Wavebob – Research & Development Network and Tools in the Context of Systems Engineering

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Abstract

Following a sequential development path with growing model size Wavebob has in recent years gained valuable experience during large scale sea trials. For the important advancement from sea going models to full scale demonstration of pre-commercial prototypes a transition in the development process is required.

The implemented systems engineering approach enables Wavebob to effectively work within a powerful research & development network, efficiently employ a range of development tools and progress a number of parallel development threads. This paper described the concept of systems engineering in its application to wave energy converters (WEC), highlights its effectiveness in mitigating risk and accelerating the development process towards full scale demonstration of commercial operations.

Keywords: Research & development network, systems engineering, wave energy converter development.

1 Introduction and Motivation

In the development of wave energy converters a number of protocols and guidelines have been suggested over the years. During 10 years of research and development and following the Irish ocean energy development & evaluation protocol [1], Wavebob has completed small, intermediate and large model scale tests ranging from 1/100th to 1/4th scale. A selection of hydrodynamic model tests configurations at different model scales in wave basin, wave flume and in benign sea sites is displayed in Fig. 1.

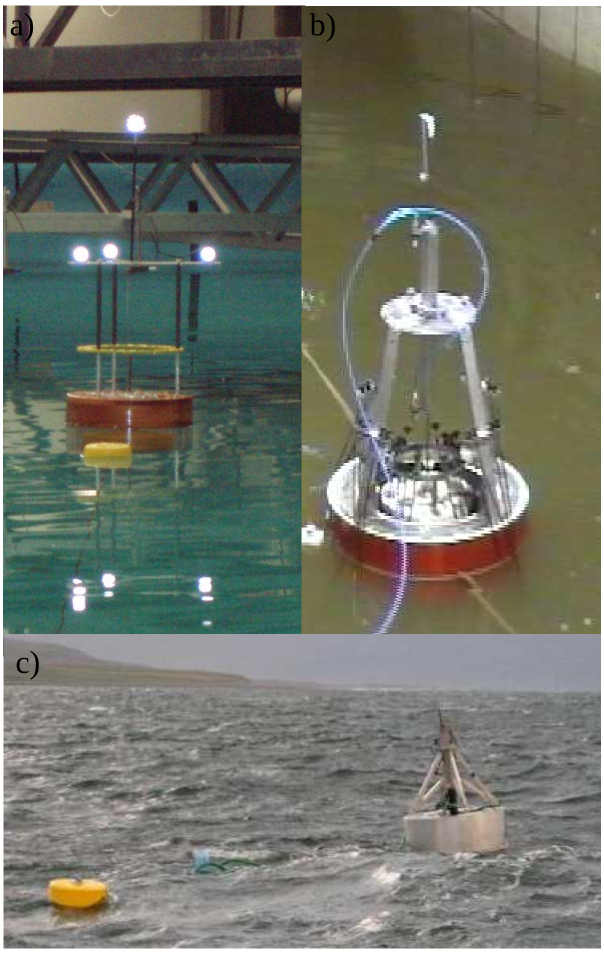

Figure 1: Wavebob scale physical model testing.
a) 1/75th scale model in wave basin,
b) 1/25th scale model in large wave flume,
c) 1/17th scale model during benign sea trials.

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Advanced development model (ADM) sea trials at 1/4th scale were undertaken in 2006 (ADM1), producing electricity from ocean waves for the first time in Ireland, and in 2007 (ADM2) confirming power absorption capability during sea operation; see Fig. 2. These important development stages were achieved under budgetary constraints, with acceptance of remaining risk factors, providing considerable learning and setting focus for further improvement.

Figure 2: Wavebob 1/4th scale sea going advanced development model 2 (ADM2) during sea trials in 2007.

For the important advancement from the large 1/4th scale sea going models to the full scale demonstration of a pre-commercial prototype, a transition in the development process is required. This transition is three-fold and comprises methodological, structural and institutional change:

- The sequential development following the increase in model scale is transformed into a **parallel development** utilising a number of scales and advanced models alongside a choice of numerical models of different complexity. This allows for the selection of the most efficient development tool for a particular aspect of the device development.
- The advanced model development is supported and continuously substituted by a **systems engineering** development approach. This is essential to reflect end-user needs as well as commercial production, operation and maintenance requirements in the design of the full scale engineering development models and WECs.
- The combination of in-house and external research & development components is extended to a **research & development network** comprising strategic partners, end users, research & technology partners and industrial subsystem developers. This provides the required framework and technological strength for pre-commercial engineering development.

