CORA Cork Open Research Archive
Cartlann Taighde Oscailte Chorcaí

Title	Designing laboratory experiments for electricity grid integration of renewable energy using microgrid, test-rig emulators and real time simulation tools
Authors	Murray, Donal B.;Erdogan, Nuh;Alparslan, Zehir;Hayes, Barry P.
Publication date	2021-07-14
Original Citation	Murray, D. B., Erdogan, N., Alparslan, Z. and Hayes, B. P. (2021) 'Designing laboratory experiments for electricity grid integration of renewable energy using microgrid, test-rig emulators and real time simulation tools', EESD2021: Proceedings of the 10th Engineering Education for Sustainable Development Conference, 'Building Flourishing Communities', University College Cork, Ireland, 14-16 June.
Type of publication	Conference item
Link to publisher's version	https://www.eesd2020.org/, http://hdl.handle.net/10468/11459
Rights	© 2021, the Author(s). This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License - https://creativecommons.org/licenses/by-nc-nd/4.0/
Download date	2026-11-14 16:44:31
Item downloaded from	https://hdl.handle.net/10468/11674

UCC
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

Designing Laboratory Experiments for Electricity Grid Integration of Renewable Energy using Microgrid, Test-Rig Emulators and Real Time Simulation Tools

Donal B. Murray[1], Nuh Erdogan[1], Alparslan Zehir[1] and Barry P. Hayes[2]

[1]Marine and Renewable Energy Centre, University College Cork, Cork, Ireland

[2]School of Engineering, University College Cork, Cork, Ireland

donalbmurray@ucc.ie, nuh.erdogan@ucc.ie, alparslan.zehir@ucc.ie, barry.hayes@ucc.ie

Abstract

This paper describes efforts to integrate advanced approaches in microgrid, test-rig emulators and real time simulation into early postgraduate and undergraduate engineering education. It describes two experiments designed for groups of early stage researchers and postgraduate students in the field of Offshore Renewable Energy (ORE). These electrical laboratory experiments are part of a H2020-funded weeklong training course and focus on a medium speed rotary emulator for wave energy applications, and a wind turbine emulator that demonstrated the operation of a Doubly-Fed Induction Generator (DFIG) in a two-machine coupled rig. This paper also discusses some initial reviews of the training course. These reviews noted that students had a desire for more hands-on experimental work, and that the requirements to cover electrical safety material limited the amount of effective time available for experimental work. Finally, the paper outlines some approaches for improving the design of future laboratory experiments in this area.

1 Introduction

Traditional approaches to electrical engineering education use laboratory experiments based on standard, small-scale machine test rigs, and power system computer modelling packages (Heydt & Vijay, 2003), (Feisel et al., 2002), (Reed & Stanchina, 2010), (Kezunovic et al., 2004). While these are important and beneficial educational tools, the evolution of laboratory-based teaching over recent decades has been slow relative to the pace of change in industry. The combination of financial restrictions within university departments and increased levels of health and safety regulation can make the installation of high-cost, high-power teaching equipment very difficult. This can lead to a large gap between the curriculum of electrical engineering programs and the reality of modern industrial technology and techniques.

At the same time, a significant amount of research activity in Ireland and many other countries has moved out of university departments and into academic and industry research centres in recent decades (SFI, 2019). This approach has significant advantages, as it concentrates applied research activities and resources in strategic areas, and enables the development of research institutes that are closer to industry. However, one drawback in moving applied research from universities to external research centres is a greater separation of research activity from teaching activities. To help address these issues, this paper describes efforts to utilise advanced research infrastructure in the Marine and Renewable Energy Centre of Ireland (MaREI) for early postgraduate and undergraduate teaching purposes. The motivation of this work is to expose students to modern industrial technology and techniques in the teaching of electrical engineering and sustainable energy technologies.

