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A Review of Power Electronics for Nearshore Wave Energy Converter Applications

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ABSTRACT In compliance with the green energy policy, mitigation from high fossil fuel dependency is becoming a new objective for most countries, including Malaysia. Wave energy is among extensively explored renewable energy relatively clean, sustainable, and inexhaustible resources. To this day, neither definite wave energy technology nor widely available commercial wave farm supplying the grid has existed. Therefore, wave energy harvesting is the most compelling solution, especially in regions where the possibility of grid connection is low in the nearest future. Like other renewable energy, the voltage amplitude and frequency generated from waves are unstable and may vary continuously. This uncertainty has created energy transfer challenges since the grid requires a stable and uninterrupted energy supply. Therefore, power electronics devices are employed to modulate the controller circuits' pulse width. Further understanding of the relationship between wave energy conversion technology and its power conversion, particularly for nearshore applications, is summarized. This work also discussed selected wave energy conversion research and power conversion system implemented and studied in Malaysia. Finally, this review can provide extensive overview and broad understanding into power conversion system for Wave Energy Conversion, especially for nearshore applications.

INDEX TERMS Power converters, power electronics converter, power electronics technology, wave energy, wave energy converter.

NOMENCLATURE

AC/AC	*AC to AC converter.*
AC/DC	*AC to DC converter.*
AC/DC/AC	*Back-to-back Converter.*
AWS	*Archimedes Wave Swing.*
DC/AC	*DC to AC converter.*
DC/DC	*DC to DC converter.*
LG	*Linear Generator*
LIMPET	*Land Installed Marine Power Transmitter.*
OWC	*Oscillating Water Column.*
OT	*Overtopping.*
P.E	*Power Electronics System.*
PA	*Point Absorber.*
PMLG	*Permanent Magnet Linear Generator.*
PTO	*Power Take-off System.*
PV	*Photovoltaic.*
PWM	*Pulse Width Modulation.*
SSG	*Sea Slot-Cone Generator.*
SVPWM	*Space Vector Pulse Width Modulation.*
WAB	*Wave Activated Bodies.*
WEC	*Wave Energy Converter.*

I. INTRODUCTION

An annual increase in energy demand, combined with a reduction in fossil fuel reserves, has encouraged countries globally to seek an alternative solution. Recent developments in renewable energy technology have led to a renewed interest in wave energy harvesting.

Wave energy is harvested using wave energy converter (WEC) devices and converted into electric power through a series of power electronics converters before being

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connected to the grid or loads. Like other renewable energy resources, wave energy is clean, sustainable, and harvested from inexhaustible resources. Considering there is no definite and conclusive WEC design or hardly any commercially run wave farms supplying the grid, this technology's development is therefore vital and worth exploring further. More research has been published in recent years on WEC devices [1]–[19] power conversion [20]–[22] control strategies [23]–[27] economics, cost, reliability, and efficiency [3], [28]–[34] and grid-connected or off-grid [35]–[40].

WEC development is a resolution to mitigate the high fossil fuel dependency, especially in regions where the possibility of grid connection is still uncertain. Malaysia consists of hundreds of small islands, and at present, most of them are heavily dependent on transported fossil fuels. This dependency causes these islands to receive limited hours of electricity daily, thus limiting any economic growth potential and development opportunities. Therefore, installing a WEC system to harvest wave energy on these islands is seen as very promising.

The WEC system and its power conversion are interrelated systems. A suitable power converter system is designed based on WEC output frequency and voltage or current amplitude at the generator side and to match the conditions at the grid or load. This process ensures a smooth power transfer from WEC devices to the grid or loads. This study will help provide an overview and understanding of power conversion systems for nearshore WEC applications.

II. CLASSIFICATION OF WEC

Wave energy is harvested when an incoming wave from all directions is exposed to a WEC device placed in that wave's vicinity. The use of WEC devices to harvest energy contained in the waves is based on their working principles, where these devices can be either fully submerged, half-submerged, or floating in the ocean. The overall wave harvesting process is shown in Figure 1.

Compared to other renewable energy devices, WEC devices are designed based on the prospective location of harvest, whether it is onshore, nearshore, or offshore. These locations are determined by the distance from the shore and the water depth at that particular location. Other considerations before WEC design include seasonal climate change, especially in regions where monsoons are expected, surrounding flora and fauna unique to the location, related government policy, and how these devices are placed and deployed in the water, i.e., submerged or floating.

