Institute for Energy Systems

Research Conference

2016

Book of Abstracts

Session 1.a: Fluids

Name: Encarni Medina-Lopez

Title: Thermodynamic processes involved in Wave Energy Extraction

Abstract: Wave energy extraction has arisen in the last decades as one of the most promising energy sources for the future. The application of the results of this thesis are mainly focused on Oscillating Water Column (OWC), equipped with Wells turbines. The operation of the OWC model has been developed by various authors that reported the formulation of the oscillation of the water surface in the chamber of an OWC using linear wave theory as well as the air expansion/compression problem inside the air chamber.

The influence of atmospheric conditions such as temperature and moisture on the performance of turbines has been widely considered in different fields from ocean energy, especially in problems related with gas turbines in power plants. However, these analysis can be widened to wave energy devices. Some OWC plants that are currently underway (e.g. Mutriku OWC in Spain, or Pico OWC in Portugal) have been reported about the differences between expected and measured power output, and performance rates. Even if predictions provide with estimated total performances (wave-pneumatic-electric) ranging from roughly 40% to 70%, actual observations are under 10% in reported cases. The effect of moisture in the air chamber of the OWC entails variations on the atmospheric conditions near the Wells turbine, modifying its performance and efficiency.

In the initial work of this thesis, the influence of humid air in the performance of the turbine was studied. The application of a real gas model and the consequent experimental study confirmed the deviations of the turbine performance from the expected values depending on flow rate, moisture and temperature, showing a difference between the available power to the turbine when considering humid air conditions. A theoretical model for a real gas applied to wave energy extraction is developed in this thesis, as well as a series of numerical tests to validate it.

Name: James Steer

Title: Stability of Surface Waves on Sheared Current

Abstract: This project will investigate the manner in which weakly nonlinear Stokes' waves propagate on vertically and horizontally sheared current. The applicability of the constant vorticity nonlinear Schrödinger equation (vor-NLS) will be explored experimentally, analytically, and numerically. Experiments will be conducted at University College London (UCL) in the coastal flume. This flume was chosen due to its well established and published, stable linearly sheared current profile. The results of these experiments will be validated using nonlinear stability analysis of the governing equations and results from a fully nonlinear, Lagrangian numerical flume. The latter portion of this project will focus on horizontally sheared current. Work on an experimental method for the creation of a high quality, horizontally sheared current in the FloWave facility will be initiated. Following the successful creation of an appropriate, horizontally sheared current, the effect of the current on trapped waves is to be investigated. Both aspects of this project are undertaken with a view to improving the design and placement of offshore structures.

First Supervisor: Dr. Ton van den Bremer

Second Supervisor: Prof. Alistair Borthwick

Name: Moika Keitmeir

Title: The Effect of Uncertainty on Tidal Stream Energy Resource

Abstract: Energy extracted from tidal streams can help bridge the energy gap while mitigating climate change effects. Rapid advances are taking place in methods used to model tidal stream resource and to optimise this extraction allowing for the feedback-effect between energy removal and natural flow conditions. At coastal-scale, most tide hydrodynamic models are based on deterministic, non-linear shallow water equations. Model uncertainties arise from several sources, one being the inexact specification of the natural environment (e.g. lack of accurate field data on the tidal velocity field, turbulence, eddying motions, etc.), the physical model parameters (bed roughness, bathymetry data, boundary and initial conditions, etc.), and numerical parameters (grid resolution, time step). Deterministic methods used to evaluate the tidal resource should therefore be supplemented by probabilistic methods to characterise and quantify the effect of uncertainty on the tidal power resource assessment. My research aims to determine the propagation of uncertainty from input parameters through to the model predictions, thereby improving the reliability of these predictions and allowing developers to make better-informed decisions in their planning.

The specification of bed roughness is a particularly important source of uncertainty. My work considers the effect of uncertainty in bed roughness on tidal stream power estimates for a linearised, one-dimensional tidal channel connecting two oceans, for which an analytical, deterministic model has previously been derived by Garrett and Cummins (2005). A stochastic mathematical model has been derived that connects the statistical distribution of the input bed roughness, used to represent the presence of tidal stream devices, to the statistical distribution of the output power estimates. The model has been validated using Monte Carlo simulations. The results are presented in terms of expected values, variances, and higher order statistical moments. The results suggest that an improved channel performance may be achieved by designing for a higher thrust from the tidal devices than would be the case for a purely deterministic model. In other words, more tidal turbines may be needed to account for uncertainty in the bed roughness, the aim being to achieve optimal performance.