In 2008 Wavebob have implemented these changes and embraced the systems engineering approach. The following sections are intended to give a concise overview of Wavebob's system development setup with regard to the concept of the adopted systems engineering approach, the structure of the R&D network and the range of R&D tools and methods utilised.

2 Systems Engineering

The systems engineering approach considers all lifecycle issues of the complete system rather than just the WEC or even just those of a functional model. It is used to capture the complexity of the system, its development process and to manage risk.

A common vision on the commercialisation strategy is built on the basis of three fundamental planning exercises. These result in detailed definitions of:

- Concept of Operations
  - "What we do"
- Programme Management Plan
  - "How we get there"
- Economic Models
  - "How we sustain it"

Based on identification of key market drivers the Concept of Operations defines operational scenarios right through from transportation, assembly, installation and commissioning to operation, maintenance, support and decommissioning. Fig. 3 illustrates the most common high demand application scenario of WECs deployed in a wave farm for electricity sale to the grid operator.

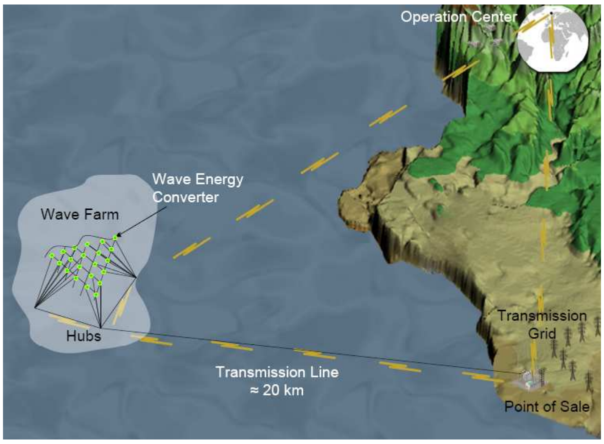

Figure 3: Systematic illustration of the wave farm operational scenario.

Other discrete targeted applications are equally analysed in detail. Based on the application scenarios the system is broken down at multiple levels identifying the system hierarchy as displayed in Fig. 4.

The resulting in-depth understanding of operation and maintenance plans in combination with the system hierarchy enables the analysis of system designs towards their failure mode effects. This provides quantitative information on statistical system availability and informs on the need for increased system redundancy or modularity, in turn providing invaluable information on the appropriateness of system designs at an early stage of the development.

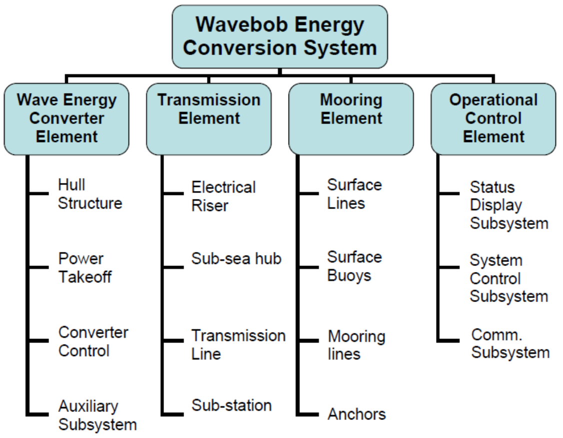

Figure 4: System hierarchy.

The Programme Management Plan integrates activities in three areas:

- Technology development,
- System development & demonstration,
- Operation & support planning

and distinguishes between

- Advanced Development Models (ADM),
- Engineering Development Models (EDM),
- Wave Energy Converters (WEC),

representing different stages of system integration. Their individual purpose and objective defines their distinction as outlined in Fig. 5.