Onshore WEC devices are usually placed on the shore or attached to a breakwater structure. There are two suitable working principles for this placement, either from water pressure channeled through a chamber in the oscillating water column (OWC) or captured in the form of a reservoir for overtopping (OT) devices. These working principles aim to enhance the wave's pressure for electricity generation purposes. The location's main advantages are the ease of maintenance, exclusion from the high cost of mooring and marine cable, and survivability issues [41]. However, compared to other locations, waves are weakened when approaching the shoreline, thus reducing their energy. Furthermore, shorelines are of high environmental concern because they serve as breeding grounds for various marine life, such as corals and fish, and can have devastating effects on shoreline characteristics [42]–[44]. Among onshore WEC devices are Limpet, deployed in the UK [1] and SSG in Norway [3].

Nearshore WEC devices are usually placed hundreds of meters from shore at a depth of between 10 and 25 meters. This placement can be up to more than 1 km in some locations in Malaysia. The working principle suitable for this location can be OWC, OT, or oscillating wave-activated body (WAB). Apart from mooring costs and sea cable placement, a medium impact on the environment is another consideration. Since the energy harvested is located before the breakwater area, the wave's energy is expected to be medium to high. Several examples of devices deployed for this location are CETO in the UK [4], WaveStar in Denmark [12], Oyster in the UK [6], and also Yongsoo OWC in South Korea [7].

Offshore WECs are typically placed far from the shore in water depths of more than 40 meters. This location's working principle can be OWC, OT, or WAB. Consideration of the high cost of mooring and sea cable for this placement and the energy harvested in this area is expected to be the highest. However, due to open water deployment, devices are often exposed to strong waves and harsh weather conditions, and there are cases of washed-away devices [10]. Another issue with this placement is the high cost of maintenance. Several devices for this placement are AWS in the UK [14], PowerBouy in the USA [15], Wave Dragon in Denmark [16], and Pelamis in the UK [17]. Summarized WEC technologies according to the deployed locations are presented in Table 1.

Despite having been decommissioned, these technologies [1], [6], [14], [17] can be continuously studied and analysed. Lack of funding and uncertainty in the environment of deployment are among the most common reasons for these WEC devices being discontinued.

Based on the characteristics of Malaysia's geography and its ocean, the nearshore location is considered the most suitable for installing WEC devices. This placement can be up to more than 1 km from the shoreline in some locations, and this can be beneficial for marine life such as coral gardens and protected marine species. Having an average of 1 to 1.5 meter wave height throughout the year makes the nearshore location the best placement. By placing the device far from the shore, can increase the overall energy harvested without compromising the importance of environmental conservation, which is the main reason green energy is being explored. Aside from that, the best working principle for this WEC in this placement are OWC, OT or WAB. For example, both the CETO and Oyster WEC devices utilize the fully submerged oscillating WAB working principle. The oscillating WAB working principle devices operate when they interact with waves, either submerged or floating on the ocean's surface. Both of these technologies are large and designed for deeper

TABLE 1. Summarized WEC devices based on locations.

Location & Depth	Power Harvest/ Installation & Maintenance Cost	Mooring & Sea Cable	Environmental Impact & Survivability	WEC Type	WEC Type/ Example
Onshore **0 m**	Low	No	High	OWC & OT	OWC/ Limpet [1], OT/ SSG [3]
Nearshore **10-25 m**	Medium	Yes	Medium to High	OWC, OT & WAB	WAB / CETO [4] WAB/ Oyster [6]
Offshore **> 40 m**	High	Yes	Low	OWC, OT & WAB	WAB/ AWS [14] WAB/ PowerBouy [15] OT/ Wave Dragon [16]

ocean depths, whereas floating WAB WEC devices are considered more suitable for Malaysian water. Details on WEC devices and related power conversion systems are discussed further in this work.

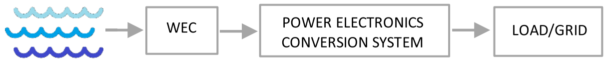


FIGURE 1. The overall wave energy extraction chain.

III. POWER CONVERSION TECHNOLOGY

In the early development of WEC, power electronic converters were studied separately from wave extraction devices [45]. Today, commercialization has forced the integration of power electronic converters into the WEC systems as an interface between the generation and the power grid. Like other renewable resources, the voltage amplitude and frequency are unpredictable and vary continuously. To ensure a stable and smooth energy transfer, the power electronics conversion system must convert either AC or DC input into AC or DC output at a constant or variable frequency through a series of converters, depending on the applications. Power electronics converters can be categorized into DC/DC, DC/AC, AC/AC, and AC/DC converters.

To illustrate an example of a complete WEC system with a power electronic converter system, when a WEC system is installed with a rotary generator and battery system, an AC/DC followed by a DC link capacitor or a DC/DC converter is required, assuming that the input source feeding the system is an AC source. Next, the DC-link capacitor or DC/DC converter is used to stabilize the DC input before it can be stored. If the system is connected to the grid, a DC/AC converter must tune the frequency and voltage amplitude to match the grid. This system is depicted in Figure 2.

