peak demand, no emissions, etc. [6]. However, unique maritime environments bring its own specificities and challenges in which after long-term utilisation, PV modules performance and reliability may become lower [5]. Namely, PV modules applied on vessels are supposed to be resistant to salty conditions, high humidity, extreme wind [7] and considerable temperature difference between day and night [5].

The marine environment poses specific circumstances like salt deposition that can induce not negligible effects on PV module performances. In such a complex environment with waves, tides and salt spray, PV modules have to be with higher durability and the stability of the whole PV system can be more demanding. Distribution and shape of sea salt deposition on PV modules surfaces are uncontrollable due to unpredictable seawater splashing on modules accompanied by evaporation and salt crystals left behind. In outdoor surroundings such as marine environments, it is not possible to control environmental factors. Likewise, certain environmental elements influencing photovoltaic power production are closely coupled (e.g. wind speed increase may decrease PV modules surface temperature; increased relative humidity may worsen scattering losses and reduce illuminance; as illuminance increases, relative humidity has affinity to decrease) [8].

PV modules in marine environments can be also affected by corrosion on the modules front glass that have considerable effects on the optical transmittance and power output of PV modules. On vessels, PV systems are usually installed on upper-deck structures that are above the splash zone which lowers direct wave-splash and intermittent wetting compared to nearwater photovoltaic systems [9].

In unbounded and ecologically diverse maritime environments, besides saline conditions and corrosion there are more elements which may influence PV modules output such as high relative humidity, strong winds, occasional extreme events, etc. [10].

With enhanced frequency of PV systems installations in marine environments, the number of studies concerning sea salt influence on PV modules in scientific literature has slightly increased. However, most of these papers consider floating PVs in marine ambience, while impact on PV systems mounted on vessels is not so common. Setiawan et al. within three days compared referent PV modules and modules exposed to saline environments and discovered that the average power of modules with salt deposits reduced by 1.3778 W (efficiency drop of 0.948%) [11]. Gao et al. showed that at an illuminance of 100,000 lx, PV modules power decline rate was 9.69% with salt deposition area proportion of 10%, and 14.52% with salt area proportion of 20%. Furthermore, with the illuminance reduced to 20,000 lx, the power decline rates rose to 48.91% and 70.29%, respectively [8].

Having in mind that in available scientific literature there is not much research on sea salt deposition and PV modules power output [8], this paper makes literature contribution since its aim is to present the influence of the maritime environment, more specifically the influence of sea salt deposits on the power output on PV modules.

MARINE ENVIRONMENT EFFECTS ON PV MODULES

In marine environments, after waves splash seawater on the PV modules, a certain amount of seawater stays on the modules surface. In marine environments characterised by strong offshore winds, PV modules usually have higher surface temperature and consequently seawater evaporates quickly resulting in salt crystallisation leaving sea salt deposits that adhere to the front surface of PV modules. Sea salt deposits block solar radiation and reduce PV modules efficiency. Seawater

distribution on PV modules depends mainly on wave conditions, but also on PV system structure and position, making measuring of sea salt distribution and mass challenging [8].

Offshore wind loads are significantly larger compared to the inland regions, generating both lift and drag forces [10]. Wind speed affects PV modules power output mostly through the influence on modules surface temperature. Although offshore wind speeds are high, wind influence on PV modules power output in marine environments is not of the main influence [8].

However, in marine environments there is a concern connected with the height of waves, that represents a function of wind speed and its extensions. It is well known that the wind is inextricably linked with the waves. Blowing wind perturbs the sea surface through friction and pressure variations, resulting in waves. Waves and currents may cause the appearance of microcracks in PV module glass and silicon cells. Glass microcracks can cause water leakage, and consequently oxidation of circuits, increased resistance, and reduced power output [10].

In marine environments, corrosion of metallic parts and electrical contact interfaces may enhance contact resistance and induce connector/junctionbox damages and insulation degradation as well as associated safety risks. Metals corrosion and its mitigation in marine environments, including selection of materials, protective coatings, sealing, and corrosion-aware design, are examined in engineering practices. In the case of inappropriate management, conditions in marine environments may shorten PV systems service life and decrease long-term energy yield and reliability [9].

PV technology that demonstrated the highest sensitivity to seawater so far is Copper Indium Gallium Selenide (CIGS) [10].

EXPERIMENT

The experiment concerning sea salt deposits' influence on PV modules output was performed on the terrace located on the roof of the Faculty of Maritime Studies Kotor, University of Montenegro. Two identical flexible PV modules were used in order to compare electrical characteristics of clean and PV modules covered with sea salt.

