Results in Physics 12 (2019) 914–916

Contents lists available at ScienceDirect

Results in Physics

journal homepage: www.elsevier.com/locate/rinp

Microarticle

Model to estimate the potential and performance of Wavevoltaics

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ARTICLE INFO

Keywords:
Wavevoltaics
Novel wave device
PV on wave device
Novel PV installation
Wave floats for PV
PV in water
Aquavoltaics
Floating PV

ABSTRACT

A new concept called Wavevoltaics is proposed by integrating the photovoltaic (PV) cells over the vacant open sky surface of wave devices. This article is intended to deliver the conceptual view of modelling this device and a method to estimate the available power potential and to evaluate the performance of Wavevoltaic device.

Introduction

Recent advancements in solar energy utilization shows the technology progress in all aspects, typically the PV cell development, PV array installation, and applications on energy utilization. Currently, the PV cell technology is much advanced when compared to the earlier developments seen with crystalline silicon. Many of us have seen the progress in solar PV panels that can even fit into the urban infrastructure making the skyscrapers into power generators [1]. This is due to the flexible nature of thin film PV cells and the advancements seen in materials. The latest developments in the PV array installations are Agrivoltaics, Aquavoltaics, Building Attached Photovoltaics, Building Integrated Photovoltaics, Floatovoltaics, and Submerged PV [1–5]. These developments are mostly influenced by the land use conflicts between PV and other relevant sectors. In this article a novel concept of PV installation i.e., Wavevoltaics is proposed. The main motivation for developing this conceptual hybrid energy device is the Floatovoltaics and Submerged PV. This new concept called Wavevoltaics shown in Fig. 1, is formed by integrating the PV cells over the vacant surfaces of wave devices. These devices can float on the ocean surface or submerged in deep waters, which is quite different from the Floatovoltaics. In Wavevoltaics, PV modules doesn't require any external floating bodies and solely depends on the open sky area of wave device where as in the case of Floatovoltaics they require external floating bodies. Design of Wavevoltaics is mostly influenced by the wave device type. The currently available thin film PV cells are flexible in nature and can easily fit onto the vacant spaces available on the wave device top surface that is elevated to the open sky. The operation and working principle of wave device remains the same and after the integration of PV cells they mostly works on the combined principles of wave energy conversion and photovoltaic energy conversion. Depending upon the wave device these operating principles varies, and they are bobbing principle, hydraulic flapping principle, mechanical flexing, overtopping principle and pressure differential principle and whereas for PV cells it is photovoltaic effect [6]. Most appropriate conversion system for wave energy would be the linear generators. The same type can be adopted in developing the Wavevoltaics and scope for developing the Wavevoltaics arrays as shown in Fig. 2 is high and depends on the wave potentials.

Methods

A mathematical model that estimates the potential and evaluate the performance of this new design that is Wavevoltaics is presented in this section. The wave power available for harnessing is given by the Eq. (1) and the PV installation capacity is given by Eq. (2) [7,8].

$$Wave\ Power = \frac{g^2 * \rho * T * H^2}{32 * \pi} \tag{1}$$

where, wave power in W/m or kW/m is the function of acceleration due to gravity i.e., $g = 9.8\,\text{m/s}^2$; ρ is water density i.e., $1025\,\text{kg/m}^3$; H is twice the wave amplitude and height of the wave in m; wave group velocity; T is wave period; and angular speed.

$$PV\ Capacity = A_{PV_{type}} * \beta_{PV_{type}} \tag{2}$$

where, PV capacity is expressed in Wp or kWp (this typically refers to the maximum allowable PV installation capacity over the vacant spaces of wave device); $A_{PV_{type}}$ is the vacant space available on the wave device for specific PV type in Sq. m; and $\beta_{PV_{type}}$ is the factor that relates the area to PV peak power capacity for PV technology type. Here the $\beta_{PV_{type}}$ factor is introduced because of PV cell area variation seen with respect to its rated power capacity for crystalline, thin film, organic etc. Using the Eqs. (1) and (2), the power capacity or the potential for Wavevoltaics

https://doi.org/10.1016/j.rinp.2018.12.057
Received 10 November 2018; Received in revised form 26 November 2018; Accepted 12 December 2018

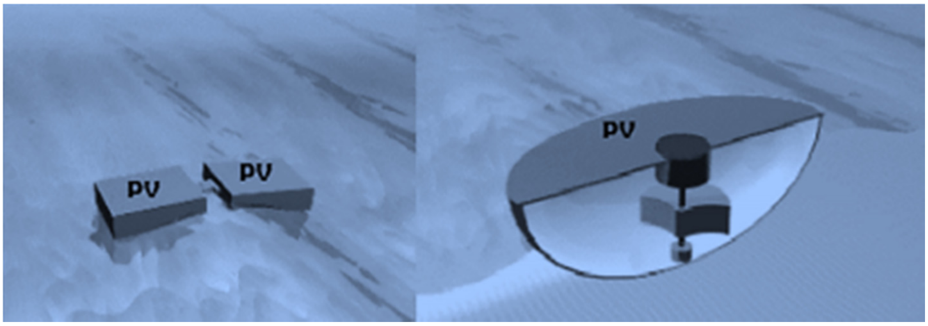

Fig. 1. Wavevoltaics devices [6].

