LOWERING THE COST OF MARINE ENERGY WITH AFFORDABLE SUBSEA CONNECTION SOLUTIONS

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ABSTRACT

It is recognised that there are significant challenges which present themselves to installation and deployment of subsea equipment and systems in offshore wave and tidal environments. A key aspect of this is the consideration given to how a subsea connection between wave and tidal energy conversion devices and the export cable infrastructure can be implemented. An approach to the installation and deployment methodology based on wet mate connectors could provide an affordable cost effective solution when considered against alternative options using hard-wired or dry mate connectivity. Wet mate connectors are not novel technology, rather, they are a field proven, high reliability key enabling technology. Existing products include high voltage electrical, low voltage electrical, Ethernet and fibre optics which provide power, auxiliary control and communications functions. When packaged, this suite of connectors provides an integrated subsea connection and cable management system as a generic interface between marine energy converter and export cable. Such a system enables subsea 'plug and play' thereby minimising activities on the surface, lessening the dependency on weather windows, vessel availability and their attendant costs. The move from single unit testing toward full scale commercialisation and multiple unit array/farm developments will attract the benefits of economy of scale and prove favourable when capex/opex costs are evaluated throughout the whole life cycle.

1. INTRODUCTION

The wave and tidal energy potential that exists in European offshore regions is a resource that provides the opportunity for economic prosperity and security of energy supply far into the future. Realising this opportunity will require a strategic approach to tackling the challenges faced if a commercially viable wave and tidal ocean energy industry is to be created.

The UK Government has established legally binding targets [1] to create a low carbon economy and reduce the UK's greenhouse gas emissions by at least 80% by the year 2050. To drive this initiative forward a system of carbon budgets was introduced which require emissions to be reduced by at least 34% in 2020. There is also commitment from the UK Government to have a dramatic increase in the electricity generation from renewable sources [2].

In order to meet the targets it is likely that renewable electricity will have to provide over 30% of electricity generation in 2020. These challenging targets clearly identify the increasing scale of the contribution from renewable electricity generation and the wave and tidal energy sectors will form a significant part of our future UK energy mix. Each is an emerging sector in its own right with commercialisation of leading technologies only just beginning. Both are characterised by high numbers of prototype technologies and of these technologies only a handful are now approaching full-scale commercial deployment.

2. COST OF ENERGY

Much has been reported on the cost of wave and tidal energy with the conclusion that in order for the technology to be widely accepted the cost must be reduced to a competitive level. The industry needs to demonstrate that energy from wave and tidal sources can successfully be generated at scale while evolving from single device prototyping to the deployment of multiple machine solutions as arrays at a reduced cost of energy produced. The current status of the technology reflects a high levelised cost of energy (LCOE) compared with other renewable energy sources.

The determination of LCOE takes a holistic view and considers the total *'Life of field costs'* and all this entails. It is a whole lifecycle approach not only including the capital and operating costs but also the cost of decommissioning, which is a statutory requirement.

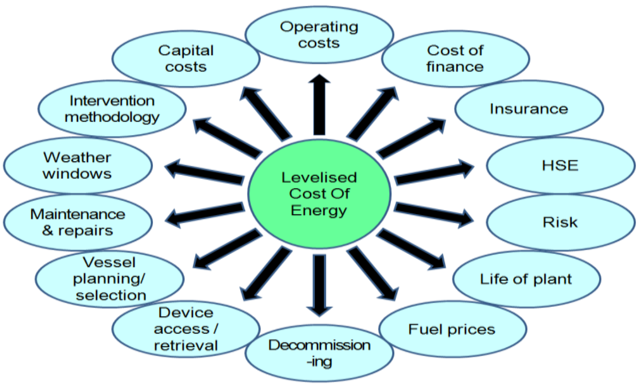

Figure 1. Levelised cost of energy (LCOE) components

If the industry is to become cost competitive with other forms of renewable energy then the estimates of LCOE determined for wave (34-63c€/kWh) and tidal (24-47c€/kWh) [3] must be significantly reduced if a desired target in the region of 10c€/kWh is to be achieved.