References:

Garrett C. & Cummins P. (2005), The power potential of tidal currents in channels, Proc. R. Soc. A 461, 2563-2572.

Name: Manuel Reta

Title: Turbulence loading effects on tidal turbines: Modelling of tidal and wave interactions within a CFD methodology

Abstract: Research deals with the combined effect of tidal currents, gravity waves and ambient flow turbulence on loading, performance and response of marine energy converters. The main objective of the research is to explain and model ambient turbulence as well as turbulence stemming from tidal-wave interaction, as well as the subsequent dynamic loads on the rotor and other structural components.
Numerical methods, with a particular emphasis on CFD, are being used to study performance based parameters such as lift, drag and power coefficients for a 2D aerofoil, 3D turbine blade and an entire tidal turbine structure in different realistic turbulence flows in both steady and time dependant flows in addition to turbulence effects on power and survivability. .

Name: Anas Rahman

Title: On the Validation of Three-Dimensional Actuator Disc Approach for a Full Size Tidal Turbine

Abstract: To be submitted

Session 1.b : Electrical

Name: Ricardo Lopez Chavez

Title: Reliability Analysis of Wave Energy Converters

Abstracts: Using generic defined wave energy converters, sub-system block diagrams and reliability diagrams are developed. Devices have common aspects such as moorings or seabed fixings, but the method of electrical power conversion can differ depending upon the device. Reliability analysis is applied to the different electrical power take off mechanisms employed, in particular hydraulic, direct drive and turbine based generation systems. Both a qualitative and quantitative analysis is performed using surrogate reliability data in order to compare the different systems. Critical components are identified and the failure modes analysed in order to provide guidance to improve component design.

Name: Ben McGilton

Title: Analysis of a magnetic gear system with Infolytica MagNet

Abstract: Magnetic gear technology presents an opportunity to greatly reduce operation and maintenance costs of marine wave and tidal energy converters due to, among other advantages, the contactless nature of their operation. An essential element to the future integration of magnetic gears to practical applications will be the development of tools which will allow for systems to be reliable and efficiently designed to specific requirements such as size and torque. A main objective of this PhD is to produce these such tools. To this end the author has been developing and testing a magnetic gear model in the 3D magnetics modelling software MagNet by Infolytica.

This work will give an introduction to magnetic gear technology, a description of the method of operation and a discussion of the operational results acquired from MagNet. This will include the verification of the operation demonstrated through the resulting magnetic field profiles and a look at how the magnetic gear's variable physical parameters effect the calculated torque of the system. Understanding these effects form the basis of future design tools and allow for a prediction of the physical dimensions that these systems will require in marine energy converter applications.

Name: Dahunsi J. Okekunle

Title: Synchrophasor Measurement-based Predictive Voltage Control for Smart Grids

Abstract: As modern power systems with integrated renewable energy sources are being operated closer to their limits, viable control algorithms are needed to take corrective and preventive actions to prevent voltage instability and collapse. These control algorithms must be able to take into account the economic and physical constraints of the system to yield the desired objectives of robust stability and optimum performance of the RES-integrated grid. However, the design of such controllers are often based on an accurate modelling of the many different power systems components. As new components are added and as old components age with time, the performance of the model-based controllers also deteriorate. In addition, such modelling inaccuracies often lead to discrepancies in actual system behaviours and those obtained from simulations. With synchronised phasor measurements available from

WAMS, this work focuses on developing an alternative approach to model-based control design by using measurement data from Phasor Measurement Units (PMUs) and Frequency

Disturbance Recorders (FDRs) in the development of a Measurement-based Predictive Control algorithm for voltage control in power systems. Consequently, our aim is to develop methodologies for designing on-line feedback voltage controllers based on the output response of a power system.