Another example is the Point Absorber WEC with a linear generator. The energy harvested from a linear generator can produce a varying frequency for the system. This situation is due to the nature of linear generator operation, which heaves upwards and downwards following the wave motion. This heaving motion can result in a range of frequencies output being compared to the fixed frequency output generated from a rotary-type generator. With an AC/AC converter's application, a stable input frequency for the system can be achieved. Figure 3 presents an example of the system. Although this converter is promising for the PA type WEC system, this converter's development is yet to be completed [21].

The AC/DC/AC converter[23], [46], [55]–[64], [47]–[54], a combination of an AC/DC converter, a DC link capacitor, or battery storage, followed by a DC/AC converter, is the most commonly used topology for WEC technologies today. This combination is due to the fact that the generator used in most WEC devices is a rotary-type generator with a fixed output frequency. Table 2 depicted several WEC research and related power converters. These WEC research used different power electronics converters according to their applications. In [23], [46]–[50], [52]–[54], [56]–[70] a three-phase AC/DC/AC converter is used to dispatch power to the grid, and in [23], an active DC/AC converter is used as the control element. In [60], a single-phase AC/DC/AC converter is used.

Based on this research, it can be summarized that the most commonly used modulation technique to control the converters is the PWM technique [23], [47], [49], [51], [52], [59], [61], [69], [71]–[73] with the specificity of the Space Vector Pulse Width Modulation (SVPWM) in [48], [59], [69], [70], [73]. According to the application, these modulation techniques control the switching operation of the IGBT/MOSFETs in the converter, which is responsible for generating and regulating the AC sinusoidal voltage output at the desired output frequency. There are no significant differences between power electronic conversion systems for onshore, nearshore, and offshore devices except that the particular design must comply with the generator side's output, followed by the grid/load side demand to ensure a smooth power transfer. However, maintenance issues can play an important role in choosing suitable power electronic converters. Authors in [21] suggested that by eliminating the DC link capacitor can improve the overall extraction system's reliability and added that maintaining these capacitors can be challenging for offshore deployment. Further understanding of the AC/AC converter without a DC link capacitor can be found in [74].

IV. CURRENT WEC RESEARCH IN MALAYSIA

Malaysia is located near the equator, surrounded by sea with a total coastline of more than 4000 km and is comprised of

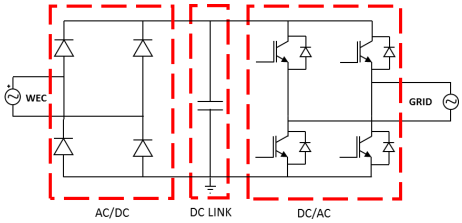


FIGURE 2. An Example of power electronic system using rotary type generator.

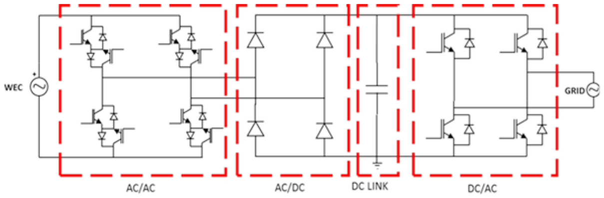


FIGURE 3. Wave extraction system recommendation for PA type WEC.

TABLE 2. WEC research and its power converter.

	OWC	WAB	OT
AC/DC/AC	[46], [47], [50]–[53]	[46], [54], [63], [64], [75], [76], [55]–[62]	[53], [77], [78]
AC/DC	[68]	[65], [66], [69], [70], [79]	-
DC/DC	[67], [68]	[54], [59], [79]	-

hundreds of off-grid islands. The Malaysian sea possessed overall low wave heights and ocean currents [80], [81]. Therefore, WEC system installation uniquely designed to suit the Malaysian sea is considered a viable solution at this moment.

Today, Malaysian research is at a preliminary stage of WEC design and understanding its surrounding ocean. The majority of this research is university-based and can be divided into WEC devices [22], [38], [82]–[89], power electronics systems [22], [38], [85], [88], [90], [91], oceanography study including environmental impact [92]–[97], location-based [84], [85] [88], [92]–[102], and government-related policy in [94], [103].

A. WEC PROJECTS AND DEVICE DEVELOPMENT

WEC projects and devices can be grouped into simulation and experimental developments. For WEC system experimentation, projects and devices are developed into lab sized WEC systems and small-scale prototypes. Summarized Malaysian WEC research is discussed in this section, as illustrated in Table 3. Nevertheless, research on WEC device development in Malaysia is still at an early stage. Several simulation models [22], [38], [82]–[86], [104], lab sized WEC devices [89], [105] and small scale prototype [88], [106], [107] are included in this study.

