Institution: 10007857 – Bangor University

Unit of Assessment: UoA 11

Title of case study:
Enhancing of National Grid Stability via optimisation of "Dinorwig Hydro Power Station"

1. Summary of the impact (indicative maximum 100 words)

Our work has facilitated the creation of a variety of innovative control strategies for First Hydro Company (FHC), owner of Europe's largest pump storage plant. FHC's two plants are both supported by the simulation platform developed as part of our research and responsible for balancing load variation on the National Grid. Critically, FHC's business model relies on their ability to provide ancillary services within a short time. Our research produced a comprehensive plant model, and was used to enhance the dynamic response of the Dinorwig station; this resulted in improvement in National Grid stability and has provided competitive advantages to FHC since 2008.

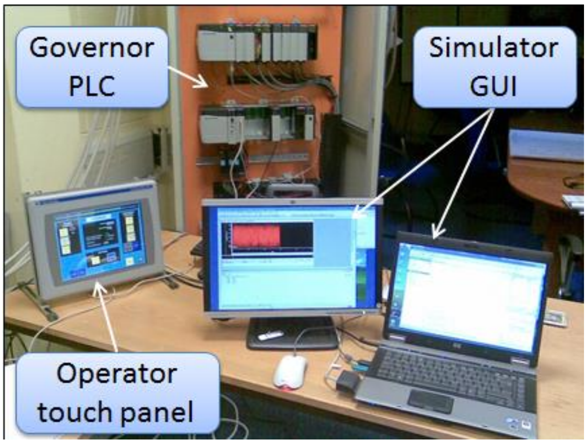
2. Underpinning research (indicative maximum 500 words)

The research underpinning this case study started in 1999 when Dr Mansoor joined Bangor and was awarded a research contract from FHC. Subsequently (from 2002-2012), Bangor University's School of Computer Science provided key R&D expertise in modelling and simulation techniques to analyse and improve the operation of FHC's Ffestiniog and Dinorwig Hydro Plants.

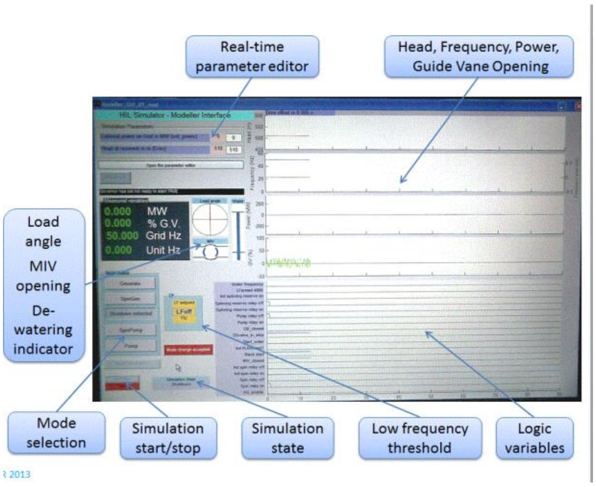
Modelling operational performance conditions
Specifically relevant to this case study, in 1999 we developed a comprehensive model of the Dinorwig power station and the National Grid System. We successfully modelled all important aspects of the energy generation process in a way that allowed us to simulate different operating conditions at both the plant and on the National Grid and so predict the performance of the station under varying conditions **[1]**.

Control system function analysis
In 2002 we completed a detailed analysis of the effect of National Grid load variations on the performance of the Dinorwig plant **[2, 3]**. The study demonstrated that the original control system was overly conservative as its control parameters were more suitable for base load supply stations (conventional hydro power) and not optimal for ancillary services (frequency control). We also found that control parameters are highly sensitive to the overall grid load size; this led us to conclude that the station's original control setting had been using a non-optimal setting derived from the assumption of a smaller than actual grid size. An improved control system has been developed based on existing systems; this has led to improvements in the ancillary response time of the station's generation system.
Subsequently, we pursued a new research direction, and in 2004 we successfully developed new control systems using neural networks, fuzzy logic and feed forward techniques, for the first time at this type of plant. These systems are have been evaluated and the results show that it is possible to construct a superior control system with these technologies **[4, 5]**.

