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Practical Analysis of Key Electrical Interfaces for Wave Energy Converter Arrays

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Practical Analysis of Key Electrical Interfaces for Wave Energy Converter Arrays

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Abstract

The authors have previously outlined a proposed path for the development of electrical networks for deepwater wave farms. This path broadly followed that of offshore wind farms as the least cost solution. The main differences between wind farm and wave farm electrical networks were identified as the method of installation and maintenance and the components at the WEC interface with the electrical network. Components such as dynamic cables, submarine connectors, submarine switchgear all form part of these interfaces.

This paper examines the key electrical interfaces for WEC arrays such as the dynamic cable to WEC interface, dynamic cable to static cable interface, and the WEC medium voltage switchgear interface. The cost and functionality of these interfaces are evaluated for a variety of options. The paper also looks at array electrical configurations beyond radial under the same criteria.

The paper concludes with an optimised solution for the key interfaces between the WEC and the electrical which minimises cost but maintains important functionality of the electrical network within the array. The preferred solution uses a combination of permanent cable joints, mate-able connectors, and onboard switchgear. The paper outlines the challenge to get the electrical systems to a cost level that will be competitive with other renewable sources, particularly offshore wind.

Keywords: Wave Energy Converters, Electrical Networks, Dynamic Cables, Submarine Connectors.

1. Introduction

The authors have previously outlined both the optimum array electrical configuration and the key interfaces in a wave farm electrical system [1]. This identified that there were multiple similarities between offshore wind and wave farms and the biggest differences were represented at the 'key interfaces' between the Wave Energy Converters (WECs) and the electrical network. Some of these differences are:

- The installation process and the requirement to remove the WEC off station for maintenance.
- The dynamic cable interface to the WEC.
- The individual rating of single WECs.
- Depth at Wave Farm sites is expected to be much larger.

This paper examines these differences and their impact on the cost and functionality of the wave farm electrical system. This paper attempts to design an optimal solution for a generic deepwater WEC array which may be universally implemented.

1.1 Wave Farm Electrical System Components

Although there are numerous WEC types with some variation in the electrical collection and transmission concepts, wave farm electrical systems will typically have the following components:

- WEC generators and balance of onboard electrical plant (transformers, switchgear etc.)
- Dynamic power cables (floating wave only)
- Submarine connectors and other submarine electrical systems
- Submarine power cables
- Offshore substations (For very large arrays)
- Onshore substations and grid connections

All of these components will be required in a wave Farm electrical system with the exception of offshore substations which may be required at large scale wave farms only. It is important that the selection of these components does not affect the functionality of the wave farm at different points in its lifecycle. Therefore the selection of components and design of the electrical system must be optimised.

2. Target Cost of Electrical System

It has often been stated that the cost of wave energy must approach that of offshore wind before the technology will be competitive. Current capital costs of offshore wind are approximately €3.8m / MW [2]. The electrical system including cabling, offshore substation, onshore grid and installation make up approximately 20-25% of this overall cost [3].

Therefore if wave energy is to be competitive with offshore wind the electrical system costs will need to be of the same magnitude as offshore wind, i.e. approximately €0.75-0.95m / MW assuming that other parts of the farm are the same proportional costs as offshore wind. This is a huge challenge for wave energy considering the additional requirements over wind such as submarine connectors, dynamic cables and potentially large transmission distances. This target cost level must be a key driver in designing the electrical systems for wave farms.

If we take the array and export cabling, and the onshore grid out of this, which account for ~80% of the electrical system cost, we are left with up to ~€0.2m / MW for the interfaces between the electrical network and the WECs in the array. This is a simplified calculation but shows the constraint on the cost for the electrical system to be in line with that of offshore wind and hence the drive for a low cost solution.

3. Array Electrical Configuration Optimisation

One major factor in the cost and functionality of the electrical system is the configuration of the array electrical network. There are a variety of alternative configurations as shown in Fig. 1 below. For wave farms some proposals have been made for submarine ‘hubs’ which could act as an aggregation point in a star network. These are discussed further in later sections.