In [22], [38], the authors proposed a hybrid photovoltaic (PV) and OWC WEC system with a battery storage model tested under variable weather and load conditions in Matlab/Simulink. This research discusses a comparison between OWC device structures and presents a simulation model of OWC WEC. Likewise, in [85], the authors proposed a standalone hybrid OWC WEC and wind technology simulation with a battery storage element. This standalone WEC system is first motivated by inadequate island electrification in Malaysia. Theoretically, these hybrid simulations of other renewable resources and WEC with battery systems can achieve uninterruptible power supply. Most of today's WEC designs have started to incorporate other types of renewable resources into achieving continuous power supply, especially during low generation periods. Although OWC WEC has been chosen for these simulations, the type of OWC WEC and prospective location on Perhentian Island are nowhere mentioned in this research.

A PA WEC with a linear generator model is designed in [82], [83] using ANSYS Maxwell software to find the optimum generator model before fabrication work. This research presents a simulation model of PA WEC tested to run a 1.5 kW motor with a rated voltage of 240 V per phase. The thorough research done by these authors is very crucial as every grams matters for the stator or translator (depending on designs) to heave up and down according to the wave motions for the PA WEC prototype. Therefore, designing an appropriate model to fit both the desired output and the wave profile at the installation site is significant.

Authors in [86] proposed an Overtopping Breakwater for Energy Conversion system and performed validation in [87]. This research discusses on Overtopping Breakwater device structure, a simulation model of OWAB WEC and performed validation study compared to the experimental results from Aalborg University for design accuracy. This study considered as preliminary study before installing this type of WEC in Malaysia.

Authors [104] present a numerical study of different buoy shapes used for PA WEC. Among the shapes studied, when the buoy's mass is fixed, the cylindrical type buoy gives the best velocity. A study in [84] observed buoy characteristics in finding the optimum interaction between the WEC device and the incident wave. Then, these results are analyzed using MathCAD software. Both of this research [84], [104] discuss hydrodynamic buoyancy studies. This research is considered partial and preliminary WEC system development. Further research is needed to test the application of selected buoys on suitable WEC devices and study the significance of buoy shape with respect to the PA WEC system.

Authors in [89] designed a small-scale PA WEC device with a linear generator, that produced 13 mV when tested in an artificial wave tank. This research is a pico lab-sized PA WEC using a linear generator tested only as a proof of concepts experiment. Although WEC model of this size have high mobility, in order to study all related concept, a full-scale device is necessary before testing it using a real Malaysian ocean data simulator and then moving it to the open ocean, which requires a separate in-depth study.

In [105], a small lab-sized hydraulic PA WEC module was built and tested at the university wave maker lab and Mukah beach. The outcome of this research confirms that the output generation from low wave height is consistently based on the slight standard deviation demonstrated between the extraction locations.

In [88], the authors proposed the UMT Eco Wave Energy System (UEW), a type of heaving buoy WEC using hydraulic power take-off system (PTO) simulation using the Simscape library in Matlab/Simulink. Both simulation and experimental results of a hydraulic system of the WEC are proposed in [106]. The constant and variable pressure transmission for the hydraulic system is documented and discussed. In [107], the authors addressed the parameter optimization of the hydraulic PTO model for the WEC system. In this paper, the authors also justify the reduction by 34% in the force applied to the WEC, which would allow the device to operate during low wave height conditions.

In this research [88], [105]–[107] hydraulic type PTO is used as it is among the most studied PTO type. Theoretically, hydraulic PTO systems are complex, low in efficiency due to shear and friction losses, and consequently prone to damage. Such damage can have a serious impact on the environment, for example, when damage to the WEC device causes hydraulic oil leakage. Although improvements have been made over the years, unnecessary complexity, failure modes, and power losses are still among the concerns. Advancements in PTO systems were made by introducing the direct drive system. This direct-drive PTO system does offer many advantages over conventional PTO systems. However, this technology is fairly new and no commercially ready equipment is available on the market [18]. This results in the continuous use of the mature and widely available hydraulic and pneumatic PTO systems.

Each of the current WEC research topics mentioned has advantage over the other regarding efficiency, reliability, and applications.

B. RELATED POWER ELECTRONICS STUDY

Power electronics systems for the WEC system are a crucial link between the WEC device and the load/grid in order to maintain a stable frequency and voltage supply. A combination of selected power converters are grouped and their purpose are discussed accordingly in this section.

Authors in [22], [38] used a combination of a passive diode rectifier, buck DC/DC converter, boost DC/DC converter, and buck-boost DC/DC converter to maintain a constant DC link voltage and a voltage source DC/AC converter for controlling the load side voltage for a proposed hybrid PV and WEC system with battery storage modeled in Matlab/Simulink. The benefit of hybrid between PV and WEC system is the capability to achieve continuous and uninterruptible power supply. This hybrid system can be reliable for WEC during low wave seasons and out of UV peak time for PV system. Both of these systems require the installation of battery system for maintaining DC link voltage stability. The integration of this hybrid system to the grid is discussed and authors reported to have achieved acceptable results. The ability to model a system with integration to the grid can eliminates dependency on energy generated at the island alone and increase the reliability of the energy supplied to the island.