MaRINET2 is a H2020 funded project on the integration and enhancement of European research infrastructures specialising in Offshore Renewable Energy (ORE) systems (Marinet2, 2019). One of the objectives of this project is to offer high-quality training relevant to ORE to academia and industry through short courses with a strong hands-on component. This includes hardware-in-the-loop (HIL) testing and simulations that provide students with opportunities to work with real-data obtained from sea trials. This approach is particularly useful when it is difficult to get access to actual ORE systems or when it is too risky to test various control schemes directly on the ORE converter (Mojlish et al., 2017). This cross-disciplinary short course took place in November 2019 at University College Cork (UCC) where relevant electrical laboratory training and experiments were performed at MaREI on the 28th November. Four groups carried out two experiments each on modelling and hardware-in-the-loop (HIL) simulation work. These models were emulated and tested on laboratory rotational rigs with power exported to the facility's microgrid or local grid. Industry specific learning outcomes are highlighted, and a comparison of current student engineering experiments with these newly developed experiments and teaching opportunities from the local linked research centre are carried out, with recommendations for improvement noted.

2 MaREI Electrical Testing Facilities for Marine Renewable Energy

The MaREI Electrical Laboratory in the Lir National Ocean Test Facility, at Ringaskiddy, Cork, Ireland, presents a range of electrical test infrastructures to help prepare marine renewable energy converters for sea trials. It consists of medium and high-speed rotary emulators, real-time hardware platforms and a microgrid. As such, using sea-trial data from actual ORE plants, various control algorithms for ORE converters can be developed, validated, and verified with the emulators. The configuration of the microgrid also allows models to be tested with various grid configuration and operation options. Figure 1 demonstrates the difference between sea trials, simulation work, and hardware emulation.

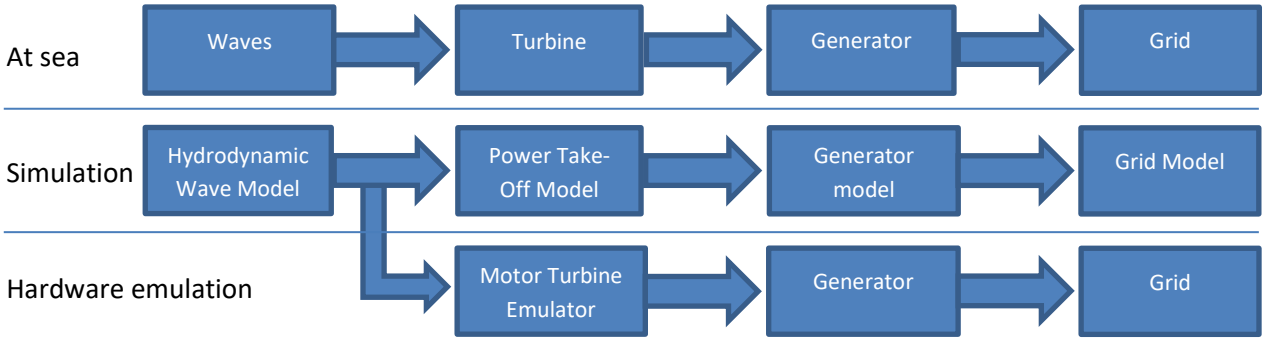


Figure 1: Sea testing Versus Simulation Versus Hardware emulation

Below, the configurations of the infrastructure are given first. Then, the HIL test and simulations performed at the training are described in detail.

2.1 Medium Speed Rotary Emulator

The medium speed rotary emulator is an electromechanical system used to replicate a rotating electrical power take-off (PTO) system for an Offshore Renewable Energy device and is shown in Figure 2 (Erdogan et al., 2019). The emulator is composed of two electrical machines directly coupled by a mechanical shaft with a torque transducer. The mechanical drive shaft also includes a flywheel, connected to the system by

a five-position gear box. The flywheel allows the drive shaft to be coupled to one of five different inertial masses, which can replicate the inertia of a system being tested. The prime mover, which is used to emulate the forces applied by an ORE turbine, is a 4-pole squirrel cage induction machine, rated 22 kW. The generator is a re-configurable slip-ring 4-pole induction machine, also rated 22 kW, where the rotor can be set in multiple configurations depending on the system which is being emulated. Speed and torque control of each machine is achieved by variable frequency drives. The full system is controlled by a Programmable Logic Controller (PLC), the industrial standard for operating dedicated power systems equipment.

