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Nearshore wave energy converters comparison and Mediterranean small island grid integration

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ABSTRACT

The aim of the paper is to preliminary analyse the performance of several nearshore Wave Energy Converters (WEC) sited in the west coast of Sicily close to the Favignana island's shorelines. In particular, the four WEC technologies that have been considered are Wave Star, Oyster, Wave Dragon and Archimedes Wave Swing. The power performance assessment has been developed through the comparison of various scaled versions of the WEC using a proved scaling process based on the Froude similitude. The best device for Favignana's wave climate has resulted to be the Wave Dragon with a rated power of 500 kW. Then, the evaluation of the Wave Dragon's effect on the off-grid system of Favignana has been analysed by means of the HOMER software. The current mix of production and the electric load of the island have been modelled on HOMER and the introduction of the Wave Dragon with and without a battery energy storage has been analysed. The obtained results underlined that high fuel savings and emission reductions can be achieved. The study has been carried out in the context of the PRISMI (*Promoting RES Integration for Smart Mediterranean Islands*) international project funded by the Interreg-MED EU programme.

Introduction

In recent decades, environmental concerns have pushed mankind to be more innovative in finding new and more eco-friendly energy sources to replace the fossil fuels that we are so heavily dependent on [1]. Global energy demand is expected to increase by 35% between 2010 and 2040 [2] which adds a greater stress to find alternative energy sources. In this research, ocean has acquired a great importance thanks to its great potential due to the vastness of the source and to the different options to exploit it. In fact, energy from the sea can be exploited in several ways, namely from waves, tides, temperature and salinity gradients. In this framework, Wave Energy Converters (WEC) have emerged as a promising technology and have the potential to contribute large quantities of low emission renewable energy [3] but they have also presented one of the most challenging technological problems of the 21st century [4,5].

Many typologies of WEC have been developed for the use of wave energy [6] both for offshore and coastal areas [7] and currently represent a possible solution for European countries to achieve the objectives of Directive 2009/28/EC, which endorsed a mandatory target of 20% of energy from renewable sources within the overall European Community by 2020 [8], and in particular to get the targets of greenhouse gas emissions reduction reported in the 2030 EU Energy Strategy and the 2050 EU Energy Roadmap.

There are many different classification for WEC based on the working principle, the size or the location. Regarding the location categorizing principle they should be categorized as onshore, nearshore and offshore devices, depending also on their depth water in addition to just the location [9,10]. This work focuses on nearshore WEC that are defined as devices that works in relatively shallow water, Drew et al. [11] suggested that the definition could be a depth of less than one quarter of the wavelength.

Considerable work has been undertaken on wave energy assessment around the world. According to Thorpe et al. [12], the potential worldwide wave power is estimated to be 2 TWh. The most powerful sites identified are of course in open seas and oceans, in particular most energetic areas are the Indian Ocean, North Atlantic and North Pacific [13], i.e. USA [14], Canada [15], Korea [16], Australia [17] and Malaysia [18]. Sheltered and semi-sheltered seas usually have a limited wave energy potential but in many cases it has been proved that it can still be suitable for energy exploitation [19] such as in the Black Sea [20], the Baltic Sea [19], the Eastern Mediterranean Levantine Basin

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Nomenclature

WEC	Wave Energy Converter
PV	Photovoltaic
G_f	diesel generators hourly fuel consumption [l/h]
P_0	diesel generator power output [kW]
P_n	diesel generator nominal power
X	diesel generator fuel curve slope [l/kWh]
Y	diesel generator fuel curve intercept coefficient [l/kWh]
P_{PV}	PV power output [kW]
P_{PVp}	PV system peak power [kW]
f_{PV}	PV derating factor [%]
G_T	solar radiation incident on the PV array in the current time step
$G_{T,STC}$	solar radiation incident on the PV array under standard condition
α_P	temperature coefficient of power [%/°C]
T_c	PV cell temperature in the time step [°C]
$T_{c,STC}$	PV cell temperature under standard condition [°C]
H_m	significant weight height [m]
T_p	peak wave energy period [s]
T_e	significant wave energy period [s]
HS	Hot Spot
C_f	capacity factor [%]
R_f	rated capacity factor [%]
AEP_{WEC}	WEC annual energy production [MWh/y]
Fr	Froude number
λ	geometric scale factor between the prototype and the model
P_{proto}	rated power of the prototype [kW]
P_{model}	rated power of the model [kW]

[21], the Beibu Gulf in China [13], the Caspian Sea and the Persian Gulf on Iranian coastlines [22–24].