Table 1. *Main technical characteristics of the flexible monocrystalline silicon PV modules used in the experiment*

Parameter	**Value**
Module dimensions (L x W)	1917 × 1020 mm
Rated maximum power (P_{mmp})	330 Wp
Maximum Power Point Voltage (V_{mpp})	37.29 V
Maximum Power Point Current (I_{mpp})	8.95 A
Open-circuit Voltage (V_{oc})	45.19 V
Short-circuit Current (I_{sc})	9.48 A
Operating temperature range	−40°C to +85°C
Temperature coefficient of P_{mpp}	−0.34 % / °C
Temperature coefficient of V_{oc}	−0.25 % / °C
Temperature coefficient of I_{sc}	+0.03 % / °C

Composite super light PV modules made of monocrystalline silicon power of 330 Wp were used in the experiment (Table 1).



Fig. 1. *PV modules used in the experiment conducted on the roof of the Faculty of Maritime Studies Kotor*

According to the producer claims, selected PV modules are salt resistant and

provide stable performance even in heat and dusty (soiling) conditions [12], whereas salt deposits represent a type of PV modules soiling.

The experiment was conducted on a sunny day with clear sky to avoid shading conditions. Before the measurements started both PV modules were cleaned. Afterwards, one module remained clean, while the other one was sprayed with seawater until totally covered (Fig. 1). The Faculty of Maritime Studies Kotor is located on the coastline of the Boka Bay, where seawater was taken from. When seawater sprayed on PV modules front surface evaporated, sea salt deposits remained that caused a certain influence on modules power.

RESULTS AND DISCUSSION

In this paper, the results of investigation of sea salt deposits effects on PV modules power output are given.

Fig. 2 shows the distribution and shape of sea salt deposits on PV modules front surface after seawater spraying and consequential evaporation. In the experiment, distribution of sea salt was additionally considered after several subsequent sprayings.



Fig. 2. *Distribution and shape of sea salt deposits on PV modules front surface*

It was determined that in every next spraying distribution of sea salt deposits was similar because spraying added new salt amounts, but also partially removed previous deposits due to seawater pressure induced by spraying.

Fig. 3 presents solar radiation intensity during the experiment period. The experiment was performed in a timespan longer than two hours, where it can be seen that solar radiation intensity was increasing until noon, and afterwards started to decrease, as expected.

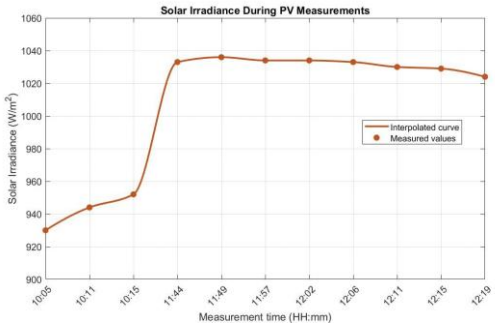


Fig. 3. *Solar radiation intensity during the experiment timespan*

Fig. 4 shows the power of the clean PV module and the module covered with sea salt deposits during the experiment period.

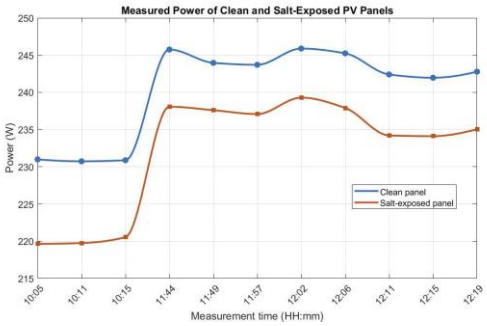


Fig. 4. *Power of the clean and PV module covered with sea salt deposits during the experiment period*

PV modules average power decrease due to coverage with sea salt deposits was 3.46%. Obtained results support producers' claim that PV modules selected for this experiment provided stable performance in salty soiling conditions.

Additionally, it can be seen from Fig. 3 and Fig. 4 that power of clean and PV modules covered with sea salt deposits follow the trend of solar radiation intensity, as expected.

In experiment it was also shown that repetitive seawater spraying does not have

considerable influence on a PV module's power output.