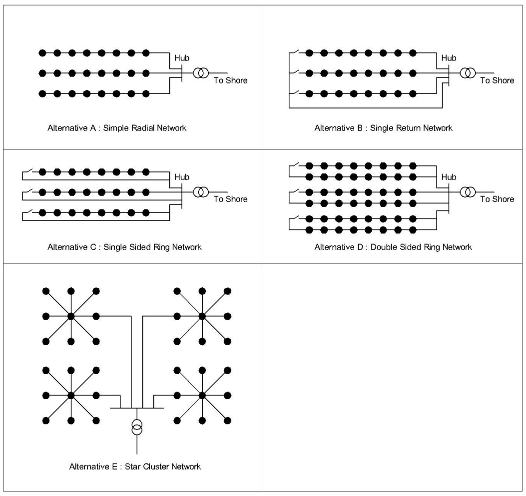

Fig. 1: Alternative Array Network Configurations

3.1 Analysis of Alternative Network Configurations

For the purpose of analysis we will use wave farm 2, from [1] as shown in Fig. 2, as our candidate wave farm. This wave farm uses a simple radial network (Alternative A in Fig. 1) and notably has no offshore substation.

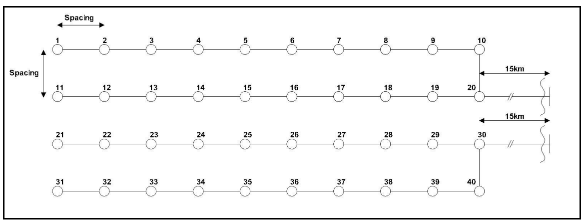

Fig. 2: Candidate Wave Farm

We can evaluate the candidate wave farm using the alternative configurations as shown in Fig. 1 under a number of criteria. These same criteria are used for evaluation in Section 4 also.

1. <u>Cost (Relative to (A))</u>
   This considers the increase in the array cable cost by a change in the configuration. The unitised cost model introduced by the authors in [4] is used to calculate the relative costs. The export cables(s) will not change based on the different configurations.
2. <u>Installation</u>
   This considers the complexity of the cable laying operation compared to a simple radial network scenario. Aspects such as the cable laying duration and complexity are considered.
3. <u>Operation</u>
   This considers the effect of the configuration on the operation of the wave farm, in particular its availability and redundancy during normal operation.
4. <u>Maintenance</u>
   This considers the ease of maintenance operations within the arrays and the loss of energy when WECs are removed from the array.
5. <u>Isolation and Protection</u>
   This considers the location of protection equipment and the ease of installation and maintenance of same

The following assumptions are made:

- The voltage is 20kV in all cases
- Each WEC is rated for 1MW
- Inter-device spacing is assumed to be 400m
- The physical grid layout of the devices is assumed to be maintained at all times, for all configurations
- Redundant circuits are assumed to be rated for worst case full load, i.e. they are 100% redundant.
- No bespoke equipment such as submarine switchgear is considered at this stage and all switching operations are assumed to be contained within the WEC.

1. <u>Cost (Relative to (A))</u>

Table 1 shows the relative cost of the array and export cabling for the various alternative configurations shown in Fig. 1. This shows that the Radial network is the least cost solution from an array configuration perspective.

This is primarily due to additional cabling required for the proposed alternatives. Also to allow redundancy in the circuits the cross sectional area (CSA) of some of the cables must be increased also increasing cost.

Network Configuration	**Relative Cost**
Radial Network (A)	1.0
Single Return Ring Network (B)	2.58
Single Sided Ring Network (C)	1.8
Double Sided Ring Network (D)	1.69
Star Cluster Network (E)	1.54

Table 1: Cost of Alternative Array Network Configurations

2. Installation
The radial network would be the simplest installation with multiple short cable runs. The installation process for the alternative array configurations would be more complex involving additional and longer cable runs and possible cable crossings.
3. Operation
The radial circuit has no redundancy in the array network meaning that in the event of a fault during normal operations all upstream WECs in the circuit will be disconnected from the system. All of the alternatives offer some level of redundancy in the circuit which has been shown to increase availability of the overall array [5].
4. Maintenance
A unique characteristic of deepwater wave farms is that individual WECs will require removal for routine and non-routine maintenance. Similar to the comments in 'Operation' above a radial circuit would have no redundant circuit. The alternative configurations would be more suitable to overcome this but there are solutions to overcome the lack of redundancy in radial circuits. These solutions are discussed below in Section 3.2.
5. Isolation and Protection
How the individual WECs and array cables are isolated is an important consideration for safe operation of a wave farm. The operation of a radial circuit is well understood where any WEC or cable can be simply isolated by switching out the connection at either side. More complicated switchgear and isolation systems may be required for the alternative networks.

