Marine Energy Electrical Array Analysis: a financial appraisal of options

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One of the many challenges facing the marine energy industry is the design of a cost effective and efficient electrical network to collect and transmit power from marine energy converters (MECs) to shore.

In order to make an informed financial decision on architecture choice, it is critical to be able to identify the factors driving differential cash flows between each option and conduct a like-for-like comparison. Without a valid comparison, decisions are likely to be financially sub-optimal.

Summary of findings

- The choice of electrical architecture for a given site is driven primarily by site-specific issues, marine energy convertor (MEC) selection and electrical array cost.
- For a 32MW array, the lifetime cost of the electrical infrastructure options identified in the report *Marine Energy Electrical Architecture Report 3: Optimum Electrical Array Architectures* varies considerably between £16 million for 6.6kV radial array and £49 million for four fixed hubs (£0.5 million to £1.5 million per MW).
- This difference in costs strongly suggests that MEC arrays must be designed as complete projects that include the MEC and electrical infrastructure.
- Including detailed cost modelling of the electrical infrastructure could justify selecting a MEC to suit the lowest cost electrical array solution, rather than having the project design driven by choice of MEC.

Recommendations

- A Net Present Value (NPV) financial appraisal of all available electrical array options should be conducted, as part of a wider assessment, to identify the option with the lowest lifetime cost.
- Key drivers of uncertainty (e.g. cable costs, component costs) should be quantified in order to compare risk across options.
- Where the choice of MEC has not yet been made, the cost differential between radial arrays (used for fixed frequency MECs only) and hub solutions (used for any MEC) should be compared with the difference in cost of fixed versus variable frequency devices to inform selection.
- Further work should be done in developing 6.6kV radial solutions, as it shows the lowest estimated lifetime cost for an array of size 32MW (£4 million lower than the next solution).

Much of the focus in the development of the wave and tidal industries is, understandably, on optimisation and cost reduction of marine energy converters (MECs).

However, the development of appropriate electrical array architecture to collect power from multiple devices and transmit it to shore will also be critical to industry success. Given the high costs of installing and operating marine energy sites, it is crucial to be able to select the most cost-effective overall MEC array design, including the electrical array. Developers face pressure to substantially reduce capital expenditure (Capex) in order to achieve a sufficient return on investment and to demonstrate a pathway to a sustainable industry.

The Offshore Renewable Energy (ORE) Catapult commissioned a report entitled *Marine Energy Electrical Architecture Report 3: Optimum Electrical Array Architectures* to investigate an optimum architecture for such arrays.

Taking into account feedback from manufacturers and developers, four options for multiple MEC connection were identified:

- Direct connection of devices to shore (surface laid, horizontal direct drilling (HDD) or a combination of the two)
- Surface piercing hub
- Floating hub
- Subsea radial network

Each of these connection options has a different Capex and operational expenditure (Opex) profile, as well as a different maintenance regime and resulting level of availability. In addition, the technology relevant to realising each option requires a different degree of development.

The choice of electrical architecture suitable for any site will be driven by three main sets of factors:

Site-specific issues

Surface-piercing hubs may not be a realistic option where significant visual impact issues arise. If the array is situated more than one kilometre from shore, direct connection with HDD may not be a practical option due to the high cost of drilling (depending on the distance which requires to be drilled as opposed to surface-laid).

Device technology

A key finding of the report is that not all architectures are technically feasible for all MEC electrical outputs: only devices that output at a fixed frequency can use radial networks. Where a developer is tied in to a MEC supply agreement for variable frequency devices, this will exclude radial arrays from the range of electrical options available. If a MEC has not yet been secured, the full range of array options should be available.

Cost (Capex, Opex and availability)

Each electrical array solution has a different cost implication. Once the site-specific and MEC technology limitations have been taken into account, it is necessary to conduct a cost comparison of the available options. The characteristics of the four options for multiple MEC array connection differ greatly and they require different fabrication, installation and maintenance solutions. Some options are more capital-intensive and some require a more cumbersome maintenance regime and/or carry a greater risk of system unavailability.