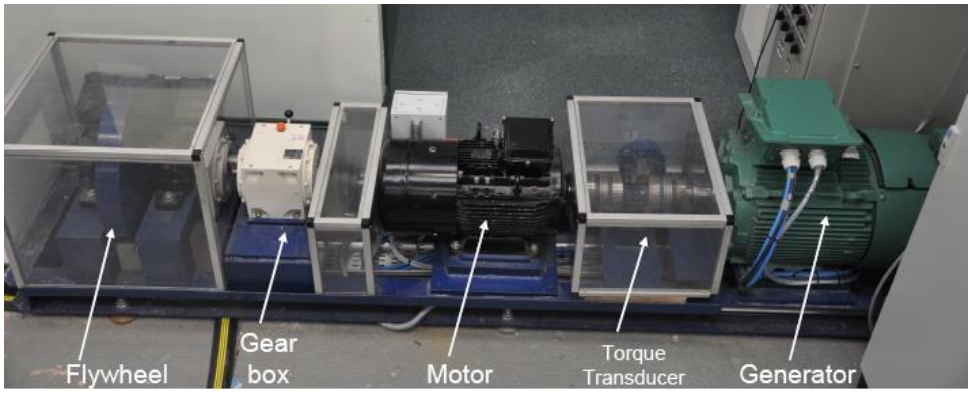


Figure 2: Drive train elements of the medium speed rotary emulator

HIL functionality is achieved with a multi-core CPU based real-time platform (e.g., *Speedgoat real-time machine*) that allows the emulator to fully integrate with software models running on MATLAB/Simulink. Conditions modelled in Simulink are relayed to the emulator machine, and the conditions of the physical hardware are fed back into the running model to affect outputs and complete the loop in real-time.

2.2 Microgrid

The microgrid is a dual bus, three-phase, 400 V local grid that can operate autonomously or in parallel with the distribution grid (Figure 3). The microgrid contains various sources and loads, as well as bi-directional power converters using real-time models that can emulate different loads, allow utilisation of energy storage, or emulate grids of different voltages and frequencies. The system contains an integrated supervisory control and data acquisition (SCADA) system, with high-frequency-sampling measuring equipment from National Instruments (NI) running on LabVIEW software. This equipment allows accurate measurements of voltages and currents, capturing their harmonic content and the effects of the control of the used hardware and software.



Figure 3: MaREI microgrid distribution panel

2.3 Wind Turbine Emulator

A modular and reconfigurable 5 kVA electrical power take-off kit for wind to wire system education in a university was purchased from Triphase NV. This kit consists of:

- Power conversion building blocks and filters suitable for motor drive and converter control
- Real-time control platform with MATLAB/Simulink programmable inverters and measurements
- Software libraries and examples to facilitate the design of applications

The specific lab setup is shown in Figure 4 where a Permanent Magnet (PM) machine emulates a wind turbine driving an induction machine configured as a doubly fed induction generator (DFIG). A model operating the power converters in real-time executes on a dedicated Linux based PC, with inputs to the operator PC allowing participants investigate voltages, currents and speed.

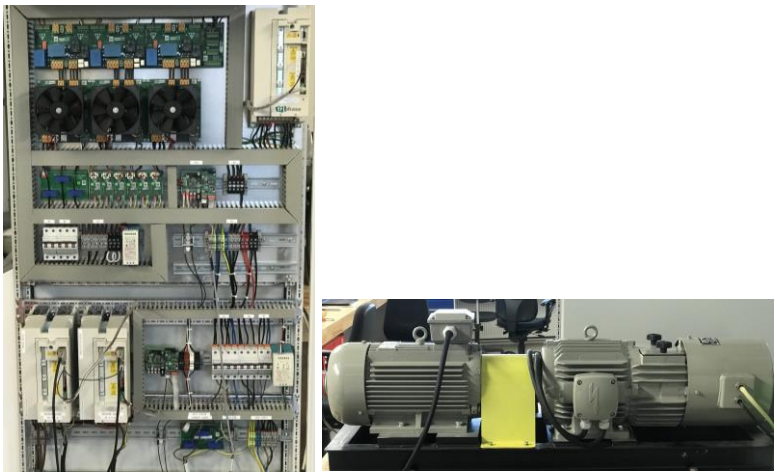


Figure 4: DFIG based wind turbine emulator and its driver

3 Course setup and comparison to typical lab setups

3.1 The MaRINET2 Course

Table I: Electrical lab schedule

9.00	G2: Safety presentation and Background and powers presentation	
9.45	G2A Medium speed emulator	G2B Wind turbine emulator
11.15	Break	
11.30	G2B Medium speed emulator	G2AWind turbine emulator
1.00	Lunch	
2.00	G1: Safety presentation and Background and powers presentation	
2.45	G1A Medium speed emulator	G1B Wind turbine emulator
4.15	Break	