What can be concluded from the above discussion is that the simple radial network appears to be the most advantageous in terms of cost; however the radial network is less suitable where redundancy is required. In reality, as shown in Section 2, the cost of the electrical system would need to be kept as low as therefore any other technical or functional considerations may not be valid. Thus radial networks are selected here as the most suitable array network configuration for wave farms.

3.2 Analysis of Alternative Network Configurations

This has proven the case with offshore wind farms, with radial networks being used in all offshore wind farm array configurations and few wind farms having any redundancy in the electrical system. However with offshore wave farms we have the issue of removal of WECs in the circuit which needs to be resolved. This can be done with a number of options including;

1. 'Standby' or 'dummy' WECs to 'slot' into place.
2. A system for temporarily 'bridging' the gap left by the WEC in the electrical circuit.
3. Submarine switchgear allowing continued operation of the infield circuit (see next section)

It is likely that that option 2 here would be the least cost solution to this issue.

4. Key Electrical Interfaces

If the array network configuration is to be a radial network then the key interfaces between the WEC and the radial network need to be optimised. This means achieving a balance between the functionality of these interfaces and cost.

These key interfaces are detailed in later sections but are categorised as;

1. Dynamic Cable to WEC interface
2. Dynamic Cable to Static Cable interface
3. WEC MV Switchgear interface
4. Offshore Substation

There is certain functionality required at the key interfaces between the electrical system and the WECs. In this section these interfaces, particular 1-3, are considered from the required functionality within the electrical system. The required functionality includes the following;

- Multiple Connection / Disconnection of the WEC
- Initial Cable Installation
- Electrical Protection
- Electrical Isolation (and earthing)
- Cable Deck Penetration
- Circuit Continuity (i.e. redundancy)

Various types of WEC will lend themselves better to some of the presented options (or another option) than others. The focus here is on a generic floating WEC.

Although the maximum functionality in the key electrical interfaces would be desirable, the cost of the key interfaces must also be minimised. Some relative costs are indicated in these sections based on information from [6] and other various sources. The costs are indicative only but are expected to be sufficiently accurate for the techno-economic optimisation undertaken in Section 5. The expected costs may limit the functionality that can be viably achieved in the key interfaces. The balance of cost and functionality is important and an optimal solution is developed in Section 5.

4.1 Dynamic Cable to WEC Interface

The method by which the dynamic cable is connected to the WEC is of critical importance to the deployment and retrieval strategy of the WEC array. Some developers have already considered this closely with Pelamis developing a proprietary connection system so the cable can be connected automatically to the device as it is latched to its moorings [7]. OPT have developed a floating connection system in cooperation with JDR cables so the cable can be connected without diver or ROV to the WEC [8]. It is possible that the method for connection / disconnection is to use the submarine connector as detailed in Section 4.2.

The system used for the interface between dynamic cable and the WEC should be simplistic to avoid lengthy offshore operations and flexible to allow for quick connection / disconnection. If the system is designed so that the cable can be pre-installed at the site and brought into the device on during deployment, this could allow for the dynamic to static cable connection to be made during manufacture of the cable, thus reducing the requirement for submarine cable connectors and hence reducing cost – this is discussed further in the next section.

Some possible riser to WEC connection schemes are shown for a generic floating WEC device in Fig. 3 below and the options shown are evaluated.

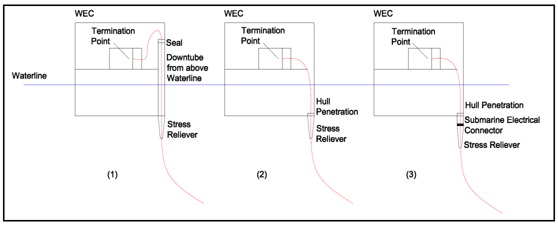

Fig. 3: Dynamic Cable / WEC interface options for WEC

(1) Cable is routed above the waterline and through a 'downtube' to the bottom of the WEC. The downtube could be internal or external to the WEC. A stress reliever would be required at the bottom of the 'downtube' to avoid stress, kinking or cable damage. If properly designed this system could allow the cable to be drawn into the device on site and the cable terminated within the WEC although this process would be difficult. This would mean that when the cable was disconnected from the device it would need to be capped before it is left disconnected in situ.