CONCLUSION

Due to restrictive legislations that require vessels designers and owners to utilize non-fossil fuels solutions, PV technology came up as a convenient solution in maritime applications. Although the initial price of solar-powered vessels, they have numerous advantages like lower operating costs, electricity production aligned with peak demand, no emissions. Still, in specific maritime environments characterised by salty conditions, high humidity and extreme wind, PV modules performance and reliability may become lower. This paper studies the influence of the maritime environment, more specifically the influence of sea salt on PV modules power output. The experiment was conducted on the roof terrace of the Faculty of Maritime Studies Kotor, University of Montenegro with two identical flexible PV modules one of which was covered with sea salt deposits. It was recorded that the average power decrease of PV modules due to coverage with sea salt deposits was 3.46%. This result is in alignment with the PV modules producers' statement that they provide stable performance and withstand well salty conditions. According to the obtained results, these purpose-designed lightweight PV modules represent a convenient option for application on vessels with low power output decrease in the maritime environment due to salt presence. It was also concluded that repetitive seawater spraying does not have a significant impact on a PV module's power output.

In the light of research presented in this paper, future work could consider integration of this type of PV modules in vessel microgrids and investigating the effects of marine environment on the whole PV system.

ACKNOWLEDGMENTS: *This paper was done with the support of the Ministry of Education, Science and Innovation of Montenegro through the Excellence Scholarship Program for Doctoral Research in Montenegro; of the Agreement 451-03-33/2026-03/200124 on the realization and financing of scientific research work of the Faculty of Sciences and Mathematics, University of Niš in 2026 by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia; and the European Regional Development Fund within the OP "Research, Innovation and Digitalization Programme for Intelligent Transformation 2021-2027", Project No BG16RFPR002-1.014-0005 Center of competence "Smart mechatronics, eco- and energy-saving systems and technologies".*

REFERENCE

[1] S. A. Ali Rizvi, A. K. Janjua, A. A. Ansari, M. U. Bin Ahmed, H. A. Raza, G. Abbas, Assessment of salt-induced performance decline in floating photovoltaics in marine environments: Experimental analysis of electrical degradation, design and techno-economic implications, Renewable Energy 260 (2026) 125189.

[2] N. Pudar, I. Radonjić, M. Petronijević, T. Dlabač, I. Knežević, Photovoltaic panels in maritime sector, International Scientific Conference "UNITECH 2025" – Gabrovo, 20-22 November 2025, Selected papers.

[3] Z. Zapałowicz, W. Zeńczak, Seawater cooling of PV modules mounted on ships in Świnoujście/Poland harbour, Heliyon 8 (2022) e10078.

[4] Z. Zapałowicz, W. Zeńczak, The possibilities to improve ship's energy efficiency through the application of PV installation including cooled modules, Renewable and Sustainable Energy Reviews 143 (2021) 110964.

[5] Y. Zhang, C. Yuan, Effects of marine environment on electrical output characteristics of PV module, Journal of Renewable and Sustainable Energy 13, 053701 (2021), https://doi.org/10.1063/5.0060201.

[6] O. Petrychenko, M. Levinskyi, S. Goolak, V. Lukoševičius, Prospects of Solar Energy in the Context of Greening Maritime Transport, Sustainability 2025, 17, 2141, https://doi.org/10.3390/su17052141.

[7] I. Kobougias, E. Tatakis, J. Prousalidis, PV Systems Installed in Marine Vessels:

Technologies and Specifications, Advances in Power Electronics, Volume 2013, Article ID 831560, http://dx.doi.org/10.1155/2013/831560.
[8] X. Gao, Y. Li, M. Liu, J. Lian, Q. Ma, J. Zhang, S. Wu, Y. Cui, An exploratory framework for analyzing the impact of salt deposition on offshore photovoltaic system, Renewable Energy 242 (2025) 122439.
[9] Z. Lv, G. Hu, Y. Zhang, L. Lu, Z. Yu, J. Li, Seawater-induced deposition and corrosion of PV glass and their impacts on module performance, Solar Energy 312 (2026) 114626.
[10] A. Djalab, Z. Djalab, A. El Hammoumi, G. M. TINA, S. Motahhir, A. A. Laouid, A comprehensive Review of Floating Photovoltaic Systems: Tech Advances, Marine Environmental Influences on Offshore PV Systems, and Economic Feasibility Analysis, Solar Energy 277 (2024) 112711.
[11] F. Setiawan, T. Dewi, S. Yusi, Sea salt deposition effect on output and efficiency losses of the photovoltaic system; a case study in palembang, Indonesia, J. Phys. Conf. 1167 (1) (2019) 12028, https://doi.org/10.1088/1742-6596/1167/1/012028.
[12] https://das-energy.com/en/services/datasheets, Accessed: 2026-10-13.