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Electrical utilization through Wave Energy

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ABSTRACT- This systematic review starts with the purpose of offering a study on the use of wave energy in the coastal zone. Scopus, ScienceDirect, EBSCO and IOP Publishing search engines were used to collect information, starting with an unfiltered search of the topic to be investigated, thus obtaining a total of 10,125 documents; After applying a series of filters through the PRISMA selection process, a total of 31 articles were obtained, which were used for the final development of the systematic review. Finally, it is concluded that the use of a wave energy converter will depend on several factors: the type of converter, the areas where the converters are more efficient and the nature of the waves.

KEYWORDS: wave energy, waves, energy converter.

I. Introduction

In the past, hydrocarbons had been regarded as a reliable source because of their abundance and low cost, but today they are considered as a source of polluting and limited energy, the first is due to the climate change caused by the greenhouse gases they emit and the second is because the reserves of these fossil fuels are increasingly being spent due to the growing demand for energy, leading to a future shortage of these resources. In the face of these problems, renewable energies are increasingly becoming the best option as the main source of energy. The idea of using renewable energy as an alternative arose in the 1970s [1], when the world oil crisis occurred. From there a great effort was manifested especially in research and development activities, including other energies. This led to progress in narrowing the gap between renewable and non-renewable energies. The constant climate change due to the increase of the global temperature makes necessary a radical change regarding our use of non-renewable energies to avoid consequences that our planet and we can regret. One of the renewable energy sources is wave energy (wave-driven energy). Ocean waves are an enormous energy resource, largely untapped, and have the potential to extract unlimited energy, so it is now used in the drive of electric converters. At present there is a wide variety of prototypes of wave energy converters, from which it is known that the first wave energy converter was patented in 1799 [2]. There is a wide variety of wave energy technologies that are related to many factors, such as the depth and location of water (coast, near shore, offshore). One aspect to emphasize would be that the energy density contained by sea waves is higher than solar and wind energy, which is an average of 100 kw/m. The global energy potential currently reaches 10 Twh, with an annual energy potential that can generate up to 93000 Twh [3]. The purpose of this systematic review is to provide a study on the use of wave energy in the coastal zone.

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II. Methodology

For the collection and selection of information for the systematic review, the PRISMA selection process was used, from which the question is formulated: How does the converter use wave energy in the coastal zone? This selection will be divided into 3 stages, each of which will offer a reduction in the number of sources taken initially, ultimately reaching a defined number of sources to be used for this systematic review.

Search engines such as Scopus, ScienceDirect, IOP Publishing and EBSCO were used to collect the information. These search engines were distributed among the 4 members of the group.

Stage 1

At this stage, we started with a filter-free search of the subject to investigate, obtaining 5101 results for Scopus, 3085 for ScienceDirect, 909 for EBSCO and 1030 for IOP Publishing: resulting in a total of 10125 documents.

Scopus

"wave energy converter" OR "wave energy converter"

EBSCO host - Science Direct - IOP Publishing

"wave energy converter"

Then a filtering was done in the search engines considering the type of document, the age of the documents, region, language, and type of access. Of which the type of document was the article, the antiquity was about 5 years (2017-2022), the regions admitted were all possible all regions, the main language of the article was English, and finally the type of access was free.

Stage 2

At this stage we started with a total of 119 articles divided into 40 for Scopus, 38 for ScienceDirect, 15 for EBSCO and 26 for IOP Publishing, being the result of stage 1. The selection process that was carried out at this stage is to identify similarities or even equalities between the documents, this is because the searches that were independently distributed among the members of the group, so in the end these similarities were found in the titles that each member selected, in addition to also equalities, the latter is probably because an author has uploaded an article in 2 or more browsers that was used. The method used to detect similarities and equalities was by Excel, annotating which titles had similarity and therefore only one of the several that were available could be selected, and in the case of documents that were the same they were simply discarded until you only have one document, for example if you had 2 documents equal then you would only keep one.

In Excel it was detected that for similarities were detected for Scopus 9 articles, for ScienceDirect 10 articles, for EBSCO 3 articles and for IOP Publishing 2 articles: resulting in a total of 24 similarities.

For the equalities were detected for Scopus 5 articles, for ScienceDirect 4 articles, for EBSCO 1 article and for IOP Publishing no article was detected: resulting in a total of 10 equalities.