(2) Cable routed directly out through a hull penetration. This would involve a submarine hull penetration including a stress reliever and seals in order to maintain hull integrity. This would mean that the dynamic section of cable would need to be connected during onshore construction and transported to site where it would be connected to the static section of cable already installed.

(3) Cable routed directly out through a hull penetration with a submarine connector. This would involve a submarine hull penetration including a stress reliever and seals in order to maintain hull integrity. On the 'wet' side of this penetration one half of a submarine connector would be fixed to the hull. This would mean that the dynamic section of cable, with the other half of a submarine connector, would need to be connected on site during installation. This could be by diver, ROV, or an automated system.

Table 2 below gives the relative costs of the various options presented. The least cost option is (1) where no hull penetration and sealing is required. Option (2) would require hull penetration and (3) requires a submarine connector which gives rise to the increase in relative cost.

Option	Relative Cost
(1)	1.0 (Base Case)
(2)	1.5
(3)	2.5

Table 2: Relative Costs for WEC to Dynamic Cable Interface

4.2 Dynamic Cable to Static Cable Interface

The method by which the dynamic cable is connected to the static cable is also of critical importance to the deployment & retrieval strategy of the WEC array. There are multiple options for submarine connectors which differ primarily in the ease and speed of connection operation and as a result cost. Submarine connectors can be broadly separated into the categories given below;

Non-'Mate-able' Connector

Permanent/Factory Cable Splice: This is a permanent splice between two cables. This is the type of splice that is regularly used in factories or in cable repair operations. Once the splice is made it cannot be separated without cutting the cable. This type of connection can only be done in very dry and controlled conditions. The cost of these connectors is expected to be ~€30-40k.

'Mate-able' Connector

Splice Housing: This is a 'mate-able' splice which can be separated and re-connected. The connector is essentially a housing in which a temporary cable splice can be made. This type of connection is undertaken on board a service vessel. The cost of these connectors is expected to be ~€75-100k.

Dry-Mate Connector: This is a 'mate-able' connector which can be separated and re-connected numerous times. The dry-mate refers to the fact that this type of connection can only be undertaken outside of the water on board a vessel. The cost of these connectors is expected to be ~€100-150k.

Wet-Mate Connector: This is a 'mate-able' connector which can be separated and re-connected numerous times. The wet-mate refers to the fact that this type of connection can be undertaken under water on the sea-bed. The cost of these connectors is expected to be ~€200-300k.

The system for interfacing dynamic cable and the static cable should be simplistic to avoid lengthy offshore operations and flexible to allow for multiple quick connection / disconnection.

Some possible dynamic cable to static cable connection schemes are shown for a generic floating WEC in Fig. 4 below.

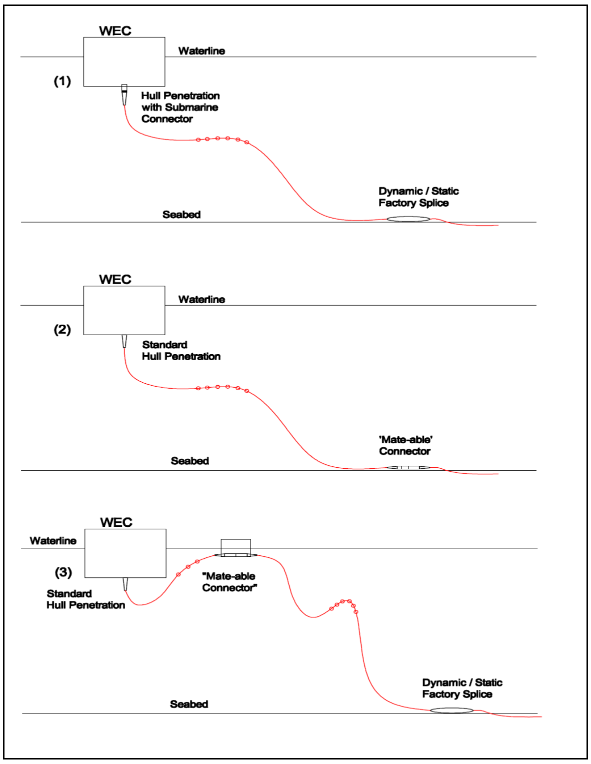

Fig. 4: Dynamic / Static Cable Connection Options for WEC

(1) As per option (3) in Fig. 3 a mate-able connector would be installed at the hull penetration. This connector would serve a dual purpose as a hull penetration and cable connector. From the connector the dynamic cable is configured in a lazy-wave to the seabed where it is connected to the static cable through a permanent/factory splice. The splice between the static and dynamic cable could be made onshore during cable manufacture to allow for a simpler installation process. This option however may require diver, ROV activities, or an automated connection system.