Simulation system development
The next major milestone was the development of a real time "Hardware in the Loop" simulation system for the Ffestiniog hydro power station in 2008, which implemented a non-linear, multiple-input and multiple-output (MIMO) model that provided a means to test a variety of on-going modifications of the station's control systems. Without the simulator the company would have been unable to undertake this development work. This approach provided valuable insight into the workings of the plant as well as allowing the testing of new control systems prior to installation at Ffestiniog power station **[6]**. In 2010, after the successful implementation at Ffestiniog, we developed a similar simulator with some additional functionality for Dinorwig Power station.



Simulator Architecture



Graphic User Interface

The key members of the School of Computer Science research team involved in this work are:

- Dr Sa'ad Mansoor, Senior lecturer and Head of the School of Computer Science 1999-present
- Dr Dewi Jones, Senior lecturer at Bangor University 1980 - 2009. Currently serving as a director of Gwefr Cyf ltd.
- Dr German A. Munoz-Hernandez, Bangor University 2003 - 2007, currently at Instituto Tecnologico de PueblaAv. Tecnologico 420 Puebla, Mexico.

3. References to the research (indicative maximum of six references)

Bangor University contributors to the following publications are highlighted in bold, other authors are industry partners from FHC.

[1] **D.I. Jones, S.P. Mansoor**, F.C. Aris, G.R. Jones, D.A. Bradley, D.J. King, A standard method for specifying the response of hydroelectric plant in frequency-control mode, Electric Power Systems Research, Volume 68(1), 19-32, 2004. (Previously submitted to RAE 2008). DOI: 10.1016/S0378-7796(03)00152-4

[2] **D. I. Jones**, Estimation of power system parameters, IEEE Trans Power Systems, Volume 19(4), 1980-1989, 2004. DOI: 10.1109/TPWRS.2004.835671

[3] **S. P. Mansoor**, **D. I. Jones**, D. A. Bradley, C. Aris, and G. Jones, "Reproducing oscillatory behaviour of a hydroelectric power station by computer simulation," Control Engineering Practice, Volume 8(11), pp. 1261-1272, 2000. DOI: 10.1016/S0967-0661(00)00068-X

[4] **D. I. Jones, S. P. Mansoor**, "Predictive feedforward control for a hydroelectric plan," IEEE Transaction on Control Systems Technology, Volume 12(6), 956-965, 2004. (Previously submitted to RAE 2008). DOI: 10.1109/TCST.2004.833405

[5] **G.A Munoz-Hernandez**, Gracios-Marin, CA, Diaz-Sanchez, A**, S.P. Mansoor, and D. I. Jones,,** "Evaluation of neural PDF control strategy applied to a nonlinear model of a pumped–storage hydroelectric power station", Proc. IEEE Conference on Informatics in Control, Automation and Robotics, Funchal, Madeira – Portugal (2008). A copy of this output is available on request

[6] **S. P. Mansoor**, **D. I. Jones**, DI, Bradley, DA, Aris, C, Jones, GR, Hardware-in-the-loop simulation of a pumped storage hydro station, IASTED Journal of Power and Energy Systems, 23(2), 127-133. (Previously submitted to RAE 2008).
DOI: 10.1016/j.rser.2005.06.003

4. Details of the impact (indicative maximum 750 words)

The primary impact of our work has been ongoing performance improvements on FHC plants. This has delivered substantial economic benefits to FHC and indirectly improved National Grid Stability. Through the establishment of a company Gwefr Cyf Co in October 2007, (5.1) the research continues to feed directly into information technology consultancy activities and benefit a range of local and national companies.