It is highly desired that voltage be kept within a statutory _6% limit of variation around the nominal operating point for satisfactory operation of various loads and distribution transformers in the power grid. We achieve this objective through our measurement-based strategy in various stages. First, state-space models are obtained from time-varying data using a

Systems Identification techniques like Eigensystem Realization Algorithms (ERA), Prony analysis, Matrix Pencil, and Yule-Walker methods. Thereafter, we set up a distributed dynamic programming problem solving at each time step, the objective of minimizing the voltage deviation from a nominal point in the presence of various power systems constraints.

Practically, voltage control is achieved by excitation control at generating stations, by Off-

Load and On-Load Tap Changers, booster transformers and induction regulators at primary distribution and transmission levels, and by synchronous condensers at mainly transmission level. Therefore, in order to keep voltage within the statutory band, appropriate control signals must be sent to targeted voltage control devices at each time instant.

The challenges in this work include, to mention but a few, the selection of an appropriate time-window for systems identification which capture the power system dynamics of interest, the determination of appropriate input signals for realized models, the minimization of control actions, the determination of compensation limits for voltage control devices, the design of ancillary services like which enhance the performance of the designed controller, the determination of a computationally-feasible control strategy, and the robust stability of the controller. Simulations are carried out in MATLAB, SimPowerSystems and PSAT while algorithms are tested for real-time performance using the OPAL-RT simulator.

The relevance of this research effort lies in the extension of the application of the increasingly-popular WAMS from mainly monitoring to autonomous feedback control as well in its promise to mitigate the voltage control problems in a RES-integrated power grid.

Name: Obinna Unigwe

Title: To be submitted

Abstract: To be submitted

Session: 2.a: Policy & Innovation

Name: Dr Adrian de Andres

Title: Design constraints for wave energy commercialization

Abstract: The purpose of this work is to provide an innovative tool based on the classic Levelised Cost of Energy (LCOE) which gives an overview of the limits for the technical parameters of Wave Energy Converters (WECs). In this case, the LCOE calculation procedure is reversed: the LCOE target is set in the first instance, followed by the calculation of the Average Energy Production (AEP) based on different scenarios. Then, the Capital and Operating Expenditures (CAPEX and OPEX) are calculated and percentages per cost centre are assigned in order to find the cost of each technical parameter, e.g. the structure, Power Take-Off (PTO), connections, mooring and installation costs. With this reversed LCOE the upper costs limits for a WEC were obtained. Moreover, an approximation of parameters such as the maximum mass of steel, mooring length or number of interventions per year are given. Five WECs classes are analysed in this paper: Oscillating Water Column (OWC), overtopping devices, heaving devices, fixed Oscillating Wave Surge Converter (OWSC) and floating OWSC. An extensive comparison with actual devices is made. Finally, a comparison with the limits in the Offshore Wind Energy sector is given as a check of the cost-reduction potential of Wave Energy. As a conclusion, although in a primary stage of development, commercial WEC projects have the potential to be competitive with the Offshore Wind Energy industry.

Name: Anna Garcia Teruel

Title: Cost and Performance Optimisation of Wave Energy Converters

Research abstract:

To find an economically competitive design of a Wave Energy Converter (WEC), device geometry has been optimised in previous studies not only for performance maximisation, but also for cost minimisation - with costs represented by the device's size. However, resulting shapes can be inadequate to survive in high energetic seas or not cost-effective to manufacture.

Therefore, the goal of the present research project is the development of a model for automatized multi-objective geometrical optimisation of WECs for performance maximisation – based on frequency-domain and time-domain modelling - and minimisation of the levelised cost of energy (LCOE) by considering various relevant factors such as loads on the device, materials, manufacturability, reliability and operability.

To achieve this, a single-objective optimisation approach is being implemented based on a frequency-domain hydrodynamic model with the help of genetic algorithms for geometry generation and selection. This initially involves the re-implementation of a computer code developed by the late Dr. A. McCabe, which is unfortunately no longer available. In this approach, each WEC geometry is defined by a set of variable control points and an initial population of WEC shapes is created by varying these points randomly. By means of algorithms defining selection and mutation processes, as they are known from evolution theory, geometries which best fulfil the defined requirements are used to create further generations of WECs. After a number of iterations (generations), it is hoped that the genetic algorithm will converge on an optimal WEC shape.