Stage 3

At this stage, it starts with 21 articles for Scopus, 25 for ScienceDirect, 11 for EBSCO and 20 for IOP Publishing, resulting in a total of 77 documents. From here, an analysis was made of the content of each research, in order to discard those documents that did not focus on the purpose of this systematic review, the analysis included a reading of the summary and a quick reading of the whole document in general, of which the topics that were selected were about the performance of a wave-power converter, a study of a wave-power converter, design and optimization of a wave energy converter, OWS wave energy converter, hydrodynamic analysis of a wave energy converter.

Finally, we obtained for Scopus 8 articles, for ScienceDirect 13 articles, for EBSCO no article and for IOP Publishing 10 articles; resulting in a total of 31 articles that will serve as bibliographic references, in addition to those already collected in the introduction.

Flowchart:

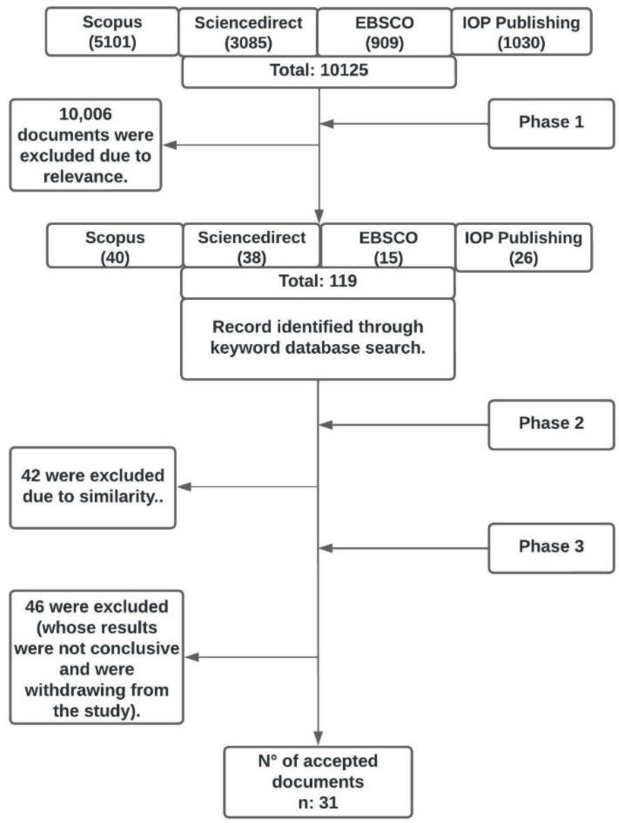

Fig. 1 Papers selection flowchart

A total of 31 articles are available, of which 13 are from ScienceDirect, 10 are from IOP Publishing, and 8 are from Scopus. The articles can also be divided by geographical location of the continents considering that some articles were collaborations of 2 countries, of which 1 was from Africa, 2 were from America, 16 were from Asia, 13 were from Europe, 1 was from Oceania.

If we divided it by year, we would have 3 articles from 2017, 5 from 2018, 5 from 2019, 5 from 2020, 8 from 2021, 5 from 2022. From where we can see that the continent and the year with more articles are Asia and 2021 respectively.

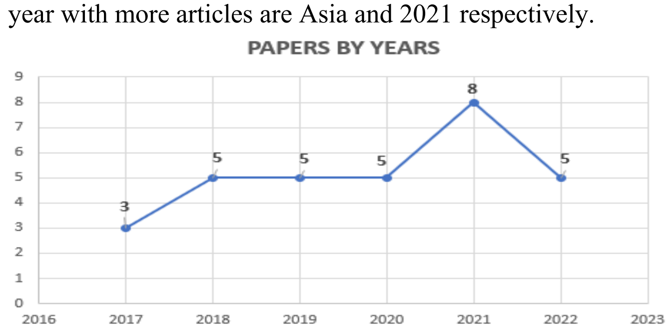

Fig. 2 Papers by years

Finally, we can divide the articles by the scope they cover, of which 7 articles dealt with a mathematical modelling of wave energy converters, 9 dealt with experimental research with the converter, 5 dealt with the dynamics of the wave converter, 4 dealt with the performance of the converter and 6 dealt with other specific areas.