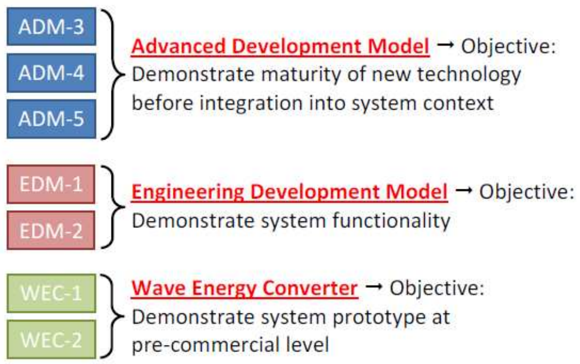

Figure 5: Definition of the development objectives of the different device development stages

For the advancement of the different development models a range of technology solutions for individual functionality of subsystems is required, examples are:

- Redundancy implementation of vital subsystems,
- Passive fail-safe systems,
- Modular connection solutions,
- Umbilical connection,
- Point load introduction into system structure, e.g. mooring connection,
- Kinematic and dynamic separation of force flux through structure and power take-off (PTO), e.g. linear and other bearing systems, PTO mountings,
- End-stop avoidance/protection solutions.

The development of these technologies is covered in separate development threads referred to as spirals. When the technological engineering solutions are designed, tested and ready, they are transferred over to be fitted and used in the advanced or engineering development models. The overall development scenario is illustrated in Fig. 6; – the Concept of Operations (CONOPS) defines the targeted system models which are developed individually in technology spirals and transferred to complement the system.

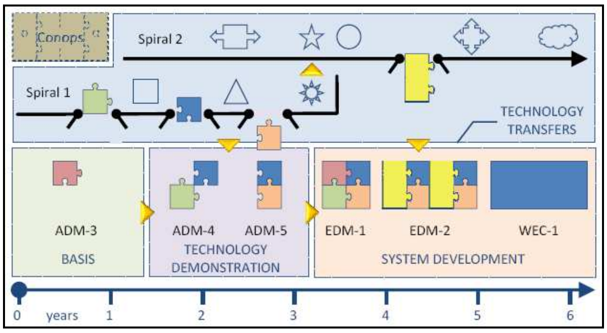

Figure 6: Illustration of the phased and concurrent structure of the Programme Development Plan.

The here described system engineering methodology in combination with the appropriately detailed documentation, comprising:

- Overall system specification and design base
- Diverse subsystem specification and design base
- Clear specification of subsystem interfaces

facilitates early detection of technology gaps and simultaneous progress of several focused subsystem development threads. These are essential prerequisites for the effective activation and cooperation of a large and powerful research & development network.

3 Research & Development Network

Particularly over the last 2 years Wavebob has managed to assemble a strong research and development network comprising recognised research institutions and expertise from mature and developed industries. The network is composed of:

- Research partners,
- Technology partners,
- Funding partners,
- Strategic partners,
- International support.

Strategic partners include end users, wave farm developers, power utilities, offshore oil and gas, marine operators and contractors and technology and component suppliers. Technology partners of essential subsystems assume the role of complete subsystem developers. The cooperation within the development network is built around an ethos of Open Innovation as illustrated in Fig. 7.

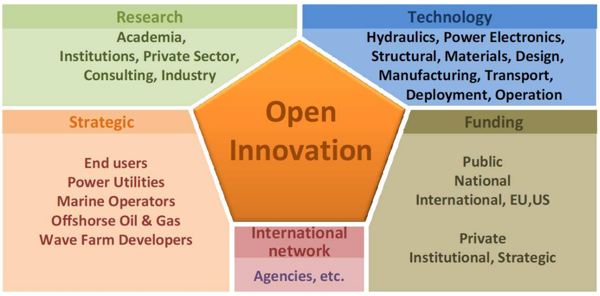

Figure 7: Wavebob research & development network.

4 System Research & Development Tools

With Wavebob being at the core of the development network the in-house research and system development tools reflect this focus. Thus the central columns of research and development methods & tools are empirical, numerical, strategic & methodological.

Empirical Modelling & Testing

- Reduced scale hydrodynamic physical modelling continues to prove an effective and efficient development tool. Different scales are employed and system refinement tests are conducted at small and large scale wave basins and at benign sea sites.
- Subsystem onshore bench testing, primarily of PTO hard and software is vital to ensure the system reliability and conduct experimental system improvements.
- System demonstration of large scale advanced and engineering development models at sea clearly continue to serve as the ultimate proof points for system function, survival and performance verification.