Even where such reductions can be made, in order to make substantial contribution to the electrical grid network both wave and tidal technologies will have to operate in array or farm installations. With an industry still in a nascent state, prototype devices are currently undergoing performance testing as the precursor to commercial scale production and deployment readiness. This progression will require the technologies to be proven, reliable and affordable.

In a recent study [3] two themes emerged from an assessment of existing gaps and barriers to the development of the wave and tidal sector. These were i) technology development and ii) deployment and risk reduction. Certain topics were highlighted as key candidates for further consideration towards meetings cost reduction targets. Of particular relevance to the subject of this paper the following topics were listed;

- Enabling technology (eg cabling and electrical connection).
- Operations and maintenance risk reduction.
- Infrastructure.

From within these topics the recommendation of the study is to prioritise and address the following;

- Power take-off.
- Array/subsea electrical system.
- Offshore umbilical/wetmate MV connectors.

In the following sections it will be shown where existing wet mate connector technology is directly relevant to the gaps and barriers identified and where proposed solutions can be applied.

3. IMPACT OF SUBSEA CONNECTION METHOD ON THE LIFE OF FIELD COSTS

3.1 FUTURE SUBSEA INFRASTUCTURE

It is recognised that there are significant challenges which present themselves to installation and deployment of subsea equipment and systems in offshore wave and tidal environments. A key aspect of this is the consideration given to how a subsea connection between wave and tidal energy conversion devices and the export cable infrastructure can be implemented.

Recent commentary within the wave and tidal community includes headlines such as "at the tipping point of pre-commercial to full scale production devices" and "moving towards arrays". Such positivity is welcomed but this ambition must be tempered by the scale of the challenge and the implications of making it happen.

A variety of wave and tidal energy converter designs currently exist and are undergoing their respective test programmes, each design having its own 'uniqueness' but collectively they will require a subsea connection infrastructure. Consented projects for large arrays/farms are already underway, these are large scale power projects and can be in the order of 400MW; with devices having a nominal rating of 1MW it reflects an equivalent number of machines deployed on the seabed. One can imagine the requirements for an infrastructure in the future and it poses the question of how all this can be deployed and connected together. Subsea cabling will provide the backbone for such an infrastructure, having an architecture which can be configured to maximise the availability of devices connected onto the grid network.

To date there is little information published on how subsea cables survive and perform in high energy marine environments. It is not an environment normally suited to cables and cable lay in such areas has been routinely avoided. The sheer number of cables also presents implications of routing management back to shore.

3.2 WAVE AND TIDAL ARRAYS

The illustration in Figure 2 identifies the principal components of a future subsea array infrastructure, comprising energy converter, subsea connectors, inter-array cables, subsea hub, export cable; an infrastructure where the cabling, connections and foundations may be pre-installed well in advance of the final turbine being connected.

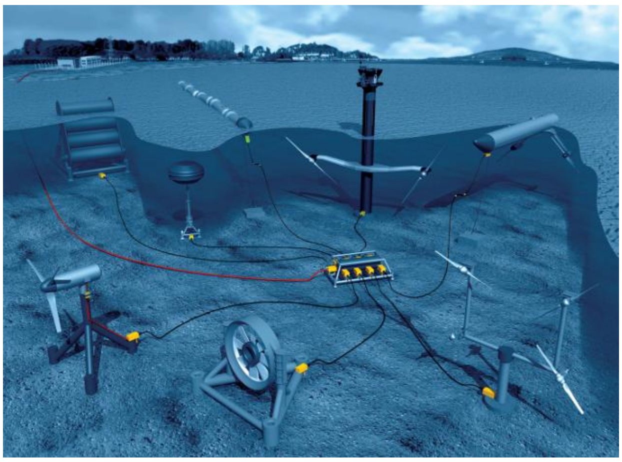

Figure 2. Wave and tidal array infrastructure.