In [85], the OWC WEC Matlab/Simulink model was presented using a combination of passive diode rectifiers and a buck-boost DC/DC converter to maintain a constant DC link voltage. The main advantage of the WEC model with a battery system is that it is reliable during power shortages due to the intermittent nature of renewable resources. WEC devices without battery storage can only function properly during a certain period of time and are only suitable for experimental purposes. For this research, the battery storage would only last for 1 hour with a battery rated at 300 V and 14 Ah during energy shortages. Larger battery storage should be considered if the island is to be self-sufficiently relying on the WEC system, which consequently calls for higher investments to ensure an uninterruptible power supply daily.

An AC/DC converter is used to store harvested energy in battery storage, followed by a DC/AC converter to meet the load side demand proposed in [88]. As earlier mentioned, with the insertion of a battery system into the model, the uncertainty of energy supply, especially in locations prone to monsoon seasons, can be eliminated. However, the hydraulic PTO systems installed in the WEC device are usually complex and would require systematic controller systems.

Authors in [90], [91] used a combination of a boost DC/DC converter and an active voltage source DC/AC converter with a hysteresis current control (HCC) technique at the grid/load side. The use of the HCC technique is uncommon compared to the widely used PWM technique for controlling current at the grid or load side. However, the HCC technique is simpler than the PWM technique. In this technique, the output current is controlled within the required limit rather than being forced to observe the reference signal as in the PWM technique. This technique is therefore fast without requiring complex and expensive devices.

The main concern for power converter systems is the voltage stability. To make sure this can be realized, aspects such as power storage, maintenance problems, safety of device location, and hardware related problems are among many concerns for power system hardware installation and special considerations for WEC systems are marine grade device specifications. Each of these research projects are unique, and only specific power converter systems are suitable for them. These considerations can be used to start the study of power converter systems for WEC research.

C. OCEANOGRAPHICAL & ENVIRONMENTAL STUDY

Prior to the installation of the WEC devices, oceanographical, location-based, and environmental studies will be conducted. The most often used methodology in oceanographic research is remote sensing, which involves gathering data by detecting energy reflected from the earth using sensors installed on satellites, ocean vessels, or air-craft [108]. In these studies, wave conditions such as wave heights, wave periods, ocean currents, breakwater characteristics, and coastal impacts are investigated in order to identify the best prospective areas for

WEC deployment. The benefits of oceanographical research are critical for both maximum energy harvesting and minimizing the negative impact of WEC system installation on the environment.

The authors of [92] advocated assessing wave energy in the South China Sea using the Radar Altimeter Database System, with the results validated using buoy measurement data. The Radar Altimeter Database System is a database tool that was originally created for expert altimetry. Today, this technology is applicable even at the entry level [109].

Authors in [93] propose a 3D Malaysia numerical ocean model based on the Princeton Ocean Model to locate a potential wave extraction area using marine current turbine technologies. The Princeton Ocean Model is an oceanic numerical model that is used to mimic ocean features like currents, temperatures, and circulations, as well as predict ocean-related problems like coastal erosion and climate change. This model has the virtue of being a simple yet effective tool for ocean modelling.

Research [94] provides an insight into potential ocean renewable energy deployments in the Straits of Malacca and ranks tidal turbines, OWC WEC, and tidal barrage technology as the most compelling investment for Malaysia. However, the impact of ocean renewable devices on marine life is still unknown. Earlier studies have shown that some marine species' navigational trajectories are being affected by electromagnetic field (EMF) emissions, although some are not. However, due to a lack of further research on the impact of EMF emissions on marine life, the claim is therefore still debatable.

Based on data from the Malaysia Meteorology Department, the National Aeronautics and Space Administration (NASA), and the Malaysia Remote Sensing Agency, the authors of [95] indicated that the Terengganu and Sarawak coasts are among the ideal locations for WEC deployment. These sites were first identified using mask analysis, and the result was modeled onto the Geographic Information System.

The author in [110] recommended three potential sites that record continuous wave energy throughout the year: Perhentian Island in Terengganu, Kota Kinabalu, and Mabul Island, both in Sabah. The research was conducted using the simulation of improved satellite altimetry. Satellite altimetry is the technique of measuring the distance difference between the satellite and the surface of a body of water using radar pulses. However, measurement errors are worse for deep ocean measurements (more than 4000 meters) due to the upward gravity field from the ocean floor to the surface, resulting in a strong high-cut filter for the gravity signal [111].