1. The need to consider costs beyond Capex

Given the high costs of installing and operating marine energy arrays, it is crucial to be able to select the most cost-effective electrical array option. Developers face pressure to dramatically reduce Capex in order to achieve a sufficient return on investment and to show a pathway to a sustainable industry. However, it is also critical that an option with low up-front capital costs is not selected at the expense of incurring disproportionately high ongoing operations and maintenance (O&M) costs and/or suffering low levels of availability due to the level of intervention required to maintain the array. A method is therefore required to compare the available options on a like-for-like basis.

2. The impact of lost revenue

One of the key issues with marine energy is the lack of proven reliability (both of MECs and of supporting infrastructure) over a sufficient project life to provide confidence to investors. Any marine energy project will only achieve a return on investment if it generates sufficient units of electricity to earn a profit. The choice of electrical architecture will have implications for maintenance and availability, which will result in different levels of downtime, where no revenue-generating electricity is being produced. The assessment of cost should account for these losses and recognise that every lost MWh has a financial consequence.

3. Uncertainty over costs

Given the relative immaturity of the wave and tidal energy industries, there is a great deal of uncertainty over the costs expected to be incurred: component fabrication costs cannot be quoted with certainty for First of a Kind technologies; cable costs vary depending on exact specifications and any supply constraints; installation and ongoing maintenance costs will depend greatly on vessel availability and market rates; and the nature of the marine environment leaves any project exposed to numerous performance risks. Decisions may be driven by risk perception as well as comparison of base cases, and so it is essential to quantify risk and translate this into financial value.

4. The scope of the electrical architecture

The direct connection to shore option necessarily includes the export cable and onshore substation. Therefore, in order to compare fairly, the export cable and onshore substation should also be included in the cost analysis for the other solutions.

Each of these four factors makes it difficult to conduct a like-for-like comparison without a detailed analysis of the financial characteristics and financial uncertainty of each option.

As such, there are a number of key questions to consider – such as what information is required on each array option – in order to conduct a like-for-like financial appraisal. Thereafter, the range of difference in lifetime cost between the options identified must be assessed, along with the range of uncertainties associated with those options.

In terms of addressing these issues, it is crucial to identify all the lifetime cost elements for each array option. The cost of each array solution should be analysed in terms of up-front Capex, annual Opex and Lost Revenue from downtime.

Table 1 sets out the metrics that should be used to quantify cost:

Capex	Opex	Lost Revenue
Component fabrication cost	Days per year for routine O&M	Average days per year for routine O&M
Component installation cost	Average days per year for unplanned downtime	Average days per year for unplanned downtime
Cable supply cost	Number of personnel	Electricity generated (MWh)
Cable installation cost	Personnel day rates	Tariff paid pre MWh
Drilling cost	Number and types of vessel	
Export cable cost	Vessel day rates	
Substations cost	Annual insurance premium	
Connectors/Transformers cost	Costs of monitoring and control	

Table 1: Key cost drivers

Methodology

Each of these elements (Capex, Opex and Lost Revenue) has a cash flow implication. As these cash outflows will be incurred over different timeframes, the most appropriate method of comparison is a Net Present Value (NPV) analysis.

This allows the future cash flows (Opex and Lost Revenue) over the operational lifetime to be valued in the same terms as the up-front Capex. As well as estimating the cash flows, this requires applying an appropriate discount rate to future cashflows to express these in today's terms.

In the analysis below, a generic rate of 10% has been used, however in a 'real world' situation, the discount rate will be specific to the developer's cost of capital.

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NPV Analysis Illustrative Results

The NPV methodology has been applied to the costs and underlying parameters included in [Marine Energy Electrical Architecture Report 3: Optimum Electrical Array Architectures].

This report includes 13 scenarios, falling into the four different types of multiple MEC connection, as illustrated in Table 2.