A subsea connection interface or 'node' potentially exists for any of the components shown; floating devices, fixed foundations, removable nacelles, multi-megawatt platforms and subsea hub. These subsea connection nodes (depicted as the yellow boxes in Figure 2) contain the wet mate connectors which are central to the deployment methodology for future arrays and consequent lower cost of energy.

An approach to the installation and deployment methodology based on wet mate connectors could provide an affordable cost effective solution when considered against alternative options using hard-wired or dry mate connectivity. The flexibility this type of solution offers has the potential to influence the life of field cost in almost all areas of a wave or tidal farm development. Such a system enables subsea 'plug and play' thereby minimising activities on the surface, lessening the dependency on weather windows, vessel availability and their attendant costs.

The concept of subsea connection nodes allows for array cable infrastructure to be accurately installed at the seabed in advance of complex turbine machine build completion. Once the turbines are installed subsea, cables are never retrieved to the surface or re-laid. Subsequent intervention regimes could be undertaken with small purpose built work class vessels.

The costs associated with installation and connection (structural, cable, device etc), maintenance and repairs methodology, intervention, vessel planning and selection, device access and retrieval are all activities which are either directly or indirectly influenced by the cable connection solution.

Estimates for the percentage of lifetime costs [4] for the main elements of early commercial wave and tidal farms are given in Table 1.

Table 1. Lifetime cost elements of a wave and tidal farm.

	Wave Farm	Tidal Farm
Installation	18%	27%
O&M	17%	19%
Foundation & Moorings	6%	14%
Structure	31%	13%
Power Take-Off	22%	10%
Grid Connection	5%	5%

With offshore vessel rates currently ranging from £50k to £200k per day, and set to become more expensive in the future, any solution which minimises installation, operating and maintenance costs will become an increasingly attractive commercial proposition.

3.3 BENEFITS OF A SUBSEA WET MATE CONNECTION SOLUTION

Lessening the degree of difficulty (and resultant costs) when conducting operations at sea can be achieved through the use of a wet mateable connection solution. Some examples of this and the potential benefits it provides are given below.

- Subsea equipment (nacelle, converter, transformer etc) can be lifted to the surface without the need to lift the power cable itself.
- Emergency disconnect is possible without the use heavy lift vessels.
- Cable faults can be manually isolated by disconnection without the need to recover to surface.
- Cable lengths can be optimised. No excess cable lengths to be managed during deployment and minimise disturbance once laid on seabed.
- Operations less affected by adverse weather.
- Nacelle can be detached and recovered without recovery of the foundation.
- Offers maintenance options for cables – i.e. simple disconnect & replace subsea operation.
- Interchangeability of connection head can be performed subsea.
- Costs minimised - maintenance and recovery performed faster & cheaper.
- Cost effective power export from multiple devices.
- HSE procedures and Safety Case development could be simplified.
- Provides flexibility of operations.

4. WET MATE CONNECTORS

4.1 GENERAL SPECIFICATION

For wave and tidal device developers a key factor in the assessment of risk mitigation is to demonstrate the reliability of product/system in accordance with recognised standards and guidelines, culminating as fit-for-purpose for the intended environment and service conditions.

Where subsea connectors are a sub-component of the energy converter system design they too must also aim to achieve compliance with the respective standards and should typically include, but not be limited to, the following requirements.

- 25 years design life
- Maintenance free
- Tested to IEC electrical standards
- Interchangeable
- Easy to install / minimise installation time
- Designed with zero harm
- Connectors & cable tested to same standard

4.2. TECHNOLOGY READINESS LEVELS

The Technology Readiness Level (TRL) helps to define the extent to which a given technology is "ready" for use. A TRL assessment enables the identification of equipment maturity and to determine its suitability for a particular application. The TRL qualification process involves progressing equipment from its initial TRL through the progressive levels to the required TRL; lowest level corresponds to a completely unproven "paper" concept, while highest level corresponds to a field proven technology which has been working reliably.