In the short to medium term, future work includes comparing genetic algorithms and particle swarm optimization approaches for this application and assessing alternative cost functions by defining metrics for relevant cost factors related to the device's geometry. Longer term goals include combining various cost functions into a multi-objective optimization and incorporating time-domain models to assess optimal coupling to more realistic PTO systems.

Name: Dr. Camilla Thmson

Title: Carbon and Energy Audit of a Polymeric Wave Energy Converter

Abstract: This study examines the environmental impacts of a novel, polymeric wave energy converter (WEC) that is currently being developed by a consortium of researchers across Europe as part of the PolyWEC project. The device is being developed to exploit the properties of dielectric elastomer transducers, integrating the wave absorber and power take-off (PTO) system into a single deformable and lightweight polymeric element. This is expected to be cheaper and have lower environmental impacts than more traditional WECs that employ mechanical systems. This study specifically examines whether the latter can be achieved, focussing on the key indicators relating to carbon footprint and embodied energy. As the device is still under development, the analysis also involves comparing different design options to provide information on their environmental performance.

The carbon and energy impacts of WECs are still relatively poorly understood, with only a handful of studies having been published. Existing estimates of the carbon footprint range from 8 to 40 g CO_2eq/kWh, and embodied energy from 230 to 440 kJ/kWh, but a preliminary study carried out in an earlier stage of this project indicated that the conversion from a conventional to polymeric PTO system could result in a decrease in carbon footprint and embodied energy of up to 47%.

The study analyses preliminary designs for a full-scale Poly-U-OWC device. This device is a bottom-fixed oscillating water column (OWC), with a dielectric elastomer generating unit mounted on top. The case considered here is an array of 40 devices in the Pilot Zone off the west coast of Portugal. The system studied includes the device, foundations, electronics and sub-sea connecting cables up, but not including the onshore connection with the electrical grid. Every stage of the life cycle is considered, from extraction of raw materials, through manufacture, installation and operation, to decommissioning and disposal at end-of-life. As the design is still at the prototype stage, this involves making many estimates of the likely processes involved in each life cycle stage.

The analysis is based on life cycle assessment (LCA) methodology, described in ISO 14040 and 14044, and applying best practice for carbon footprinting according to a wide range of other published guidance. It was carried out using SimaPro LCA software and the Ecoinvent life cycle inventory database.

Preliminary results indicate that the carbon footprint and embodied energy of the materials extraction and manufacturing stage are 120 g CO_2eq/kWh and 1280 kJ/kWh, respectively. These values are much higher than for other WECs, but of a similar magnitude to unpublished estimates for traditional OWCs. Significantly, however, carbon payback is likely to be achieved within 5 years, and the energy return on energy invested is around 3, which suggests that the additional cost and reliability benefits provided by the polymeric generator, combined with future design refinements, may well make this a viable WEC in the future.

Name: David Crooks

Title: The OPERA project

Abstract: Although wave energy is recognised to have the potential to provide 10-15% of European electricity needs, installed capacity is still marginal. Open sea operating experience is extremely limited and it highlights challenges to be addressed to improve device survivability, component reliability and overall poor power performance. Innovation is needed in open sea operating conditions to ensure efficient and effective long term cost reduction, demonstrate the bankability of projects, attract investors and meet European goals. The primary objective of OPERA is to gather open-sea operating experience to reduce the cost of wave energy. This will be achieved by fully exploiting the opportunity presented by the nationally funded open-sea testing of a floating Oscillating Water Column Wave Energy Converter at bimep (an open-sea test facility for research in Spain) in order to improve survivability and reliability, reduce technological and business risk, and validate promising cost-reducing technologies. The OPERA project's consortium brings together world leaders in their respective fields to move the most critical components for wave energy technologies (mooring, air turbine, generator, control) from TRL3-4 to TRL5. Resulting from the open-sea testing process, the tested device will also progress from TRL4 to TRL5. Special focus will be put on the exploitation and dissemination of project results. Not only will the consortium benefit from the exploitation of results, technologies and operating data, but also these will have a wider impact on the wave energy value chain: RTOs, OEMs, technology developers, offshore services' companies, standardisation bodies and investors. As final indicators, OPERA aims at an increase in power performance over 50% and reducing extreme mooring loads by 70%. Technologies validated through this project can reduce the cost of wave energy by 50%. The success of this project will accelerate the time to market of wave energy technologies.