(2) From the WEC standard hull penetration (option (2) in Fig. 3) the dynamic cable is configured in a lazy-wave to the seabed where it is connected to the static cable through a mate-able connector such as those outlined in Table 2. This option could also be used with option (1) in Fig. 3 where the cable is routed directly into the WEC on site without the need for a mate-able connector (the dynamic/static cable interface could be a permanent splice).

(3) From the WEC a short length (~50m) of dynamic cable is connected to a floatation module containing a mate-able connector. This floatation module may be part of the WEC mooring system. From the floatation module the dynamic cable is configured in a lazy-wave to the seabed where it is connected to the static cable through a factory made joint such as that described in option (1) above. The short length of dynamic cable to connect to the floatation module would also be pre-installed before deployment.

Table 3 below gives the relative costs of the various options presented. The least cost option is (1) where the submarine connector forms part of the WEC to Dynamic Cable interface and the Dynamic to Static cable interface is the lowest cost splice connection. Option (2) would be slightly more expensive depending on the type of 'mate-able' connector used. Option (3) would be the most expensive depending on the connector used.

Option	Relative Cost
(1)	1.0 (Base Case)
(2)	1.2 – 2
(3)	1.3 – 2.5

Table 3: Relative Costs for Dynamic Cable to Static Cable Interface

4.3 WEC MV Switchgear Interface

In order to connect the WECs in a radial circuit MV switchgear will be required for protection of the WEC electrical system and cables and also for isolation purposes. A similar switchgear arrangement to offshore wind farms will be required in a WEC array.

If submarine switchgear is employed this can be coupled with a mate-able connector system. Submarine switchgear systems have been developed by Siemens, ABB, GE Vetco Gray, MacArtney and OPT [9]- [13]. With the exception of MacArtney and OPT these have been predominantly designed for offshore Oil and Gas applications where the economics are of a different order of magnitude to offshore energy generation. Hence they are designed for extreme deepwater operation (>1000m)

Some possible switchgear configuration schemes are shown for a generic floating WEC device in Fig. 5 below.

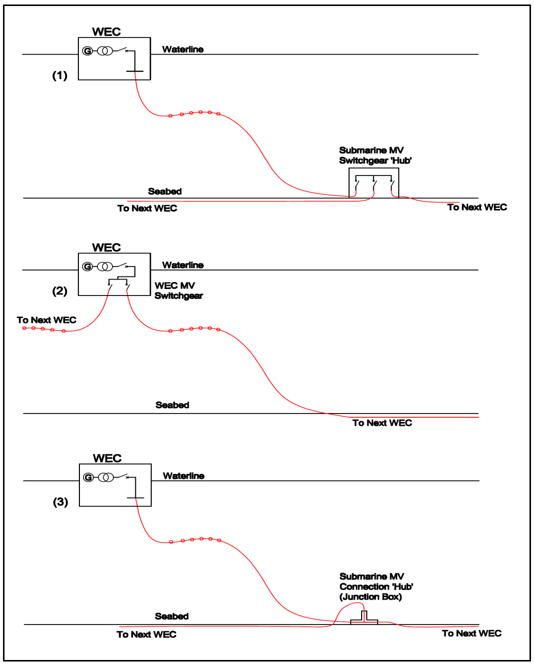

Figure 5: Switchgear Options for Floating WEC

(1) From the onboard transformer a dynamic cable is connected (optionally with a onboard MV circuit breaker) to a submarine switchgear unit (‘hub’) which includes a protection circuit breaker for the WEC electrical system and dynamic cable, and switch disconnects for isolation of the cable section. In this way all protection and isolation functions are done within the subsea module which would contain protection relays also. This has the advantage of only one dynamic cable required for connection to the WEC but has issues with regard to electrical safety and maintenance of submarine electrical equipment. Connectors would also be required to be added to the switchgear unit to allow a connection / disconnection function also.

(2) From the onboard transformer a cable is connected to onboard switchgear which includes a protection circuit breaker for the WEC electrical system and switch disconnects for isolation of the dynamic and static cable sections. This system would require two dynamic cables for WECs connected in a radial network.