Wet mate connectors are not novel technology, rather, they are a field proven, high reliability, key enabling technology and have been used subsea in the Oil & Gas market for over 30 years. Although oil and gas and marine renewable energy environments are distinct in their own right, there can be read-across from the oil and gas American Petroleum Institute (API) standards which are directly relevant to the duty that subsea connectors must perform in harsh wave and tidal environments.

The suitability of the Siemens range of subsea connector products for wave and tidal energy applications can be assessed through a comparison of the TRL definitions they have been developed and qualified against for oil and gas projects [5] with the guidance currently available to support the development of the wave and tidal sector. A body of work [6] is currently being co-ordinated by the European Marine Energy Centre (EMEC) to develop the standards and guidelines specifically for the wave and tidal industry. Within this work the TRL definitions as specified in the Horizon 2020 initiative [7] have been adopted. The respective TRL definitions are given below.

API TRL Definitions

- TRL7 Field Proven Production system field proven)
- TRL6 System Installed (Production system installed and tested)
- TRL5 System Tested (Production system interface tested)
- TRL4 Environment Tested (Pre-production system environment tested)
- TRL3 Prototype Tested (System function, performance and reliability tested)
- TRL2 Validated Concept (Experimental proof of concept using physical model tests)
- TRL1 Proven Concept (Proof of concept as a paper study or R&D experiments)

Horizon 2020 TRL Definitions

- TRL 9 Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)
- TRL 8 System complete and qualified
- TRL 7 System prototype demonstration in operational environment
- TRL 6 Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 5 Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 4 Technology validated in lab
- TRL 3 Experimental proof of concept
- TRL 2 Technology concept formulated
- TRL 1 Basic principles observed
- TRL0 Unproven Concept (Basic R&D, paper concept)

4.3 SIEMENS SUBSEA CONNECTORS – PRODUCT HISTORY

A brief overview of the history of Siemens subsea connector products will serve to illustrate the maturity of wet mate connector technology and evolution to its current state of being a field-proven reliable key enabling technology.

Established in 1978 Tronic Ltd (now a Siemens Subsea company) has developed and delivered a comprehensive range of subsea electrical and fibre optic connectors which have set the benchmark for innovation and reliability in the oil & gas industry.

1979: The first subsea mateable connector was developed to provide a more reliable alternative to existing methods of connection technology. The design consisted of a single barrier system with male and female separable housings and was capable of being mated subsea. The design was suitable for diver or ROV operation.

1986: The introduction of the enhanced seawater environment (SE) connector. This multipin connector was capable of being mated subsea and featured a cup and cone arrangement which expelled the water from the contact area. With high conductivity high corrosion resistant contacts, the connector incorporated a pressure balanced glanded termination assembly providing double integrity cable sealing.

1985-87: Introduced the world's first controlled environment connectors (CE) which featured dual oil filled chambers, where the electrical contact is made in a fully enclosed pressure balanced oil filled environment, pin wiping action and dual redundancy. The pressure-balanced feature allowed this new design to be repeatedly mated and demated subsea.

1988: The development and manufacture of the world's first high power high current wet mateable connector (3 phase, 11kV, 400amp) for a subsea gas compression project. The commercial and technical success of this development led to the evolution of a portfolio of high power products which have been deployed in some of the most challenging subsea environments worldwide.

1991: A miniaturized version of the highly successful CE connector, incorporates all the high integrity features of its predecessor in a small size suitable for instrumentation and low power.

2000: The upgrade of the miniaturised CE saw the introduction of the Digitron^{TM} range which incorporated new injection moulding techniques and enhanced elastomeric components, as well as a rationalization of the product range to deliver high volume turnover.

2003: The desire for increased reliability of sensing devices and real time data combined with technological advances in optical transmission lead to the development and product launch of the FoeTRON^{TM} fibre optic connector. The connector design utilizes the same operating principle, design philosophies and high performance materials as used in the family of electrical connectors.

2011: The most recent addition to the Siemens connector family is the Ethernet compatible Digitron^{TM} e connector. Reliable and efficient access to information has become increasingly important, achieving high data rates for real time control. Ethernet is now gaining increasing popularity as the preferred data transmission protocol for subsea use.