Direct Connection	Fixed Hubs	Floating Hubs	Radial Arrays
Direct Connection	4 Fixed Hubs	4 Floating Hubs	6 x 6.6kV strings
	3 Fixed Hubs	3 Floating Hubs	3 x 11 kV strings
	2 Fixed Hubs	2 Floating Hubs	2 x 20kV strings
	1 Fixed Hubs	1 Floating Hubs	1 x 33kV strings

Table 2: Scenario list

The NPVs of the 13 scenarios have been calculated for the 32MW (16 x 2MW devices) array outlined in the report, under the following simplified assumptions:

- Capex is incurred in Year 0 and not discounted
- Opex is incurred at the same rate each year in Years 1-20
- Revenue generation and downtime are incurred evenly over Years 1-20
- Revenue is earned at a strike price of £305/MWh
- All cash flows are in pre-tax real terms and the 10% discount rate is assumed to be pre-tax real

The resulting NPVs are shown below by Capex, Opex and Lost Revenue. This allows an appraiser of the project to understand where different factors (e.g. Lost Revenue) are more or less significant relative to other options.

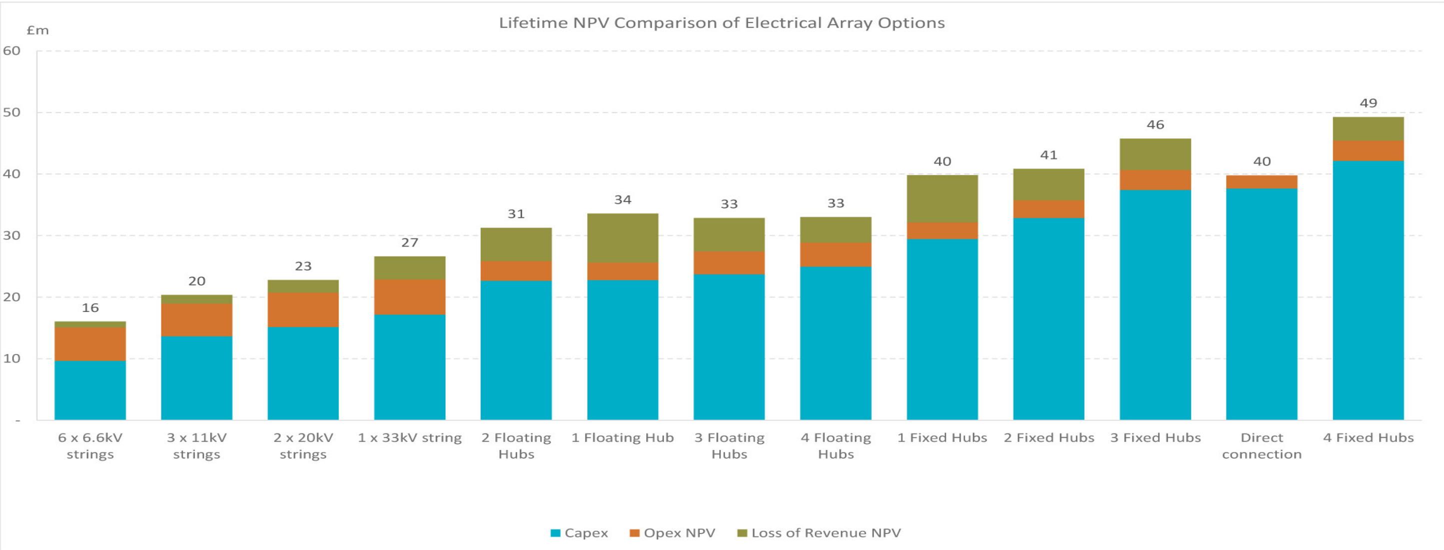

Figure 1: Lifetime NPV comparison of Electrical Array Options

Note that for the direct connection scenario, as the cable is buried, it is assumed that the cable will be maintenance-free and therefore there is no revenue loss associated with the electrical architecture.

The results have been sorted from lowest to highest Capex and confirm that the 6 x 6.6kV string architecture is the lowest cost solution in this case, not just in terms of Capex but also in terms of overall lifetime cost.

However, while total NPV generally follows the Capex trend, this also illustrates that lifetime Opex and Lost Revenue can be a deciding factor driving choice of electrical architecture.