The National Hydraulic Research Institute of Malaysia [96] proposed a wave energy harvesting device for coastal wave breakers. This floating device is an example of a type of breakwater structure that is commonly used for coastal control. The initial motivation for this development was to decrease coastal erosion. Although this technology has the potential to improve coastal management, it must be deployed in a certain formation to be effective.

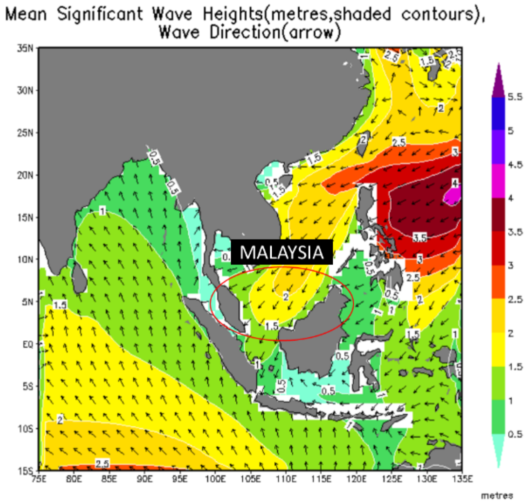


FIGURE 4. Malaysia wave height in December.

The assessment of potential deployment locations is critical because WEC devices are distinctive and must be constructed based on the location of placement. These studies are typically supplemented with the analysis of wind and tidal data from meteorological data, as shown in Figure 4. Since Malaysia is exposed to the monsoon season, extreme measurements can be recorded during these months (November to January) as opposed to non-monsoon months, which are believed to have lower and more steady wave heights. These measurements are often reliable and can be predicted earlier due to the wind direction that is usually predicted annually. Research in [84], [85], [88], [92]–[101] discussed several potential locations for WEC deployment in Malaysia based on mean wave height and wave period. Among suggested locations are the South China Sea [92], along Malacca Straits [94], and the east coast [85], [88], [96], [97], [99], [100], [102] particularly on the Terengganu coast [85], [88], [97], [99], [100], [102].

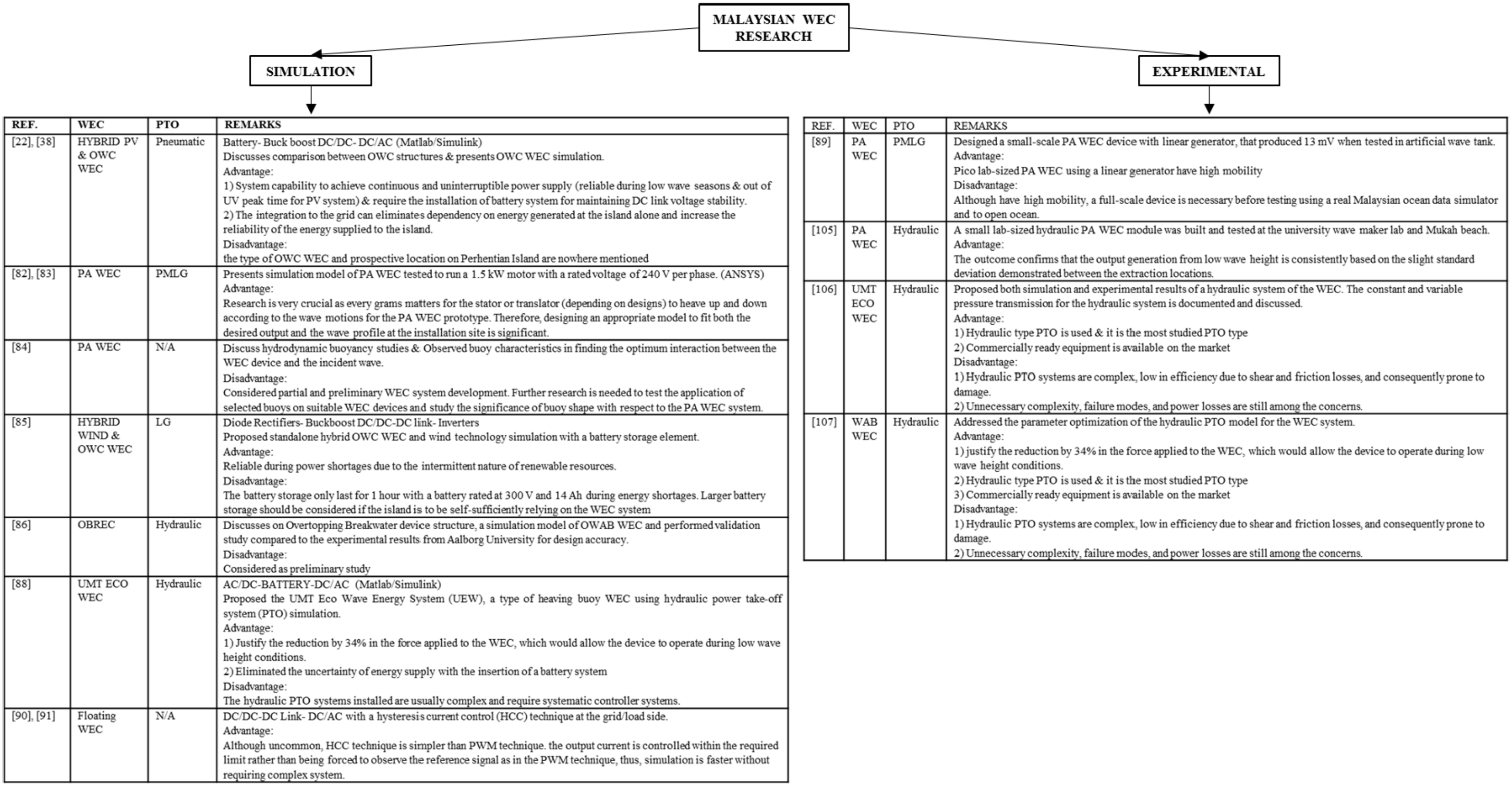
Some of the benefits of remote sensing include vast area coverage, the ability to use obtained data for a variety of applications, and the reduction of field effort because data is typically processed and evaluated in a laboratory. The disadvantages of remote sensing are that it is usually very expensive and that the sensors used require human intervention, such as adjustments and calibrations, which are the main sources of errors in this type of analysis. In addition, some sensing equipment emits electromagnetic radiation that may interfere with the readings.