Figure 3. Wet mate connector evolution.

5. CONNECTION MANAGEMENT SYSTEM

Existing wet mate connector products include medium voltage electrical, low voltage electrical, Ethernet and fibre optics which provide power, auxiliary control and communications functions respectively. When packaged, this suite of connectors provide an integrated subsea connection and cable management system, the connection management system (CMS), as a generic interface between marine energy converter and export cable.

As highlighted in Figure 2, subsea connection nodes comprising wet mate connectors will provide the interface between nacelle/foundation and foundation/export cable to the rest of the cabling network. The physical arrangement of the subsea connection is shown in Figure 4 and comprises a wet mate connector pair (plug and socket) housed in a subsea enclosure. One half of the subsea enclosure, the cable termination head (CTH) contains the plug (male) connectors and includes cable termination and protection; the other half, the receiver frame (RF) contains the socket (female) connectors and is terminated to the nacelle electrical generator/power take-off connections. Similar arrangements can be made to implement the connection interface between the nacelle and foundation ie. as with removable/detachable nacelle designs. In each case further consideration will need to be given to the method of actuation of the connectors in the engagement process and this will depend on the end user requirements.

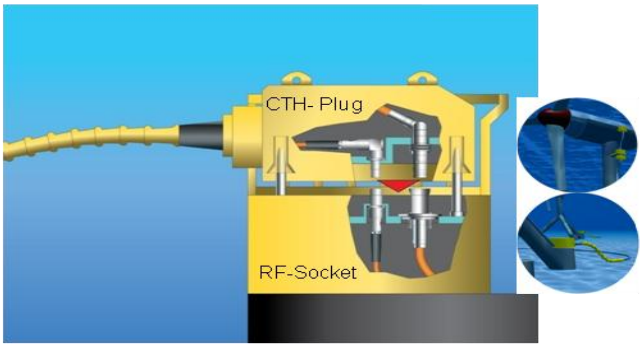

Figure 4. Connection Management System (CMS)

6. CONNECTION MANAGEMENT SYSTEM (CMS) DEPLOYMENT METHODOLOGY

6.1 INSTALLATION SEQUENCE

The requirements and design of any CMS equipment need to be considered in conjunction with the installation methodology that will be used. The sequence of events in the deployment of a CMS for the converter foundation/export cable interface is illustrated and described in the following diagrams.

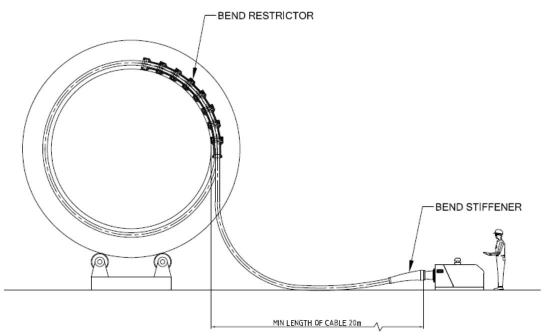

Figure 5. Onshore preparation - connection of CTH to subsea cable

Preparation of the entire CTH onto the marine cable along with all sub-systems and cable protection is done onshore in the factory. This allows for productionised assembly and testing prior to shipment to turbine sites.

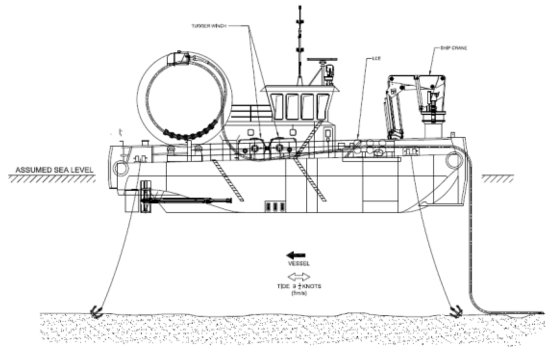

Figure 6. Vessel mobilisation and cable lay

The cable lay and connection procedure is carried out with one vessel mobilisation. The vessel is of minimal classification, resulting in the same vessel being used for pre-installation of the cable infrastructure and future disconnect reconnect maintenance regimes.