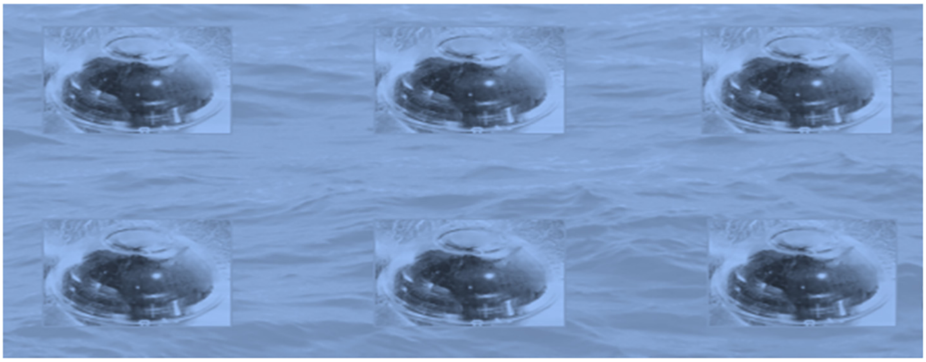

Fig. 2. Wavevoltaics array (Schematic view).

device can be estimated. The energy generationed from the Wavevoltaics device needs two different mechanisms: 1). the wave energy generation considered here is based on the linear generator concept (Buoyant moored devices generally uses the linear generator concept) and, 2). the PV energy generation based on the light energy conversion into DC electricity. The power generation is possible in two different channels one from a linear generator and other from PV cells but however, the power at the output can be connected to a single channel by using the power electronic devices. The power rating of the linear generator can be selected as per the available wave potential. Power available by linear motion of the generator (LG) in wave device is given by the Eq. (3) [9].

$$LG_{Power} = F * S \tag{3}$$

where, F is the force which is usually from the power take-off (PTO) unit of the wave energy generation system, and S is the speed or displacement of the floater. Mostly, in wave devices, the PTO unit is designed for high forces and low speeds. There is a possibility of power loss and efficiency issues, typically the efficiency of assumption would be 50% or less than it. The expression for power loss due to friction caused by the bearings is given by Eq. (4) [9].

$$Power_{Loss\ due\ to\ Friction\ in\ LG} = F * S * fc_b \tag{4}$$

where, fc_b is the friction caused by bearings in the linear generator. This parameter contributes to the power losses in the wave device.

The power from the PV system is given by the Eq. (5).

$$PV_{power} = A_{PV_{type}} * \eta_{PV} * I_{eff} \tag{5}$$

where, η_{PV} is the efficiency of the PV cell technology used in the Wavevoltaics device; I_{eff} is the effective solar irradiance incident on the Wavevoltaics device considering the beam irradiation I_b, diffused irradiation I_d, reflected irradiation with a reflectance coefficient α. Also, the effect of albedo is to be considered as our device is floating on the water surface. The effective irradiance I_{eff} that is incident on the PV cell surface in the Wavevoltaics is given by Eq. (6) [10]. Here, θ_i is the incident angle, θ_t is the angle of installation at which PV cells are tilted on the wave device vacant surface, θ_z is the zenith angle, P_1 and P_2 are the statistical coefficients that define the degree of circum-solar and horizon anisotropy given by the Perez's in [11].

$$\begin{aligned} I_{eff} = \Bigg(& \left(I_b * \left(\frac{\max(0,\ cos\theta_i)}{\max(0.087,\ cos\theta_z)}\right)\right) \\ & + \left(I_d * \left((1 - P_1) * \left(\frac{1 + cos\theta_t}{2}\right) + P_1 * \left(\frac{\max(0,\ cos\theta_i)}{\max(0.087,\ cos\theta_z)}\right)\right.\right. \\ & \left.\left. + P_2 * sin\theta_t\right)\right) + \left((I_b + I_d) * \alpha * \left(\frac{1 - cos\theta_t}{2}\right)\right)\Bigg) \end{aligned} \tag{6}$$

Efficiency of the PV system that is embedded in Wavevoltaic device is given by the Eq. (7) [10].

$$\begin{aligned} \eta_{PV} = \eta_{inv} * \eta_{loss} * \eta_{ref} * & \left(1 - K_T * \left(\left(T_{WC} + \left(\frac{T_{NOCT} - 20}{800}\right) * I_{eff}\right)\right.\right. \\ & \left.\left. - T_{ref}\right)\right) \end{aligned} \tag{7}$$

If the Wavevoltaic system is designed for generating the AC electricity, the inverter efficiency (η_{inv}) is considered in the equation. Here, η_{loss} is the total losses possible in a PV system, η_{ref} is the reference efficiency of the PV cell at standard test condition, K_T is the thermal coefficient of the PV cell as per selected technology, T_{NOCT} is the maximum temperature that will be attained by the PV cell as per the manufacturer in °C, T_{ref} is the 25 °C, and T_{WC} in °C is the wind chill temperatures possible on the water surfaces (lower when compared to the ambient temperatures possible on the land surface, in general $T_{WC} < T_{ambient\_temperatures}$) [10].

Conclusion and future research

A performance method considering the weather and system configuration parameters for Wavevoltaics is given. The method shown here is the combination of wave energy device performance and solar PV performance modelling. However, this method can further be modified based on the type of wave energy converter used in hybrid combination with PV to form Wavevoltaics. Also, based on the selected linear generator the power equation for wave energy channel can be modified. Future research directions will be on developing an experimental prototype, scaling up, safeguarding the Wavevoltaics from the sea-fouling, degradation due to seawater and mineral depositions. Power conversion and control strategies would be another research direction for improving this concept.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rinp.2018.12.057.

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