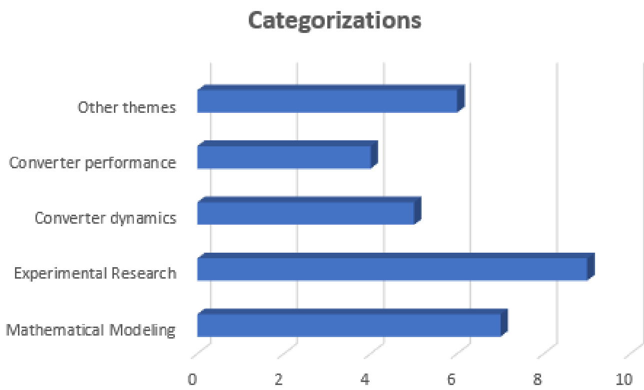

Fig. 3 Article Categorizations

III. RESULTS

TABLE I
BRIEF SUMMARY OF RESEARCH

	Font	Country	Short Summary
1	Jeongrok Kim; Il-Hyoung Cho. 2021	South Korea	The extraction of wave energy has been investigated by multiple wave energy converters (WECs) deployed in a Y-shaped water channel resonator (WCR).
2	Sung-soo Kim; Jae-chul Lee; Donghoon Kang; Soon-sup Lee. 2019	South Korea	An experiment was carried out to study the motion characteristics of a wave energy converter with a wave-activating body type.
3	L. Wilkinson; T.J.T. Whittaker; P.R. Thies; S. Day; D. Ingram. 2017	United Kingdom	Hydrodynamic energy capture with the bottom-hinged flap device was evaluated, based on physical models.
4	Yu Zhou; Dezhi Ning; Dongfang Liang; Shuqun Cai.2021	China	The hydrodynamic performance of a floating cylindrical oscillating water column (OWC) wave energy converter was investigated experimentally and numerically.
5	Kaustubh Khedkar; Nishant Nangia; Ramakrishnan Thirumalaisamy; Amneet Pal Singh Bhalla. 2021	USA	The dynamics of the inertial sea wave energy converter (ISWEC) device were investigated using fully resolved computational fluid dynamics (CFD) simulations.
6	Rong-quan Wang; De-zhi Ning.2020	China	The effects of geometry parameters of the chamber of an oscillating water column (OWC) device, such as front wall draft, chamber width, and aperture ratio (i.e., orifice width), were studied. of air).
7	Nicolas Quartier; Alejandro J.C. Crespo; José M. Domínguez; Vasiliki Stratigaki; Peter Troch.2021	Belgium	The numerical modeling of an Oscillating Water Column (OWC) Wave Energy Converter (OWC) was studied using DualSPHysics, a software that applies the smoothed Particle Hydrodynamics (SPH) method.
8	Qian Zhong; Ronald W. Yeung.2022	USA	A control strategy was established to coordinate the individual WECs and maximize energy extraction by applying Model Predictive Control (MPC) to an array of point damper type WECs.
9	Zhou, Zhimin; Ke, Song; Wang, Rongquan; Mayon, Robert; Ning, Dezhi. 2022	China	A numerical investigation was carried out regarding the response of a wave converter to irregular waves created by a wave channel, where several parameters are compared, such as the hydrodynamic efficiency offered by the converter with regular and irregular waves at various frequencies.
10	Michele, Simone; Buriani, Federica; Renzi, Emiliano; Van Rooij, Marijn; Jayawardhana, Bayu; Vakis, Antonis. 2020	United Kingdom - Netherlands	A mathematical model for the extraction of wave energy from flexible floats was made, where it is then compared experimentally.
11	Castellucci, Valeria; Strömstedt, Erland. 2019	Sweden	The variability of the level of the Baltic Sea in Sweden and the surrounding areas of low frequency was studied over 10 years, this variability decreases the absorption of energy, it was found that the places where there was less variation in sea level are the sea of Bothnia and the Gotland Basin.
12	Wang, Dong; Lu, Kaiyuan. 2018	Denmark	An energy storage system was optimized for the absorption of power fluctuation in order to generate uniform electric power, where the increase in system pressure will increase its efficiency, but also increase costs.
13	Song, Ruiyin; Dai, Yong; Qian, Xiaohua. 2018	China - United Kingdom	An intermittent wave power generation system was introduced that converts unstable wave energy into stable intermittent electrical power, thus improving power quality and converter efficiency.