D. RENEWABLE ACT AND POLICY

The current state of the renewable act and policy for wave energy in Malaysia is still uncertain.

Authors in [94] have highlighted the exclusion of wave energy and wind energy from the Renewable Act 2011 due to its early development stage. In [103], authors surveyed Malaysian citizens to study their readiness to accept and support marine renewable energy implementation. Among the questions asked are the public's willingness to pay for

TABLE 3. Summarized malaysian research on WEC system.



SIMULATION

REF.	WEC	PTO	REMARKS
[22], [38]	HYBRID PV & OWC WEC	Pneumatic	Battery- Buck boost DC/DC- DC/AC (Matlab/Simulink) Discusses comparison between OWC structures & presents OWC WEC simulation. Advantage: 1) System capability to achieve continuous and uninterruptible power supply (reliable during low wave seasons & out of UV peak time for PV system) & require the installation of battery system for maintaining DC link voltage stability. 2) The integration to the grid can eliminates dependency on energy generated at the island alone and increase the reliability of the energy supplied to the island. Disadvantage: the type of OWC WEC and prospective location on Perhentian Island are nowhere mentioned
[82], [83]	PA WEC	PMLG	Presents simulation model of PA WEC tested to run a 1.5 kW motor with a rated voltage of 240 V per phase. (ANSYS) Advantage: Research is very crucial as every grams matters for the stator or translator (depending on designs) to heave up and down according to the wave motions for the PA WEC prototype. Therefore, designing an appropriate model to fit both the desired output and the wave profile at the installation site is significant.
[84]	PA WEC	N/A	Discuss hydrodynamic buoyancy studies & Observed buoy characteristics in finding the optimum interaction between the WEC device and the incident wave. Disadvantage: Considered partial and preliminary WEC system development. Further research is needed to test the application of selected buoys on suitable WEC devices and study the significance of buoy shape with respect to the PA WEC system.
[85]	HYBRID WIND & OWC WEC	LG	Diode Rectifiers- Buckboost DC/DC-DC link- Inverters Proposed standalone hybrid OWC WEC and wind technology simulation with a battery storage element. Advantage: Reliable during power shortages due to the intermittent nature of renewable resources. Disadvantage: The battery storage only last for 1 hour with a battery rated at 300 V and 14 Ah during energy shortages. Larger battery storage should be considered if the island is to be self-sufficiently relying on the WEC system
[86]	OBREC	Hydraulic	Discusses on Overtopping Breakwater device structure, a simulation model of OWAB WEC and performed validation study compared to the experimental results from Aalborg University for design accuracy. Disadvantage: Considered as preliminary study
[88]	UMT ECO WEC	Hydraulic	AC/DC-BATTERY-DC/AC (Matlab/Simulink) Proposed the UMT Eco Wave Energy System (UEW), a type of heaving buoy WEC using hydraulic power take-off system (PTO) simulation. Advantage: 1) Justify the reduction by 34% in the force applied to the WEC, which would allow the device to operate during low wave height conditions. 2) Eliminated the uncertainty of energy supply with the insertion of a battery system Disadvantage: The hydraulic PTO systems installed are usually complex and require systematic controller systems.
[90], [91]	Floating WEC	N/A	DC/DC-DC Link- DC/AC with a hysteresis current control (HCC) technique at the grid/load side. Advantage: Although uncommon, HCC technique is simpler than PWM technique. the output current is controlled within the required limit rather than being forced to observe the reference signal as in the PWM technique, thus, simulation is faster without requiring complex system.