4.30	G1B Medium speed emulator	G1A Wind turbine emulator
6.00	Finish	

The MaRINET2 training consisted of a week-long short course for 20 participants on integrated tank testing for the Offshore Renewable Industry. It was jointly run by Ifremer, Technalia and UCC, focussing on a mix of presentations, case studies, lab work and project work. The electrical lab and testing work occurred on Thursday the 29th November, with the 20 participants divided into four groups. The electrical schedule is shown in Table 1 with each experiment having one supervisor.

This course was targeted towards early-stage researchers and postgraduate students, and the participation of interested applicants from industry, private sector companies, research groups, educational institutions was encouraged. For this course it was found that very few participants had an electrical/electronic engineering background. This led to the following desired learning outcomes for the laboratory:

1. Develop a healthy fear of electricity, and understand some best practice safety guidelines
2. Experience what is involved in electrical lab testing
3. Understand and appreciate Sea testing versus Simulation versus Hardware Emulation
4. Electrical equipment identification
5. Three phase power understanding

This course did not have a marked assignment. Participants followed a lab manual per experiment with supervisors assisting and clarifying with any issues.

3.2 Typical departmental lab setups

The typical lab setup for undergraduate and postgraduate students in electrical and electronic engineering in UCC takes place over a three-hour block, with each experiment typically being conducted by about four people with one supervisor per three or four lab setups.

The labs typically start with a safety talk, with a theory handout given in the weeks before the session and a workbook to work through and give up at the end of the lab. The labs are marked and count towards the student's module grading. One example of an electrical lab experiment is shown in Figure 5.

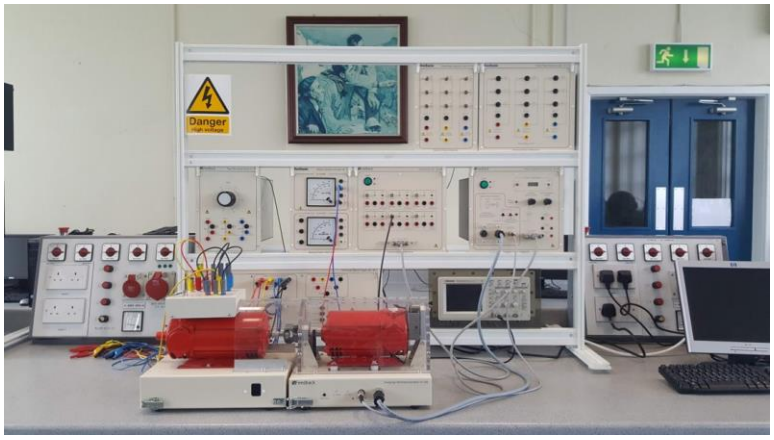


Figure 5: A three phase electrical engineering student laboratory setup using equipment from Feedback

4 HIL Experiments

4.1 HIL Emulation of a Wave Energy Converter

The purpose of this experiment is twofold. The first objective is to duplicate real-word electrical power output of a single oscillating water column converter in laboratory conditions. For this, a hydrodynamic software model in conjunction with the HIL based medium speed rotary emulator was used. The second objective is to analyse the grid integration of the renewable power generated using actual data from Mutriku buoy. This sea-trial data was collected within the OPERA project (OPERA, 2019).

In the training, students were asked to configure and control the emulator through HMI software. The data was collected at a sampling frequency of 20 kHz for 1-minute windows and line and load voltages and currents were measured. For the experiment, the rotor was configured as a squirrel cage induction generator. In the selected configuration, the emulator was connected to the distribution network through one of the microgrid buses and a resistive load of 15 kW was connected. During the experiment, various control schemes were tested. These were constant speed, constant torque, and HIL torque curve mode. For the constant speed and torque operational modes, students set different speed and torque values for the motor and generator drives. In the HIL mode, the turbine input torque was determined based on the hydrodynamic wave model in Simulink and sent to the PLC as a reference torque to drive the motor that acts as the turbine. The controller for the generator resides on the PLC and determines the generator braking torque. Figure 6 shows the load voltages and currents acquired during the HIL testing. After performing the test, students were asked to plot voltage and current data acquired, to calculate rms values of the measured quantities and to assess power and energy exported to the grid and load. Power quality issues were also examined.