FHC's Dinorwig plant is the largest pump storage station in the UK (the second largest in Europe) and therefore is vital to the National Grid infrastructure, ensuring stability of electricity supply nationally under highly dynamic grid-load perturbations. By generating up to 1.8GW within 16 seconds upon demand from the grid, the plant gives the grid fast effective energy storage. The increasing emphasis on renewables such as wind power within the national energy strategy, places additional focus on the importance of FHC plants. The latter has been highlighted by the Chief Scientific Adviser, who has suggested that the UK needs more pump storage plants in order to balance the power supplied by wind turbines (5.2).

Ongoing impacts of interventions carried out 1999-2008
Our model has been utilised for numerous projects at Dinorwig since 1999. The initial modelling [3.1], for example, was used to investigate a serious incident on the Grid in 1999 involving unwanted oscillations in the range 49.9 – 50.1 HZ. We demonstrated that this was incorrectly attributed to a problem at Dinorwig. The National Grid Regulator originally attributed blame to FHC and as a consequence FHC was liable for substantial contractual penalties. The Regulator accepted our findings however, and new control procedures were put in place to prevent similar events occurring in future [3.3]. This demonstrates a direct and ongoing impact of our model on the improved control and regulation of National Grid oscillations (5.3).

Additionally, the model has provided insight into complex interactions between different components of plant operating dynamics. As a direct result a new operational strategy was put in place using our control parameter recommendations. This lead directly to an improvement of around 10% to the plant's response time. Without the availability of our modelling and simulation techniques to develop and test it would not have been feasible to explore new control strategies due to operating constraints. The resulting improved performance continues to provide direct financial benefits to FHC and a permanent improvement to maintaining grid stability (5.3).

Real time simulator impacts on FHC performance
In 2008, our research was used by FHC to upgrade the control system at the Ffestiniog power station. Prior to commissioning, the new hardware needed testing to ensure its correct operation. Without this reassurance, FHC could not commit to any upgrade due to the unacceptable costs involved with a potential failure. Our real time hardware in the loop simulation platform demonstrated that the proposed platform produced the same response as the real plant across different operating conditions [3.6]. This gave the company the necessary confidence to commission a new control unit in June 2008 (5.3).

In 2010, FHC planned to upgrade the control system at Dinorwig. A new simulator platform was developed in collaboration with Gwefr Cyf Co. [3.6], it was able to accurately reproduce the response of the real plant, and therefore could be used to validate the new hardware. This lead to the commissioning and installation of a new control unit in May 2012 (5.4).

Our findings have a direct, ongoing and fundamental impact on the FHC plants. Without the simulator the time required to test the new unit would be prohibitively long and the process would be dangerous as it could cause serious damage to the plant. Without this work commissioning becomes prohibitively expensive. In addition to this direct financial impact from reduced commissioning time-- one unit generating at 300MW for 8 hours produces about £36,000 revenue per day. The simulator is also being used by FHC for training purposes, providing direct benefits in staff knowledge and skills (5.3).

In addition, Mansoor et al. have jointly published Modelling and Controlling Hydropower Plants; a book that provides both practising professionals and academics with necessary information on models used for simulation and control analysis of hydropower stations, enhancing the reach of the applications and wider use of their models (ISBN 978-1-4471-2291-3 Springer 2012, see (5.1)).

5. Sources to corroborate the impact (indicative maximum of 10 references)

(1) Company Gwefr Cyf Co. website http://www.gwefr.co.uk/ can confirm the activities of this company.
(2) BBC news coverage on the Dinorwig plant (June 2011) is available at: http://www.bbc.co.uk/news/business-13725906, including reference to the government's chief scientific adviser on the importance of pump storage plants for National Grid stability in order to balance the power supplied by wind turbines.
(3) The head of Control and Instrumentation at First Hydro Company can be contacted and can corroborate all claims of impact of the research on First Hydro Company.
(4) An email conversation from the head of Control and Instrumentation, First Hydro Company, (01/08/2012) is available on request.