For example, while the Capex for 1 floating hub is expected to be approximately £2.2 million lower than for 4 floating hubs, the higher expected lifetime revenue losses associated with 1 hub (since an outage on the hub will impact the whole array) mean this solution has an estimated NPV of £600k higher, and so the optimal choice could actually have higher up-front capital expenditure.

Uncertainty Analysis

There is a high degree of uncertainty surrounding the costs and maintenance requirements for MEC electrical array solutions which are, as yet, largely unproven.

It is therefore important for a decision maker to form a view of the quantum of risk attached to the various options. Here, this is framed as financial (cost) risk only.

In a full decision making process, the technical and other risks (e.g. certification, demonstration, original equipment manufacturer (OEM) strengths and experience, breadth of the available supply chain) should also be fully assessed.

To quantify the impact of uncertainty on the results of the analysis in a simplified manner, a high, medium and low range has been estimated for key inputs relevant to each scenario.

The key variables in each scenario for this illustration are as follows:

Scenario	Capex Sensitivity	Opex Sensitivity	Revenue Sensitivity
Direct Connection	Drill cost per metre	Unplanned downtime	Unplanned downtime
Fixed Hubs	Cable cost per metre	Unplanned downtime	Unplanned downtime
Floating Hubs	Cable cost per metre Fixed cost per hub Variable cost per hub	Unplanned downtime	Unplanned downtime
Radial Array	Cable cost per metre 3-way connectors Transformers	Unplanned downtime	Unplanned downtime

Table 3: Uncertainty variables by scenario

The key inputs detailed in Table 3 have been used to generate a range of NPVs for each scenario, as illustrated in the chart below. The bars show the range of NPVs, from high to low, for each layout, with the mid case shown by the red square for each layout.

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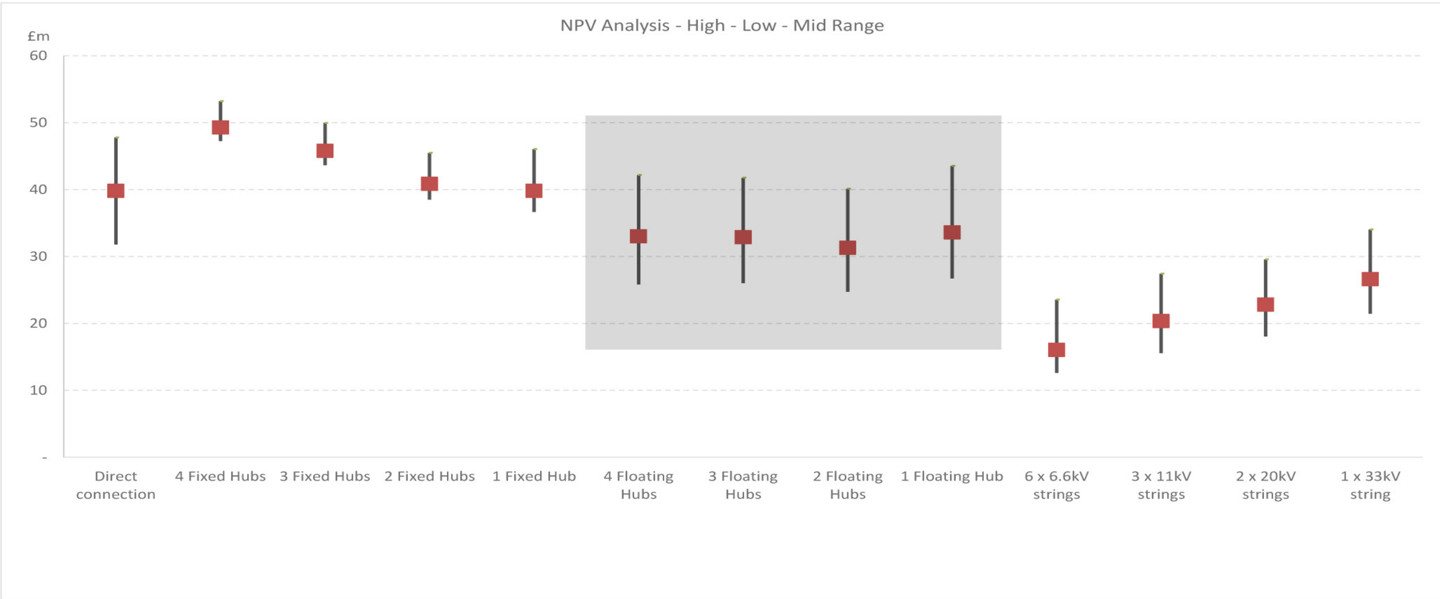

