Institution: University of Manchester

Unit of Assessment: UOA14 Civil and Construction Engineering

Title of case study: Accelerated development of a tidal stream energy industry

1. Summary of the impact

Our research has been key to the development of investor confidence in an emerging UK tidal stream industry. We have contributed to the development and validation of commercial and open-source software for tidal stream system design and our expertise has been instrumental to the successful delivery of major objectives of two national industry-academia marine energy projects commissioned by the Energy Technologies Institute (ETI). Taken together, these outcomes have reduced engineering risks that had been of concern to potential investors. Investor confidence in tidal energy has been increased, as highlighted by Alstom's £65m acquisition of a turbine developer following a key outcome of the ETI ReDAPT project.

2. Underpinning research

The key researchers are:

Professor Peter Stansby (1990-date)
Dr David Apsley, Lecturer (2000-date)
Dr Tim Stallard, Lecturer (2006-date)
Dr Imran Afgan, Lecturer (2010-date)

Our research on tidal stream systems has addressed the development and validation of computational methods for prediction of the power output from arrays (farms) of tidal stream turbines [1] and of the unsteady loading of tidal stream turbines in realistic tidal flows [2]. This builds on research into wave energy arrays [3], CFD methodologies [4] and the physics of shallow water flows [5]. The key outcomes have been to:

1) Quantify the influence of hydrodynamic interactions on the loading and power output of closely spaced groups of horizontal axis tidal stream rotors. This was enabled by the:
   a. Development of unique experimental equipment for friction compensation systems to represent individual generators at a sufficiently small scale to study the loading and performance of multiple devices at a laboratory scale [3].
   b. Development of unique experimental equipment for the generation of both turbulent flow and wakes that are representative of a full-scale turbine [1].
   c. Design, conduct and analysis of an experimental study of the loading and wake of multiple configurations of tidal stream turbines [1].

2) Develop and validate Computational Fluid Dynamics (CFD) methods with High Performance Computing for prediction of the time-varying loads on a tidal stream turbine subject to turbulent flow. This has been achieved by the:
   a. Development and evaluation of a methodology for simulation of fluid flow past a rotating turbine within close proximity to a stationary support structure and within a much larger channel flow [4].
   b. Simulation of the characteristics of the turbulent flow measured at a full-scale tidal stream test-site at the European Marine Energy Centre (EMEC) accounting for complex tidal turbulence [2] by use of Synthetic Eddy Methods previously developed by another group at The University of Manchester.
   c. Evaluation of the influence of CFD methodology, including both Reynolds Averaged Navier Stokes (RANS) and Large Eddy Simulation (LES) methods, on the accuracy of load predictions by comparison to scaled experiments and full-scale data from field trials [1,4].

3. References to the research

The outcomes of this marine energy research have been published in leading academic journals, international conferences, PhD theses and industrial reports.

Key Publications:

[1] Stallard, T, Collings, R, Feng, T and Whelan, J., 2013 Interactions Between Tidal Turbine Wakes: Experimental Study of a Group of 3-Bladed Rotors. *Phil. Trans. Royal Society Part A*. 371, 20120159. doi:10.1098/rsta.2012.0159

[2] Afgan, I, McNaughton, J, Rolfo, S., Apsley, D.D., Stallard, T and Stansby, P.K., 2013 Turbulent flow and loading on a tidal stream turbine by LES and RANS. *International Journal of Heat and Fluid Flow*. (In press, online 17 Jun 2013) DOI: 10.1016/j.ijheatfluidflow.2013.03.010

Further Publications:

[3] Weller, S.D., Stallard, T.J. and Stansby, P.K., 2010 Experimental measurements of irregular wave interaction factors in closely spaced arrays. *IET Renewable Power Generation*. 4(6), 628–637. DOI: 10.1049/iet-rpg.2009.0192,

[4] McNaughton, J. 2013 Turbulence modelling in the near field of an axial flow turbine using *Code_Saturne*, PhD dissertation University of Manchester, provided as ETI reviewed technical report for EDF and ETI ReDAPT project.

[5] Stansby, P.K. 2003 A mixing length model for shallow turbulent wakes, Journal of Fluid Mechanics, 495, 369-384. DOI: http://dx.doi.org/10.1017/S0022112003006384

4. Details of the impact

Context

The development of a marine energy industry in the UK, with tidal stream a major component, is forecast to generate more than 68000 jobs, 20% of electricity supply and an export market valued at more than £70bn (House of Commons Select Committee, HC1624, 2012). It has been widely recognised (UKERC, DECC, ETI) that investors would only make a significant commitment to tidal stream development after several key engineering developments had been made including:

i) development and validation of engineering models to predict energy yield, and hence revenue, from commercial scale farms
ii) demonstration of deployment and operation of a commercial scale turbine,
iii) development and validation of engineering tools to enable system refinement, and hence cost reduction,
iv) increased understanding of the environmental flows at tidal stream sites pre- and post-deployment.