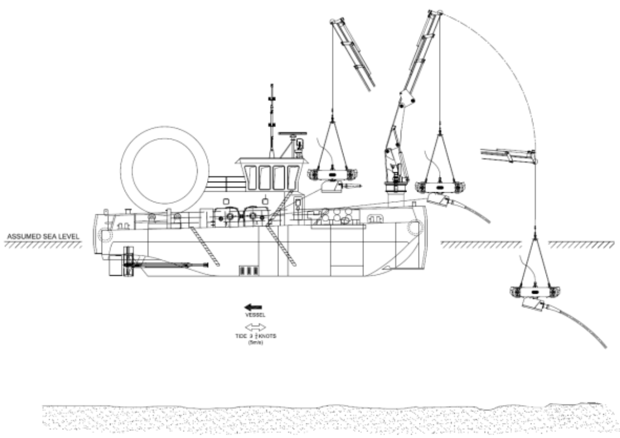

Figure 7. Positioning tool and CTH deployed from vessel

Ships craneage is used to deploy all parts of the system. The positioning tool remains latched to the CTH throughout deployment until the connectors are mated and confirmed.

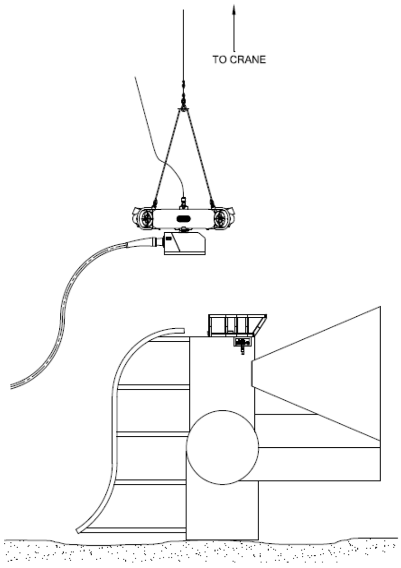

Figure 8. Alignment of CTH with Reciever Frame

The positioning tool is used to manouevre the CTH. Vessel motions are decoupled from the CTH and positioning tool when wet mate connector mating occurs.

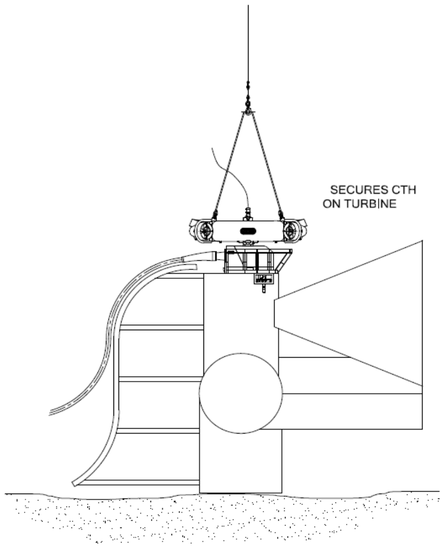

Figure 9. CTH and Reciever Frame engagement completed

Throughout any stage of the procedure, the positioning tool acts as the only seabed level intervention tool. It provides lifting, actuation and surveillance for all sub-systems.

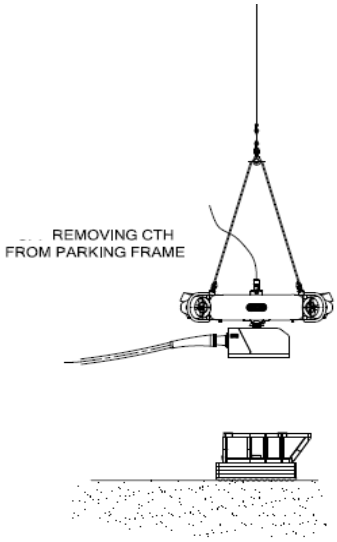

Figure 10. CTH deployment from Parking Frame

A subsea Parking Frame is used to deploy the CTH during cable lay prior to turbine deployment. It is used during the disconnection/reconnection regime ensuring that laid cable does not need be retrieved to the surface, thereby minimizing the risk of cable damage.