(3) From the onboard transformer a cable is connected to onboard switchgear which includes a protection circuit breaker for the WEC electrical system and dynamic cable and switch disconnects for isolation of the cable section. One dynamic cable is connected to a ‘T’ connector on the seabed (submarine connection ‘hub’). This means that only one dynamic cable is required for devices connected in arrays. However to isolate the dynamic cable section the entire circuit (including all WECs on the radial) must be switched out and isolated.

Table 4 below gives the relative costs of the various options presented. The least cost option is (2) where the switchgear is contained within the WEC itself although this requires two dynamic cables per WEC. Option (3) is the next most expensive due to the requirement for additional submarine connectors and a submarine ‘T’ connector. Option (1) is considered the most expensive due to the requirement for additional submarine connectors and submarine switchgear.

Option	Relative Cost
(1)	3 – 5
(2)	1.0 (Base Case)
(3)	2 – 3

Table 4: Relative Costs for Dynamic Cable to Static Cable Interface

4.4 Offshore Substation

In offshore wind, an offshore substation would be required for arrays over 100MW or further than approx 10km from shore as these are the breakeven points where the cost of the substation is less than the cost of multiple MV connections. Also important in the consideration of an offshore wind farm is the voltage for connecting to the grid which would normally be HV (>100kV) for large generators.

There are many offshore substations installed on existing offshore wind farms with further projects in development or construction. These substations are normally installed in up to 35m water depth

As offshore wave farms will likely be located in 100m water depth, although the onboard equipment will be identical, the type of foundations typically used in offshore wind farm substations will not be practical, i.e. monopile, tripod and gravity base. Jacket structures have also been used for ‘deepwater’ sites such as in [14] however this is still only 45m depth. So the choices for an offshore substation in 100m water depth would be the following;

- Strategically locating the wave farm in proximity to a <50m water depth location and locating the offshore substation at an midpoint between the wave farm and the shore
- Building a fixed jacket or compliant tower type structure such as that in use for oil platforms
- Building the substation on a floating platform such as the semi-submersible, tension leg or spar type structures in use for oil platforms
- Locating the offshore substation on the seabed

Essentially this will come down to a question of cost and feasibility. The technologies in use for oil platforms are well proven but the economics of O&G is very different than that for offshore wave farms so may prove too expensive for use in this industry. Locating the offshore substation on the seabed would solve the foundation platform issue; however this has only been achieved on a small power scale and again in the O&G industry. There would be the same access, maintenance, and safety concerns for this equipment if this was the case. Sites that have a shallow water location in the vicinity could possibly be utilised but the economics of the longer MV cables may outweigh the benefits of this approach. Essentially a cost benefit analysis must be undertaken on this aspect and this will not be undertaken accurately until such time as a project at this scale is in development.

It is very likely that the cost of the foundation for a deepwater offshore substation would be significantly higher than that of a foundation in 0-40m water depth. The full cost would include the construction and installation including potentially expensive deployment vessels. The topside of the substation would be approximately the same cost although some increase in protection may be necessary to deal with wave loading and installation may also be more expensive. Therefore it is very likely that the breakeven point for an offshore substation for a wave farm will be higher than 100MW. It is difficult to establish what the exact breakeven point will be as there are numerous variables in a cost model but detailed financial models of large wave energy project could establish this.

4.5 Other Bespoke Solutions

The focus here has been on offshore wave farms with radial array networks. Other bespoke solutions have been proposed which all fall into a general category of submarine 'hubs' utilising star cluster type network configurations.

These hubs in general collect the generated power from several WECs and condition it for transmission to shore. These hubs can contain one or all of the below equipment:

- Power Electronic Converters
- LV & MV Switchgear
- Power Transformers
- Energy Storage Solutions
- Battery Chargers and Auxiliary Systems

Although these are not explored in detail here there are several major challenges that must be overcome in order to make these types of solutions viable. They are the same challenges that apply to larger submarine offshore substations (Section 4.4). These challenges are outlined here for information only:

- Access to complicated equipment such as power electronic converters, digital protection relays, battery chargers etc. would be required in the event of even a simple fault. This operation alone would be a huge cost.
- There are safety implication with have a point of isolation and earthing in a location where it can not be verified or locked out.
- The practicalities of connecting multiple LV and MV cables to a submarine hub are onerous. This would require multiple expensive mate-able connector and/or ROV operations.
- The potential construction and installation costs of a submarine hub are very large and there is little experience here apart from the oil and gas industry.
- There are other, less technically and economically challenging options for electrical connection schemes which should be explored first.