14	Stokes, Christopher; Conley, Daniel. 2018	United Kingdom	Modeling methods were performed to study the impacts of wave farms on the Irish coast, considering wave climate, beach morphology, and bather surf resource.
15	Hollm, Marten; Dostal, Leo; Yurchenko, Daniil; Seifried, Robert. 2022	Germany - United Kingdom	The dynamics of a wave converter based on a guided inclined point absorber was investigated, where the angle of inclination significantly influences the energy absorption, this absorption being higher than in a standard vertical point absorber.
16	Saenz-Aguirre, Aitor; Saenz, Jon; Ulazia, Alain; Ibarra-Berastegui, Gabriel. 2022	Spain	An analysis was made of the capacity of wave energy converters to increase hydrogen production in hybrid wind and wave farms in the Atlantic Ocean, this is done offshore because its energy resources are more profitable.
17	C. Sun; Z. Luo; J. Shang; Z. Lu; Y. Zhu; G. Wu. 2018	China - United Kingdom	An investigation was carried out on the energy characteristics of waves and the energy storage characteristics of wave energy converters.
18	EA. Bekirov; MM Asanov; E. R. Murtazaev. 2021	Russia	It is proposed on a simple mathematical model of a wave, representing it in the form of a sinusoid.
19	C.Sun; Z. Luo; J. Shang; Z.lue; R. Wang. 2018	China	The current wave energy technology was thoroughly investigated, and the application fields of wave energy technology were classified and summarized.
20	Rupesh PL; Histesh Kumar Rana; Soma Shashidar. 2021	India	The concept of using wave energy in power generation was investigated.
21	Bo Li; Junmin; Junliang; Ping Shing; Wuyang Chen. 2020	China	Wave characteristics on the northeast coast of Dongluo Island, Sanya are investigated.
22	B Triasdian; YS Indartone; NS Ningsih; D Novitasaria. 2019	Indonesia	The present study evaluated selected wave energy converters (WECs) and determined their ability to perform energy capture at the potential site in the Indonesian seas.
23	Yu Huang. 2020	China	The hydrodynamic behavior characteristics of the wave energy conversion device are studied.
24	K Cross; FDator; Jong; N Bumbalang; M. C. Pacis. 2019	Philippines	This study focused on the design and construction of a wave power generation system
25	Zahra Shahroozi; Malin Goteman; Jengs Engstrom. 2022	Sweden	Wave tank experiment of a 1:30 scale point absorption wave energy converter subjected to extreme waves.
26	Jorge Lavida. 2019	Netherlands	Operational availability for wave energy converters (WEC) greater than 60% in milder environments.
27	Hafsa Bouhrim; Abdellatif El Marjani. 2017	Morocco	Analysis of the Atlantic coast wave energy resource and flow behavior within the chamber of an oscillating water column (OWC) device using a numerical flow simulation code.
28	Roberto Mayón; Dezhi Ning; Chongwei Zhang. 2021	Australia	Novel system combines the directionally independent wave energy capture of a cylindrical OWC WEC with the unique energy focusing attribute of a parabolic reflector.
29	Kesayoshi Hadano; Ki Yeol Lee; Byung Young Moon. 2017	Japan - South Korea	The practical use of the wave energy converter, dynamic model to evaluate the electrical power.
30	Bo Zhang; Tao Wang; Zhuo Wang. 2020	China	A wave-driven buoy rolling power device, which has compact structure and convenient installation under the high level of coastal environment and sea conditions.
31	Rizki Mendung Ariefianto; Yoyok Setyo Hadiwidodo, Shadow Rahmawati. 2021	Indonesia	It proposes the WEC oscillating buoy concept based on a direct mechanical drive system, which is designed with a unidirectional gear system to be able to generate power in both the rising and falling wave phases.

IV. Discussions

The wave energy potential (kW/m) depends on the geographical location (height) and the period of the waves. As can be seen in figure XX, the areas that can take advantage of wave energy the most are the areas near the South Pole, such as southern Chile and Argentina; the areas near the Hawaiian Islands; and the western coasts of Europe. On the other hand, the least usable areas are the areas near the Equator.

Fig. 4 Distribution of articles by continents [35]

Research for **mathematical modelling** found that in the case of the nature of waves, regular and irregular waves have a different impact on the efficiency of the converter, depending on their frequencies [4]; we also studied both the climate and the morphology of the beaches, because they can give a considerable impact on wave farms [5]. On the other hand, an PTO system of the Oscillating Water Column Wave Energy Converter was found which is numerically modelled by adding a force on a plate floating on the free surface within the OWC chamber and the air flow velocity to through the hole are compared for different wave conditions and different PTO systems [6]. An application of the analysis of the wave energy resource on the Atlantic coasts and the flow behaviour within the OWC chamber was also found by means of a numerical flow simulation code [7]. Considering the above, a simple mathematical model of a wave was proposed, representing it in the form of a sinusoid, from which we will be told how much energy the converter receives [8], in addition, a dynamic modelling was presented to evaluate the electrical power in the practical use of the wave energy converter [9]; another study evaluated wave energy converters (WEC) selected and determined their ability to realize energy capture at the potential site of the Indonesian seas [10].