EXPERIMENTAL

REF.	WEC	PTO	REMARKS
[89]	PA WEC	PMLG	Designed a small-scale PA WEC device with linear generator, that produced 13 mV when tested in artificial wave tank. Advantage: Pico lab-sized PA WEC using a linear generator have high mobility Disadvantage: Although have high mobility, a full-scale device is necessary before testing using a real Malaysian ocean data simulator and to open ocean.
[105]	PA WEC	Hydraulic	A small lab-sized hydraulic PA WEC module was built and tested at the university wave maker lab and Mukah beach. Advantage: The outcome confirms that the output generation from low wave height is consistently based on the slight standard deviation demonstrated between the extraction locations.
[106]	UMT ECO WEC	Hydraulic	Proposed both simulation and experimental results of a hydraulic system of the WEC. The constant and variable pressure transmission for the hydraulic system is documented and discussed. Advantage: 1) Hydraulic type PTO is used & it is the most studied PTO type 2) Commercially ready equipment is available on the market Disadvantage: 1) Hydraulic PTO systems are complex, low in efficiency due to shear and friction losses, and consequently prone to damage. 2) Unnecessary complexity, failure modes, and power losses are still among the concerns.
[107]	WAB WEC	Hydraulic	Addressed the parameter optimization of the hydraulic PTO model for the WEC system. Advantage: 1) justify the reduction by 34% in the force applied to the WEC, which would allow the device to operate during low wave height conditions. 2) Hydraulic type PTO is used & it is the most studied PTO type 3) Commercially ready equipment is available on the market Disadvantage: 1) Hydraulic PTO systems are complex, low in efficiency due to shear and friction losses, and consequently prone to damage. 2) Unnecessary complexity, failure modes, and power losses are still among the concerns.

higher electricity prices and government participation in marine renewable energy development.

The willingness of Malaysians to pay a higher price for this green technology is still low, and more exposure to raise society's awareness is required. All participants, including the government, energy provider, and society as a whole, should support this awareness campaign. Since 2016, the government of Malaysia, together with energy providers, has provided a plan for customers to participate in small-scale or domestic-sized energy harvesting. Such an idea is considered fairly new, and this trend has started to spread, and awareness among customers has been sparked. Energy education is no longer a hushed issue, and each day, active participation from all can bring a great future for green energy in Malaysia.

V. CONCLUSION

Wave energy converter systems are a very promising renewable energy resource. With a long, stretched out coast and available in abundance all year round, wave harvesting is among the most favourable renewable resources in Malaysia. Until today, there has been no absolute technology able to optimize the harvest of the ocean wave's energy. Predicting that wave energy could be where wind energy was 25 years ago, creating numerous development possibilities.

This review has presented the latest WEC technology and its power conversion system, and WEC research status in Malaysia. Despite having numerous research, power electronics for WEC are still very briefly mentioned and rarely given full specifications and parameters. Realizing that it is significant to combine power electronics conversion with the WEC extraction devices, more research at the simulation stage has started to incorporate the two systems. Based on previous research, AC/AC converter implementation has yet been used in any WEC research. However, it can introduce tremendous improvements in terms of reliability by eliminating the DC link capacitor, which is generally used in the power conversion topology.

The AC/AC converter, also known as a frequency converter in a matrix converter topology, can be very versatile. It can either convert a constant input frequency into variable output frequencies or vice versa. For example, in Malaysia's case, with overall low wave heights, the implementation of an AC/AC converter for PA WEC with a linear generator can be interesting. An extensive range of low frequencies generated by this device can be controlled using an AC/AC converter to produce a constant output frequency to match the load side demand. In unpredictable sea conditions, this system's adaptability with frequency variation can be used.

Considering the Malaysian shore's overall depth and restricted access to long shallow water, nearshore locations are considered the most suitable deployment for the Malaysian sea. Currently, Malaysian WEC research mainly focuses on developing WEC extraction devices and oceanography research. Several WEC development have started to incorporate power electronics conversion and oceanography studies into their research. Further research is needed to understand and address the overall system's economic, cost, reliability, and efficiency factors to suit the Malaysian environment. While this research is considered in its early stages, consistency and continuous research are essential to ensure research on wave energy reaches a certain maturity. Although wave energy incentive are yet to be included in the Malaysia Renewable Act 2011, continuous development will encourage active participation from policymakers and investors to get involved and invest in this particular technology.

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