5. Techno Economic Optimisation

It has been shown in this paper that a radial array network configuration is the least cost option for wave farm arrays. This solution, however, suffers from not having redundancy in the network to cater for WEC removal; however solutions are proposed for this in Section 3. The optimisation of wave farm electrical networks therefore comes through the selection and design of appropriate interfaces between the WEC and the electrical network. These interfaces must balance cost and functionality.

5.1 Least Cost Solution

The least cost solution would involve minimising the use of any expensive components in the system such as submarine hubs, submarine connectors etc. Although detailed costs are not available for components, the least cost solution is based on the relative costs outline in Section 4.

Interface	Option	Description
Dynamic Cable – WEC	4.1 (1)	Downtube
Dynamic Cable – Static Cable	4.2 (1)	Submarine 'non mate-able' connector
WEC MV Switchgear	4.3 (2)	WEC MV Switchgear and Two Dynamic Cables

Table 3: Least Cost Solution Proposed Options

This would minimise cost due to no requirement for mate-able submarine connectors and no submarine switchgear/hub requirements. However this would require two dynamic cables from the WEC and could potentially require a long and complicated installation process. This solution would lack some functionality as the disconnection of a WEC could be a long process.

5.2 Maximum Functionality Solution

The maximum functionality solution would involve increasing the availability of the overall wave farm and reducing the time required to undertake maintenance activities. The maximum functionality solution is proposed to comprise of the following options outlined in Section 4.

Interface	Option	Description
Dynamic Cable – WEC	4.1 (3)	Hull Penetration / Connector Combination
Dynamic Cable – Static Cable	4.2 (1)	Submarine 'non mate-able' connector
WEC MV Switchgear	4.3 (1)	Submarine MV Switchgear 'hub'

Table 4: Maximum Functionality Solution Proposed Options

This solution would allow for easy isolation and removal of the WEC for maintenance activities while keeping the electrical circuit integrity for upstream devices to continue generating. Although detailed costs are not available for components, this solution would be expected to be up to three times the cost of the least cost solution from Section 5.1.

5.3 Optimised Solution

The optimised solution will seek to maximise functionality at the lowest. It is proposed here that circuit continuity will be achieved with a system such as that proposed in Section 3.2. Therefore the only functionality required is to disconnect WEC quickly and at low cost. The optimised solution is proposed to comprise of the following options outlined in Section 4.

Interface	Option	Description
Dynamic Cable – WEC	4.1 (2)	Submarine Hull Penetration
Dynamic Cable – Static Cable	4.2 (3)	Floating dry-mate connector
WEC MV Switchgear	4.3 (2)	WEC MV Switchgear and Two Dynamic Cables

Table 5: Optimised Solution Proposed Options

This solution will give the required functionality for the WEC electrical system and is gives only ~25% increase over the least cost option given in Section 5.1. This system would allow for easy, cost effective disconnection of the WEC. The electrical system could be safely isolated for these activities.

6. Conclusions

This paper presents an optimised configuration for a wave farm electrical system focusing on optimisation of the system for cost and functionality.

A radial configuration is selected as a preferred array electrical network solution based primarily on it being the lowest cost option. The drawback of this network is the lack of redundancy during operation and maintenance activities however some solutions are proposed to overcome this drawback for maintenance in Section 3.2.

Several options are presented for the key interfaces between the WEC and the electrical network. A solution is optimised which minimises costs while maximising functionality of the electrical system.

In order to make wave energy viable in the long term it is shown that the electrical system costs must be below €1m / MW. This presents a huge challenge for designers in minimising the use of expensive components such as submarine connectors.

Expensive bespoke solutions such as submarine 'hubs' may mean that the electrical system is too expensive to be used in viable project. These solutions may be viable in the short term for prototype testing but the aim should be to design these solutions out of the system in the longer term to achieve target costs.

In the longer term WECs must have suitable maintenance intervals of approximately 5 years. If this is achieved the devices would be rarely removed from station and therefore submarine connection system may only be used a small number of time during the project lifetime. This also should be considered before utilising expensive mate-able submarine connection systems which while suitable for prototypes in the short term, need to be cost effective in the long term.

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