Pathways to Impact

To ensure rapid exploitation of research findings and methods, our research has been conducted in close collaboration with leading engineering companies including EDF, GL-Garrad Hassan, Alstom Ocean Energy and EON. In particular, Manchester has contributed to the national projects PerAWaT (Performance Assessment of Wave and Tidal Array Systems) and ReDAPT (Reliable Data Acquisition Platform For Tidal). Both projects were commissioned by the Energy Technologies Institute (ETI) and focused on the engineering topics recognised to be of major concern to potential investors. Much of the work on these projects has been documented in peer-reviewed technical reports that are confidential to the ETI and industrial contributors. This well-managed approach has enabled industry exploitation of our research in parallel with publication.

Specifically, Manchester researchers have:

1. Developed experimental methods that have led to high quality experimental data on the

loading and wakes of tidal turbines in arrays. The understanding and data from these experiments has "***contributed to the development of GL-Garrad Hassan commercial software tool GH Tidal Farmer***" [C]. This software enables independent assessment of energy yield, and hence revenue, from tidal stream farms – a key requirement of energy project investors.

2. Developed CFD methods for massively parallel computing to enable the simulation of turbines and their supporting structures due to complex tidal flows representative of a real tidal stream test site. These methods have been implemented in the EDF open-source CFD solver Code_SATURNE. These numerical tools are "***important to the tidal stream industry since they allow detailed evaluation of design options prior to field trials***." [D]. This has reduced the dependence of product development on full-scale field trials that typically cost several million pounds per turbine. These methodologies are also being used by EDF to analyse different locations and sizes of offshore wind farms with the approach proving "***useful, as most of our [EDF] previous work has been in CFD of power generation from nuclear or fossil fuel source or turbo-machinery CFD, which are quite different areas***." [B].

3. Developed and conducted CFD simulations and informed field studies of tidal stream flows to provide data "***used to develop and validate GL-Garrad Hassan commercial software including Tidal Bladed***" [C]. This software is a design tool for tidal turbines based on an existing code – GH Bladed – for wind turbine design. Validation of such models specifically for tidal stream turbines has addressed one of the key engineering risks identified by investors.

4. Contributed to expert panels and management committees of national projects. In 2008 Professor Stansby was invited to join the Severn Tidal Power Feasibility Study expert panel on behalf of the Royal Academy of Engineering. This appointment was based on recognised expertise in coastal hydrodynamics including wave effects, turbulent coastal flows and marine turbines and complemented the expertise of the five other panel members. One option under consideration was a tidal fence or row of tidal stream turbines. Since 2009, Manchester researchers have contributed to the steering and technical committees of the national industry-academia projects ReDAPT and PerAWaT commissioned by the Energy Technologies Institute (ETI). On ReDAPT Manchester researchers are subcontracted by the project partner EDF. These roles have been instrumental in ensuring the effective delivery of key project outcomes focused on development of engineering credibility to reduce investment risk.

Reach and Significance

Manchester's research has increased investor confidence in tidal stream energy systems. Research outcomes have been "***critical to the development and validation of tidal stream modelling tools***" [A]. This includes commercial software for farm energy yield predictions and both open-source CFD and commercial software for turbine design. Increased understanding of array energy yield prediction methods has been developed that "***reduces the investment risk of marine energy project developers; this is critical to stimulating investment in early farms to enable the industry to grow.***" [A]. CFD methods have been developed and evaluated that have improved understanding of complex tidal flows and their influence on turbine loading. This CFD capability has enabled ***"further de-risking of the tidal turbine design process, providing increased turbine system robustness and commercial attractiveness"*** [A]. High quality data from CFD simulations and from field trials informed by our research have also been used to evaluate the GL-Garrad Hassan turbine design software Tidal Bladed.

Taken together, the models that have been developed and evaluated and the other outcomes of the ETI projects to which we have contributed have addressed the main engineering risks that had been identified as barriers to investment in tidal energy. Increased investor confidence has been demonstrated by the £65m acquisition of Tidal Generation Ltd by Alstom from Rolls Royce during 2013 [E]. This acquisition was completed following a key outcome of the ETI ReDAPT project [F].

The findings and process of our research have therefore had a significant impact on industrial investment in an emerging industry with recognised value to the UK.

5. Sources to corroborate the impact

Corroboration letters have been provided by the following to confirm the contributions of research conducted by the University of Manchester:

[A] Letter from Deputy Chief Engineer, Energy Technologies Institute confirming the contribution to the projects ReDAPT and PerAWaT and the significance of specific outcomes of the research to the tidal industry.

[B] Letter from Turbulence and CFD expert research engineers, EDF R&D confirming the inclusion of the CFD models in Code_Saturne.

[C] Letter from Head of Marine Energy Group, GL Garrad Hassan confirming the contribution to development and validation of software tools TidalFarmer and TidalBladed and to the effective delivery of ETI projects.

[D] Letter from ReDAPT programme Manager, Ocean Energy, Alstom confirming the contribution to the ReDAPT programme and the significance of the CFD model developments to the tidal stream industry.

In addition the following public documents confirm related facts:

[E] Wave and Tidal Energy in the UK: Conquering Challenges, Generating Growth, Renewable Energy UK Report, February 2013, (Page 5).

[F] Announcement of Alstom acquisition of Tidal Generation Ltd.
http://www.tidalgeneration.co.uk/content/news (dated 30/01/2013)