Name: Owain Roberts

Title: A whole system approach to techno-economic assessment for the ocean energy sector

Abstract: The commercialisation of ocean energy has not been achieved despite several developers reaching full-scale, open-water deployment, an advanced milestone on the technology readiness level (TRL) scale. This calls into question the current development path of ocean energy, which has significantly lagged behind other renewable energy technologies. Resultantly, there is now a focus on a more considered approach to the development trajectory, for example, it has been suggested that support mechanisms and investment have not been applied appropriately.

One key problem is a lack of design convergence which results in unstructured and unfocused resource allocation and adds confusion for investors. The lack of a robust method for comparing and assessing devices at early stages of development has led to a fixation on designs which once deployed are found to under-perform. To address these issues a clear methodology for techno-economic assessment on a subsystem level is required.

For the early stages of technology development current indicators in the ocean energy sector are not accurate enough to describe the commercial ability of a technology due to the large number of assumptions required. This includes the Levelised Cost of Energy or LCOE which is widely used to compare emerging renewable generation and sets the basis for governmental decision making, despite the large uncertainty in its calculation for low TRL technologies.

This project aims to develop a unified economic modelling methodology for the assessment of ocean energy components, subsystems and converters through the observation of key metrics. It will provide informed guidance on the level of investment and the correct strategy required to successfully progress along the TRL scale and investigate how to deal with uncertainty in techno-economic assessment and its implications on meaningful decision making.

The impact of this research will be to facilitate public sector programmes, such as the EU’s Horizon 2020 or calls by Wave Energy Scotland (WES), in their evaluation of projects and setting of award criteria. A standardised techno-economic assessment framework will be proposed so that fair comparison among components and devices is achieved within the ocean energy sector. By highlighting only those components and/or devices with true commercial potential it will ensure resources and investment is focused and will help to drive the innovation required to improve performance, reliability and, ultimately, sustained cost-reduction. This unified process will help the development and deployment process for ocean energy to be de-risked and design consensus to be achieved.

Name: Alastair Heggie

Title: Modelling Energy Networks in Developing Countries

Abstract: In developed countries it is assumed that electricity must be reliably available whenever there is consumer demand. However, the electricity systems in many developing countries are in a state of constant capacity crisis, which necessitates a policy of power rationing. As a result of power rationing existing customers find that their connection is intermittent and unreliable. This situation has immediate negative consequences for system stability and the shed load is either unsupplied or has to be met by self-generation at a high cost. In addition large numbers of potential consumers are unable to connect to the grid. When scheduling current customers connections and considering connecting new customers policy makers face a trade-off between new connections and power quality. There is a need for models to assist energy policy makers in developing countries to analyse these issues. This is the subject of my thesis.

In this presentation I will give an overview of several sections of my research. These include regulator/system operator view of power rationing, optimal load rotation policies from the point of view of an electricity distribution company and transmission and generation expansion planning.

I have developed a modelling framework to help policy makers in developing countries ration scarce power and quantify the trade-off between efficiency, in terms of maximising the total served load, and fairness, in terms of the quantity of power delivered to different regions in the network. We use a multi-objective form of the Optimal Power Flow (OPF) problem to determine how the regional distribution of load shedding affects the total level of load that can be served by the power system. We apply this framework to a model of the Nigerian power system and show how transmission constraints limit what policy makers can achieve and how fair the policy can be. We analyse different regulatory approaches to power rationing and then show the cost of a fairer policy in terms of load not served. We discuss the disadvantages of the DC approximation for this application.

I will discuss future plans to incorporate geospatial data into a transmission and generation expansion planning model. This will help to analyse how to prioritize resources in order to meet energy access targets at least cost. I intend to demonstrate this approach in the Nigerian context.