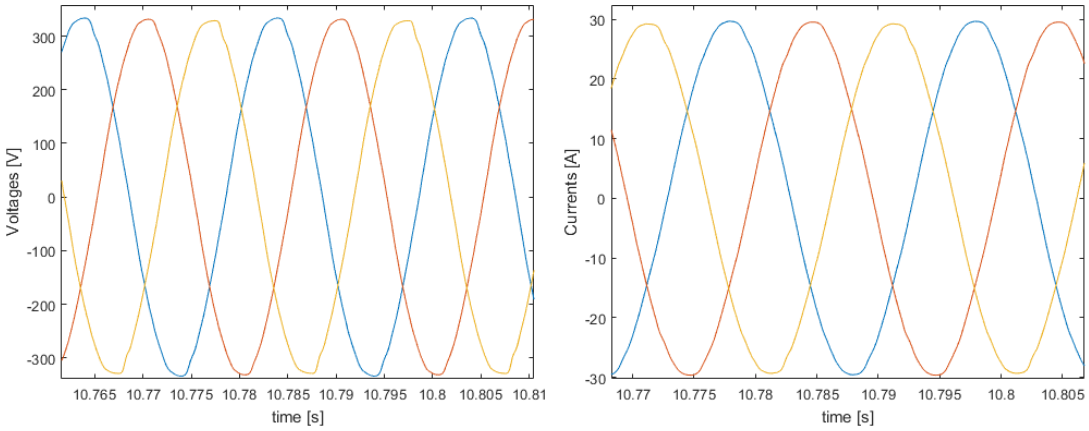


Figure 6: Load voltages and currents during HIL testing

4.2 HIL Emulation of a Wind Turbine

While the emulation of a wave energy converter experiment gave participants an insight into the typical electrical testing associated with ORE development, the objective of the emulation of a wind turbine experiment was to familiarise participants with industry standard electro-mechanical equipment, emulator test rigs and differences in measurements between ideal simulated values and real-world devices. The setup for this experiment is shown in Figure 7 where a Permanent Magnet (PM) machine fulfils the role of wind

turbine emulator. It should be noted that the grid feeding the PM machine and the grid to which the generator generates power is the same grid connection.

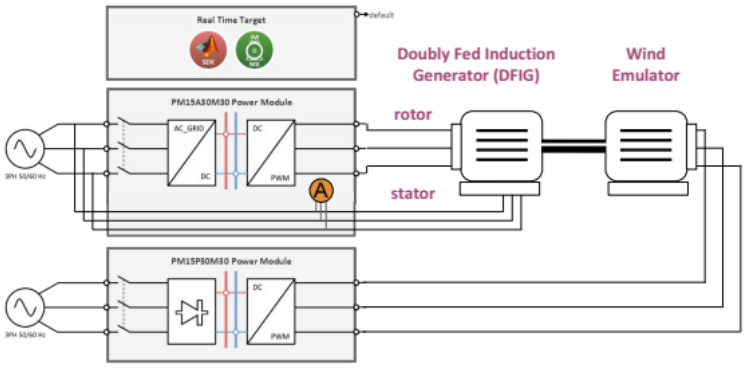


Figure 7: Wind turbine emulator lab setup

As many participants did not have an electrical/electronic background, the manual for this experiment consisted of (i) background information on the test rig and emulators, (ii) acronym usage in the industry, (iii) instructions on how to setup, check and operate the rig, (iv) further work and plot investigations as well as (v) troubleshooting. The controller PC used a web-based GUI to operate the rig with minimal inputs and clear real-time pre-scaled plotting available. A typical plot from this is shown in Figure 8.