6.2 VESSEL REQUIREMENTS

A major consideration in the vessel selection process is to ensure that vessel costs are reduced as far as possible, a key factor being the ability to utilise a vessel with a low day rate. The deployment and recovery activities involved with the proposed connection solution and installation methodology can be undertaken using a Work Class Multicat vessel. The equipment and system supplied does not preclude its use for any vessel classification, sea state or tidal flow, allowing for the system to operate throughout the tidal cycle, reducing the time to install multi turbine arrays.

For the deployment scenario described above, the use of a Work Class Multicat vessel provides the following functions;

- Mobilisation of all CMS equipment and specialist tooling.
- Mobilisation of cable reel.
- Mobilisation of minimal personnel required for connection and cable lay (no ROV crew or diver support).

- Cable lay within tidal environment.
- Subsea cranes suitable for all subsea lifts during connection and recover.
- Station keeping within tidal flow at up to 5m/s.

7. CONNECTION SYSTEMS COSTS

The move from single unit testing toward full scale commercialisation and multiple unit array/farm developments will attract the benefits of economy of scale and prove favorable when capex/opex costs are evaluated throughout the whole life cycle. From our own engineering analysis we anticipate that a Siemens connection solution represents less than 2% of a typical 10MW farm development. Even though the overall cost impact of a wet mateable connection solution is low it has the potential to significantly influence costs in other areas.

Affordability is being addressed as shown by the proposal for a CMS as a cost effective connection 'system'. Through accelerating the development and de-risking of a CMS which incorporates new products focussed on cost and specification for high volume and low cost manufacture, a reduction in the cost of energy can be achieved. Today, for single unit manufacture the costs reflect a non recurring engineering (NRE) element and bespoke project specific solutions. For the future, towards arrays and farm deployment these increasing volumes will create the scope for significant cost reduction in the region of 80% compared with single unit production.

Indicative costs for a CMS at production quantities are shown in Figure 11 and presented against an anticipated timeline that such volume production may occur.

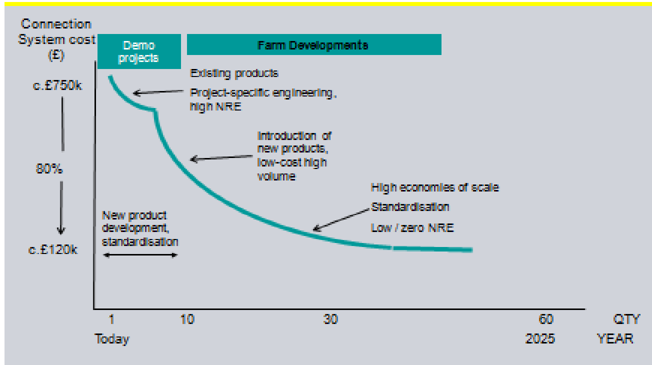

Figure 11. CMS cost curve

8. CONCLUSIONS

The scale of future arrays and farms will require a subsea connection infrastructure that can serve to maximise the availability of wave and tidal devices to deliver energy into the grid network. Wet mate connector methodology is a prerequisite to the affordability of large scale wave and tidal device deployments. The technology exists and is proven and reliable.

As the requirement for volume production increases so does the scope for cost reduction through new product development and standardisation while at the same time capitalizing on the reliability and pedigree of the original designs.

Initiatives have been set up to identify and address the gaps and barriers to the development of a wave and tidal industry; the current status of wet mate connector technology and the proposals for the design and deployment of an integrated subsea connection system solution strengthens this position to move forward.

ACKNOWLEDGEMENTS

CMS deployment sequence diagrams provided by Soil Machine Dynamics Ltd, Newcastle.

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