Session: 2.b: CCS & Combustion & Energy Storage

Name: Dan McKinely

Title: Pumped-Heat Energy Storage: Experimental Work to Date

Abstract: Electrical energy storage is often touted as a golden bullet towards optimally integrating large amounts of renewable generation into the grid, but few technologies exist today to realistically fill this role. Pumped-Hydro storage, while mature and appropriately sized, is severely geographically constrained and expensive to build. Batteries are useful for frequency and voltage support, but don't yet provide storage on scales needed to meaningfully balance the grid. Our vision is for a storage system which routinely balances supply and demand on scales similar to hydro storage (the de facto standard), but without the geographical and scale inflexibility. To this end Prof. Win Rampen has proposed a Joule-Brayton cycle based 'Pumped-Heat' energy storage system, with the aim of hitting several key metrics at full scale: 70% round-trip (AC-AC) efficiency, <700 £/kW, <100 £/kWh, and 30yr+ life. A time domain simulation has been completed which verifies the concept and predicted operation, but several key components require validation. The work presented today focuses on the piston compressor/expander, which compresses/expands the working gas while simultaneously mixing in liquid. Specifically, if the gas were compressed adiabatically to the desired top system pressure (needed for a minimum power rating), the resulting temperature rise would exceed the limits of the liquid used elsewhere in the system. By mixing liquid into the compression chamber, the temperature rise can be tuned to a desired value, effectively tweaking the polytropic constant in the relation PVn=C. This process is only effective if the gas and liquid are well mixed, so an experimental setup has been devised to test a novel gas-liquid mixing device which sits within a piston-compressor. A system overview and experimental design, setup, and results to date are presented.

Name: Jafar Daoud

Title: Developing of solar powered air refrigeration system

Abstract: The need for air refrigeration is increasing worldwide as it became the basic of everyday life. The climate model projections indicate that the earth surface temperature is going to increase by 1.1 to 6.4oC over the next century, which increases the need for more refrigeration units. This is expected to put more pressure on electricity grids even in developed countries.

The fuel crises, electricity prices and the unreliability of electricity grids encourages researchers and scientists to look for different energy resources. Energy crises, CO2 emissions and electricity grid problems make the renewable resources attractive to researchers from all over the word, among the renewable resources solar energy is the most suitable one for refrigeration purposes. Its power density, cleanness, availability and its coincidence to cooling demand make it an ideal source.

The Stirling cycle is a promising technology. It has been used over the last century as heat pumps and as engines powered by solar and waste energy. The Stirling engine is theoretically a Carnot engine whose experimental second efficiency can reach 88%. The reversed cycle of this engine makes it working in heat pump or refrigeration mode. In addition to their quiet operation, efficiency and simplicity, Stirling engines uses gasses like hydrogen, helium and air, which have zero impact on the environment. So far problems like low power density, complex heat exchangers, dead volumes, efficiencies at low temperatures, gas leakage and hence the price prevent the engine to be adopted for household applications.

In this research the air filled Stirling heat activated heat pump is being studied for domestic air refrigeration purposes that works on temperatures up to 600k. This temperature provides good efficiency and can be easily achieved using solar parabolic troughs. The mentioned problems are avoided by using the Franchot configuration. It is a double acting Stirling engine, in which the expansion and compression cylinders are heated and cooled directly without any additional heat exchanger. This forces the Stirling cycle to work in polytropic mode with limited heat transfer; which is better than the adiabatic one. The heat transfer is being studied and improved by changing the geometry of the engine to be more like pipes, so that the heat transfer area is larger than the squared engine and the Reynold number is higher due to higher strokes. The connecting rod size is being studied as it has a positive effect on the heat transfer and swept volume. This configuration eliminates the shuttle losses and some of the conduction losses as well as removing the displacer. But it has a sealing problem which can be avoided by using graphite seals.

In this research the maximum power is being tracked by controlling the phase angle to maximise the power density. Yet, the phase angle control is found inevitable. It resulted in better performances than increasing the dead volumes. The maximum power efficiency is found a bit behind the theoretical Curzon efficiency. The connecting rod sizing is found important to improve the engine performance. About 5mm gap between the connecting rod and the cylinders wall gives the highest power density at 1500rpm.

Name: Laura Herraiz

Title: Selective Exhaust Gas Recirculation in Combined Cycle Gas Turbine Power Plants with Post-combustion Carbon Capture.

Abstract: Combined cycle gas turbine (CCGT) power plants with carbon capture and storage (CCS) are expected to play an important part in low-carbon electricity systems, providing dispatchable low carbon energy while maintaining system flexibility.

The low CO2 concentration and large volume of flue gas exiting an air-fired CCGT power plant makes the CO2 separation in post-combustion carbon capture (PCC) technologies difficult, highly energy intensive and costly, which is reflected in a reduction of the power output and high cost of electricity.