For **experimental research** the hydrodynamic performance of a floating cylindrical oscillating water column (OWC) wave energy converter [11], where it was found that wave energy production can be affected by the elasticity of floats influencing the resonance frequency [12]; certain scales were established for the construction of wave tanks of point absorption to be able to take advantage of wave power [13], in addition to new systems for the capture of undimotriz independent directional energy of an OWC - Cylindrical WEC with the particular energy focus attribute of a parabolic reflector [14], also wave-driven buoy rolling power devices with a compact structure at the high level of the coastal environment [15]. In addition, an investigation was conducted into the extraction of wave energy by multiple wave energy converters (WEC) deployed in a Y-shaped water channel resonator (WCR) [16], the investigation allows to take advantage with multiple WEC in the long water channels and a V-shaped wave guide installed at the entrance of a water channel the period of the incident waves coincides with the natural periods of the fluid in a WCR, resonance occurs, As a result, the internal fluid in a WCR is greatly amplified, to estimate wave power [17]; it was also possible to classify according to the fields of application of wave energy technology in three generations [18]. According to this, an analysis is made on the behaviour of the waves and according to these calculations a better location of the converters is made [19], in addition it is possible to explain about the manufacture and operation of a prototype energy converter [20].

In the **dynamics of the wave-motor converter**, wave energy was harnessed by capturing hydrodynamic energy with the lower-hinged flap device, based on physical models, as opposed to a ship-shaped floating hull that was moored to the seabed, internally, a gyroscopic PTO unit converted the wave-induced pitch motion of the hull into electric power [21], the dynamic concept of WEC oscillating buoys based on a direct mechanical drive system designed with a unidirectional gear system to generate power in both the ascending and descending wave phase [22] was also proposed. Through the research methods of theoretical analysis and numerical calculation, the hydrodynamic behaviour characteristics of the wave energy conversion device were studied and the simulation analysis was performed using the hydrodynamic software AQWA [23], energy absorption is also achieved to be greater when the float has an inclination angle as opposed to a vertical one [24], through research methods of theoretical analysis and numerical calculation, the hydrodynamic behaviour characteristics of the wave energy conversion device were studied and the simulation analysis was performed using the hydrodynamic software AQWA [25].

For **converter optimization and performance**, 60% functionality was established for smoother environments [26]. Even optimizations could be made in the converter where the pressure increase increases its performance, but it does so based on higher costs [27]. Sin embargo, otro estudio habló acerca de los requisitos de rendimiento de los convertidores de energía para maximizar la eficiencia operativa y el uso de la energía de las olas [28]. However, another study talked about performance requirements of energy converters to maximize operational efficiency and energy use of waves [29]. An experiment was also carried out to study the motion characteristics of a wave energy converter with a wave activating body type [17].

In other areas, research was conducted on how sea level variability decreases long-term energy absorption [30]. In addition to how these converters increased hydrogen production for offshore hybrid wind and wave farms [31] The effects of chamber geometry parameters of an oscillating water column (OWC) device were also studied, such as the draught of the front wall, the width of the chamber and the opening ratio (i.e., the width of the air hole). On the other hand, a control strategy was established to coordinate the individual WEC and maximize the extraction of energy, applying the predictive control of models (MPC) to a matrix of WEC of type of point damper [32]. Finally, an energy converter was designed and built [33].

V. CONCLUSIONS

How a converter can harness wave energy depends on several factors, one of which is the mechanism used to harness this energy, such as a wave tank, which absorbs points in extreme states of the sea and intermediate depth of water; flexible floats, whose flexibility favours resonant frequency in order to increase the production of wave power; a bottom-hinged flap device, which have several advantages near the coast, such as high energy conversion efficiency and survival ability; an oscillating water column device, in which its OWC-WEC system is numerically modelled by adding a force on a plate floating on the free surface within the OWC chamber; and a system of buoys, which is to be distinguished from the other devices by having a superior structural resistance and a low loss of energy transmission.

Another factor influencing energy use is in areas where converters are most efficient, such as the Indonesian coast, the Atlantic coast, Dongluo Island, the Irish coast, the Bothnian Sea and the Gotland basin.

The use of wave energy can also depend on the nature of the waves, which are divided into regular and irregular waves, in the case of regular waves their efficiency is higher as long as the waves are not acting at low frequencies, which is where irregular waves have a slightly higher efficiency. Island, the Irish coast, the Bothnian Sea and the Gotland basin.

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