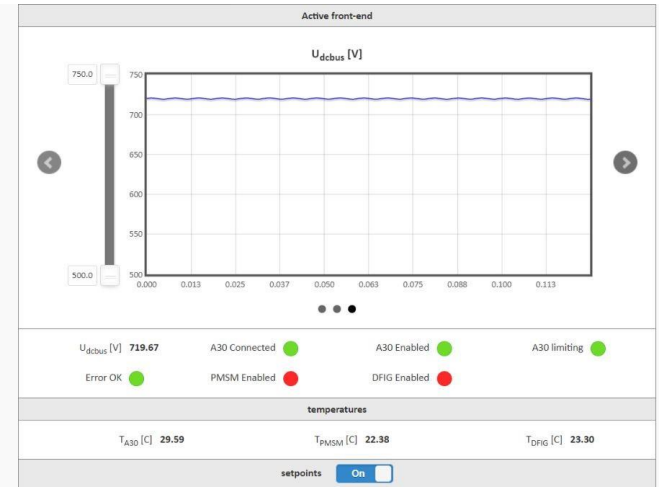


Figure 8: Voltage of the dc bus of the generator connected inverter showing some ripple

5 Conclusions

The two described experiments in this paper were developed as potential lab options for the engineering department in UCC. They were altered slightly and focussed for participants of the MaRINET2 training course which primarily had participants who were early stage researchers or postgraduate students studying offshore renewable energy devices. The review of the week-long course consisted of handouts to all participants allowing anonymous feedback. Applicable electrical lab feedback was that more and longer testing take place as participants enjoyed the hands-on component. This echoed feedback given by

participants to supervisors at the end of the experiments. The electrical lab related feedback was not collected using anonymous feedback forms and to develop this lab further this should be looked at. Feedback from the supervisors and paper writers found that:

- There was a responsibility for these labs to focus on electrical safety if participants had not had electrical laboratory/equipment experience previously, and this affected available limited time.
- Structuring the participants work in groups with a hands-off manner, fostered a dynamic and student-centred environment.
- Allowing participants work with industrial equipment and systems showing many connections hardwired to an industrial standard in a typical electrical panel as shown in Figure 4 gives an alternative laboratory environment, to the other departmental student labs. For example Figure 5 shows a lab with defined connection options using 4mm plugs.
- Avoiding the pressure of filling in a workbook to be graded, allowed minimal paper usage and a learning environment typical for a research centre.
- Simple learning outcomes such as three phase power understanding, helped focus explanations, and distributing soft-copies of well-commented MATLAB code on this topic aided this.

Further reflections on these labs as part of the training course, developed an idea of using established, coherent training courses and laboratory sessions in future for research centres as a source of income.

References

Heydt, G. T., and Vijay V. 2003. Feeding our profession (power engineering education). *IEEE Power and Energy Magazine*, **1(1)**, 38-45.

Feisel, L. D., Peterson G. D., Arnas, O., Carter L., Rosa A., & Worek, W. 2002. Learning objectives for engineering education laboratories. *In: 32nd IEEE Annual Frontiers in Education*, *Nov. 6-9, Boston, MA*.

Reed, G. F., and Stanchina, W. E. 2010. Smart grid education models for modern electric power system engineering curriculum. *In IEEE PES General Meeting*, *July 25-29, Providence, RI.*

Kezunovic, M., Ali A., Huang, G., Bose, A., & Tomsovic, K. 2004. The role of digital modeling and simulation in power engineering education. *IEEE Transactions on Power Systems*, **19(1)**, 64-72.

SFI. 2019. *SFI Research Centres*. http://www.sfi.ie/sfi-research-centres/.

MaRINET2. 2019. *Marine Renewables Infrastructure Network for Emerging Energy Technologies.* http://www.marinet2.eu/about/.

Mojlish, S., Erdogan, N., Levine, D., & Davoudi, A. 2017. Review of hardware platforms for real-time simulation of electric machines. *IEEE Transactions on Transportation Electrification*, 3(1), 130-146.

Rea, J., Kelly, J., Alcorn, R. & Sullivan, D.O. 2011. Development and operation of a power take off rig for ocean energy research and testing. *In European Wave and Tidal Energy Conference, Sept 5-9, U.K.*

Erdogan, N., Murray, D. B., Giebhardt, J., Wecker, M., & Donegan, J. (2019). Real-time hardware emulation of a power take-off model for grid-connected tidal energy systems. *In 2019 IEEE International Electric Machines & Drives Conference (IEMDC), 1368-1372, May 12-15, San Diego, CA.*

OPERA. 2019. *Open sea operating experience to reduce wave energy costs.* http://opera-h2020.eu/.