Figure 2: NPV analysis - high - low - mid range

This analysis allows the decision maker to look beyond the central case for each scenario and quantify how high the costs could become based on the chosen sensitivities. This will allow the appraiser's view of risk to inform the decision.

For example, if MEC choice and consenting issues were to narrow the feasible electrical array options down to floating hubs only (as per the range of options shaded in Figure 2), the analysis shows that, while the single floating hub option has only a marginally higher Base Case NPV than 3 and 4 floating hubs, the high case sensitivity is also approximately £1.5 million higher than the worst case sensitivity for either the 3 or 4 floating hubs solutions.

It also shows that the 2 floating hub solution is now the most cost effective of the floating hub solutions not only in terms of central NPV but also in terms of the range of potential costs. This could reinforce a decision to use a multiple hub rather than single hub solution in such a scenario.

Figure 2 also illustrates that there is some overlap between the risk associated with the lowest cost option (the 6 x 6.6kV string option) and a number of other options, for example the 3 x 11kV string option. This could be used to drive uncertainty reduction activities surrounding these alternative solutions.

Quantifying the risks for each solution will provide insights into what is driving the cost risk and therefore how this might be mitigated, e.g. through technology development or contracting strategy.

Conclusions

On the basis of the assumptions included in *Marine Energy Electrical Architecture Report 3: Optimum Electrical Array Architectures*, the lowest lifetime cost solution (assuming no site-specific or MEC technology constraints and further research and development on the technical feasibility) for a theoretical 32MW tidal array is a 6 x 6.6kV string array. This solution is £4 million (£0.25m/MW) lower than the next option and £15 million (£0.5m/MW) lower than the lowest cost hub solution.

This significant cost differential suggests that, as radial arrays can only be used with fixed frequency MECs, the lifetime costs for the entire site should be compared between using fixed frequency MECs with radial arrays and variable frequency MEC devices with fixed or floating hubs.

Where the reduced lifetime cost from using radial arrays is greater than any increase in lifetime cost from using fixed frequency MECs, selection of fixed frequency MECs is preferable from a financial point of view.

As such, there appears to be a strong case for further development of radial array technology and for OEMs to consider developing fixed frequency devices in order to make their offering more cost-effective over a wider range of marine sites.

An NPV analysis of the lifetime costs of the competing array architectures confirms that the 6 x 6.6kV string array remains the lowest-cost option even after accounting for the operational lifetime of the tidal array.

Where choice of electrical array architecture is limited to floating hubs only, the analysis shows, for this particular scenario, that a dual hub solution is the optimal choice, not only in terms of lifetime cost but also in terms of the uncertainty around that cost.

Recommended reading

Marine Energy Electrical Architecture Report 3: Optimum Electrical Array Architectures, ORE Catapult, September 2015, available online at https://ore.catapult.org.uk/documents/10619/205783/pdf/b1c1f5c8-434f-4655-b8e9-6b7d366f7bd8

Author Profile

Gavin Smart holds the post of Investment & Financial Analyst at ORE Catapult and is responsible for developing and maintaining ORE Catapult's financial and economic modelling, which feeds directly into the organisation's commercial strategy.

Gavin spent three years as Senior Investment Analyst for a major European utility, developing models and analysis tools for UK and European offshore wind and marine projects. Prior to this, he worked as a Valuation & Business Modelling consultant in the Middle East for one of the 'big four' accounting and consultancy firms.

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