This work investigates options for the integration of Selective Exhaust Gas Recirculation (S-EGR) and post combustion capture technologies in CCGT power plants. Selective exhaust gas recirculation strategy consists of selectively transferring CO2 from the exhaust gas stream into the air stream entering the gas turbine compressor. Unlike in "non-selective" Exhaust Gas Recirculation (EGR) technology, recirculation of, principally, nitrogen does not occur, and the gas turbine still operates with a large excess of air.

Two configurations are proposed: one with the CO2 transfer system operating in parallel to the PCC system; the other with the CO2 transfer system operating downstream of, and in series to, the PCC unit. S-EGR allows for higher CO2 concentrations in the flue gas of approximately 13-14 vol%, compared to 6.6 vol% with EGR at 35% recirculation ratio. The oxygen levels in the combustor are approximately 19 vol%, well above the minimum limit of 16 vol% with 35% EGR reported in literature.

At these operating conditions, process model simulations show that the current class of gas turbine engines can operate without a significant deviation in the compressor and the turbine performance from the design conditions. Compressor inlet temperature and CO2 concentration in the working fluid are critical parameters in the assessment of the effect on the gas turbine net power output and efficiency. A higher turbine exhaust temperature allows the generation of additional steam which results in a marginal increase in the combined cycle net power output of 5% and 2% in the investigated configurations with S-EGR in parallel and S-EGR in series, respectively. With aqueous monoethanolamine scrubbing technology, S-EGR leads to operation and cost benefits. S-EGR in parallel operating at 70% recirculation, 97% selective CO2 transfer efficiency and 96% PCC efficiency results in a reduction of 46% in packing volume and 5% in specific reboiler duty, compared to air-based combustion CCGT with PCC, and of 10% in packing volume and 2% in specific reboiler duty, compared to 35% EGR. S-EGR in series operating at 95% selective CO2 transfer efficiency and 32% PCC efficiency results in a reduction of 64% in packing volume and 7% in specific reboiler duty, compared to air-based, and of 40% in packing volume and 4% in specific reboiler duty, compared to 35% EGR.

Previous work has essentially been focused on applications with membrane technology. This work examines the potential of adsorption technology for this particular application when combined with a rotating wheel, similar to regenerative gas/gas heat exchangers used in coal-fired power plant applications.

Name: Juan Riaza

Title: Ignition and combustion of single particles of coal and biomass under O2/CO2 atmospheres

Abstract: Biomass is a renewable fuel which can be used to reduce CO2 emissions. It is being increasingly implemented as an energy source for residential and industrial heating, electricity production in modern biomass power plants and co-firing or to replace other fuels such as coal. The use of co-fired biomass in existing pulverized coal power plants requires only minor modifications compared to the construction of new biomass-only fired power plants. This makes co-firing biomass with coal an attractive option for making effective use of biomass energy. Additionally, combining biomass combustion with carbon dioxide capture and storage (CCS) is a promising approach to achieve net removal of CO2 from the atmosphere.

Combustion behavior of biomass fuels especially the behavior of biomass in oxy-combustion conditions has rarely been reported, and this is of special interest for future oxy-fuel power plants development. The present work aims at providing a systematic combustion study of different biomass fuels with high speed video under both conventional (air) and oxy-fuel conditions to examine the impact of particle size on ignition, devolatilisation, char combustion, and burn-out times for different coal and biomass. In this work, a single particle rig has been developed for rapid heating of coal and biomass particles to study the combustion behavior with high speed camera recording. The study includes a range of sizes in order to obtain combustion test data to improve understanding of milling requirements for biomass.

Images produced by the apparatus show the ignition and the flame surrounding the contour of the biomass particle. Biomass pyrolysis, ignition of the volatile flame and char combustion can be observed. Differences between coal and biomass combustion can be identified. For example, biomass char combustion took place for a shorter time than in the case of coal char combustion due to the lower carbon content of the biomasses with respect to coal and higher reactivity. The way the volatiles are released was also very different between coal and biomass. Burnout times can also be obtained for each particle from the video recording.