As regard the Mediterranean sea many studies have been undertaken [25–29], the wave energy resource contribution in Spain, France, Italy and Greece is totally estimated as 30 GWh [30]. In particular, Italy has a geographical position that allows the exploitation of different sources of renewable energy, including waves, mainly due to the significant length of the Italian coastline [30]. Currently Italy still imports oil and gas and requires about 11–12% of electricity from other countries. On the other hand, the energy production using Renewable Energy Sources (RES) is increasing and currently covers about 18–19% of the total energy production [31]. Moreover, the use of storage systems [32,33], including high performance batteries power to gas options [34,35] and CO_2 methanation processes [36] is facilitating a further development of variable renewable energy sources [37], including waves, both for electric and thermal needs [38,39].

The highest wave energy potential in Italy is mainly located in the west coast of Sardinia and Sicily [40], in particular, the values of wave power onshore have been estimated as 10 kW/m on the west coast of Sardinia and 4.5 kW/m on the west coast of Sicily [31,40].

In this context, the aim of the present work is to analyse four different nearshore WEC technologies for the wave energy exploitation on Favignana Island, located on the west coast of Sicily. A scaling process has been used in order to find the best technology and size for the specific site. HOMER software has been used to analyse the impact on the case study island's grid.

Methodology

In order to evaluate the effect of wave energy exploitation on Favignana Island’s standalone grid, precise steps have been followed. First, the specific location has been studied in terms of electric load and RES potential, namely solar and wave. The second step consisted in the analysis and comparison of four different WEC technologies by means of a scaling process. Once the best fitting technology and size had been identified its impact on Favignana’s energy system has been evaluated by means of the HOMER software. HOMER is a powerful software for hybrid energy system analysis that has been developed by the US National Renewable Energy Laboratory (NREL). It is one of the most used software to calculate the energy performance of grid connected and stand-alone energy systems. HOMER is mainly used for its optimisation tool. It works by analysing and comparing different energy system configurations by running several simulations at the same time in order to compare the system performance from both technical and economic point of views, HOMER is also a powerful tool for sensitivity analysis.

Two different scenarios have been analysed and compared with the baseline scenario (represented by the current energy supply system) in order to analyse the benefits introduced by an energy storage system. The same order has been followed in this paragraph to describe the research methodology.

Site description and load estimation

Favignana island has been chosen as a case study to perform the WECs analysis and the effect of wave energy production on an off-grid system. Favignana is located on the west coast of Sicily, latitude 37°55′N longitude 12°19′. With a surface of 19.8 km^2 it is the main island of the Aegadian archipelago and it is 17 km far from the Sicilian mainland (Fig. 1).

Favignana presents the typical South Mediterranean climate: hot and dry during summer and mild in winter, while rainfall are moderate and concentrated in coldest seasons. The climate is perfect for the exploitation of the solar resource with a horizontal yearly irradiation of 1300 kWh/m^2 [42]. Furthermore, Favignana presents an interesting wind potential recording average wind speed at 25 m height between 6 and 7 m/s [42]. The energy system strongly depends on fossil fuel since the grid is not linked to the mainland and the island's load is covered by seven diesel generators with a total power installed of 12.03 MW. Particularly, five generators have been designed to have a nominal power of 1.89 kW while the other two have a nominal power of 1.29 kW [43]. Furthermore, in the island there is a small production from RES, due to 25 Photovoltaic plants (PV) with a total power installed of about 170 kW_p.

Load data estimation has been the first step for the assessment of the impact of a WEC on the grid.

The sector with the highest energy consumption is the marine transport that causes an annual diesel consumption of 49,647.5 MWh/y [43]. The annual electric consumption is equal to 12,563 GWh/y while the one for thermal purposes is equal to 3410.5 MWh/y and is entirely due to natural gas [43]. As regard the electric consumption, the most consuming sectors is the residential one that accounts for 41% of the overall electric consumption. Then, tertiary buildings and municipal buildings are the second and third most consuming subsector with 32% and 23% respectively. A minor relevance have public lighting and industry that accounts for 3.5% of the whole annual electric consumption [43].

Monthly data (Fig. 2) has been obtained starting from the information reported in the Sustainable Energy Action Plan of the island [43].

The analysis highlighted the strong seasonality of the load, the ratio between a summer month load and a winter one reaches the maximum value of 3.5. Such value is absolutely comparable to the touristic fluxes that, in summer months, make the population on the island rise by three