Numerical Modelling & Simulation

- Hydrodynamic modelling in frequency and time domain, based on linear and non-linear Laplacean Boundary Element Methods (BEM) and Navier-Stokes Computational Fluid Dynamics (CFD) solvers,
- Non-linear overall system dynamics including mooring systems
- Detailed and purpose built PTO models for hydraulic, electromechanical and power electronic subsystems,
- Control modelling of power absorption, conversion and delivery and overall system operation for simulation and operational control,
- Hybrid device modelling combining CFD and detailed PTO representations,
- Design systems linked with structural system simulation and analysis,
- Economical wave-to-wire modelling,
- Overall system parameter sensitivity analysis and system optimisation,
- Operational simulation and system animation.

Strategic & Methodological

- Detailed system specification, design base and subsystem interface definition,
- A range of methods closely associated with the systems engineering approach.

It is important to stress the value of growing and maintaining a wide spectrum of research and development tools. This is central in facilitating effective and rapid system development while reducing technological, strategic and corporate risk.

5 Technology Evolution & Intelligent Design

It is of the essence to emphasise a very specific aspect of wave energy converter development; a feature which is most simply described when first considering a technology development case of opposite character.

Wind energy converter technology has been developing and evolving over decades, even centuries. The development process has to date largely been one that is characterised by technological evolution. This has been due to a number of key factors including:

- Early convergence of converter system concepts,
- Technical feasibility, industrial production and market opportunity at all and growing scales,
- Availability of technological knowhow and experience in the theory, design, production and operation of very similar industrial applications,
- Cheap and easy access (onshore) to operating system, allowing gradual failure rate reduction during commercial operations.

These conditions have been providing a physical, industrial and economical environment suitable for technological evolution.

As opposed to the wind industry, WEC development is characterised by rather different circumstances:

- Large spectrum of different converter system concepts,
- Strongly decreased market opportunity at reduced scales,
- Limited transferability of technological experience, design, production and operation of similar industrial applications,
- Expensive and delayed access to operating system (offshore), prohibiting high failure rates from the onset of commercial operations.

Numerical implementation of evolutionary WEC system optimisation has proven to be immensely effective as shown in [2]. However, numerical methods are dependent upon parameterised representations of the system and are therefore mostly limited to a single species of WEC system concepts. At the same time fundamental system concept decisions are often made at the onset of a WEC development when technological challenges or e.g. the potential for optimised system performance can not be foreseen. There are a number of WEC system developments that have suffered from these circumstances.

6 Conclusion

The implementation of the systems engineering approach has proven invaluable in many respects.

The method ensures to the highest possible level the essential identification of technological barriers at an early enough stage of the system development, alleviating unnecessary technology cost, reducing development, operational and corporate risk, while shortening the development time.

Further, it is an effective strategy to structure, interface and control the research & development tasks within a focussed, powerful and highly qualified research & development network. Within the network Wavebob is in a position to concentrate on the core WEC system development activities. Major subsystems are being development by overall subsystem technology partners in conjunction with corresponding in-house expertise.

The clear identification and specification of the multi-layered subsystem elements allows concurrent and independent development threads to provide designed and tested technology solutions for integration into advanced and engineering development models.

The evident analysis of the WEC technology development environment with respect to the limited opportunity for evolutionary technology development identifies the necessity for intelligent design. These circumstances clearly underline the importance of implementing a well-structured development approach to minimise corporate and technology risk and to give the optimised exemplar of the developed ‘species’ the best opportunity to survive and efficiently deliver in the given economical and operational conditions.

Summarising the improvements associated with the systems engineering and development methodology and more so, analysing the findings and experience of the wave energy community as a whole, the following proactive recommendations are made:

- Fully recognise the challenges in their entire complexity,
- Embrace these to the necessary depth and detail,
- Put a sound and proven methodology in place,
- Assemble a strong R&D network,
- Equip the R&D network with appropriate tools,
- Optimise and refine overall- and sub-systems,
- Maintain a targeted development path,
- Ensure identification and prevention of possible cul-de-sacs in the development at the earliest stage possible,
- Be prepared to consider the initially set conceptual system perimeter when significant needs or options become apparent.

Given the fundamentals of the Wavebob WEC concept, a decade of development experience, the strength of the research & development network, the access to a wide range of development tools and the effective process and control of systems engineering in place, Wavebob is well positioned in the arena of WEC developers.

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References

[1] HMRC & Marine Institute Ocean Energy: Development and Evaluation Protocol, Ireland, 2003.

[2] A. Babarit. Hydrodynamic optimisation and optimal control of wave energy converters. In *Workshop on WEC system optimisation*, NUIM Maynooth, Ireland, 2009.