The results shows the relation between particles sizes ranges of coal and biomass and their burnout times, as well as their combustion behavior. The data obtained can be useful to understand the differences in biomass milling requirements and the overall combustion performance, stablishing a size range that would be comparable in burnout time with pulverized coal sizes for an efficient burnout, providing important data for the design and operation of effective co-firing of biomass with coal in both air and oxy-fuel conditions.

Name: Thomas Spitz

Title: Operational flexibility of CCS systems

Abstract: In a world in which the dependency on fossil fuel is expected to grow in the near and medium future, carbon capture and storage is commonly considered as a technology of vital importance to reduce greenhouse gas emissions significantly and already in the near future. CCS technology can be fitted on fossil fuel fired power stations in order to provide firm and flexible low carbon electricity and act as the backbone of future electricity systems dominated by intermittent renewable energy and inflexible nuclear power supply.

Modelling of the IPCC has shown that the inclusion of CCS in the capacity mix reduces the costs dramatically of limiting the global temperature rise below 2oC (by more than 50%). In fact, in most models deployed by the IPCC it is not even possible to reach the target of keeping global temperature rise within 2oC degrees without the use CCS in the capacity mix. Day (2015) has shown that including CCS in the UK's energy system reduces the costs of reaching the desired 80% reduction in GHG emissions by approximately £30bn per year.

Most technical studies examining CCS in the literature optimise the operation of individual processes or subsystems along the CCS process chain (CO2 capture, transportation, storage) for base-load/design conditions. However, this fails to acknowledge the need for flexible operation of fossil CCS units required in future low carbon energy systems, characterised by a high share of inflexible nuclear power and intermittent renewable power. In these systems CCS enabled fossil power stations are most likely required to stabilise the grid by providing firm but flexible capacity.

This research project addresses an identified gap in the literature and examines the feasibility, required extent and issues associated with flexible operation of CCS systems. It does this in 3 steps:

(i) It investigates the role of CCS power stations in future low carbon electricity systems (e.g. operating profiles). A purpose build unit-commitment-economic-dispatch (UCED) model of the UK power system is deployed to simulate and understand the operating behaviour of CCS power stations in future UK electricity system scenarios.

(ii) It explores the issues associated with flexible operation of the system along the CCS chain (i.e. capture, transportation, storage) and presents operating and design solutions to mitigate the identified issues.

(iii) Through rigorous power plant process modelling it examines to what extent CO2 flow rate fluctuations caused by flexible operation of the base power station can be balanced within the boundaries of the power plant.

The preliminary findings suggest that flexible power plant operation causes significant integrity risks for the downstream transportation system, and in particular for the injection system, if not designed accordingly. There exist, however, a variety of operating and design solutions to deal with high CO2 flow-rate fluctuations in the system as the fundamental underlying problem. The cost optimal solution depends on the system design, and has to be found on a case by case basis.

Name: Erika Palfi

Title: Activated Carbon for Selective Exhaust Gas Recirculation in Combined Cycle Gas Turbine Power Plants with Carbon Capture

Abstract: Introduction

This work combines the principle of a large scale rotating adsorption unit using activated carbon, with the advantages of Selective Exhaust Gas Recirculation (SEGR) for natural gas combined cycles (NGCC) with post-combustion CO_2 capture (PCC) system. SEGR consists of selectively transferring CO_2 from a flue gas stream into an air stream used for the combustion of the fuel, while other components in the flue gas, e.g. nitrogen and water vapour, are ideally not recirculated. It increases CO_2 concentration in the exhaust flue gas and drastically reduces gas flowrates through the capture system, resulting in capital and operating cost reduction. Furthermore SEGR shows an increase in the net thermal efficiency of the combined cycle of up 1% point, mostly due to higher heat transfer and increased steam generation in the heat recovery steam generator [1]. Yet, a step change in adsorption performance is necessary for deployment to reduce the size of the selective CO_2 transfer system.

Process development and implementation

For this application, cyclic adsorption/ desorption with structured adsorbents in a rotary wheel configuration is investigated. CO_2 is adsorbed when the flue gas enters into contact with the solid material located in a rotor operating at low rotational velocity, and then desorbed into an air stream. This replicates in size large scale regenerative rotary gas/gas heat exchangers. In a first conceptual design assessment of the selective CO_2 transfer system, based on an equilibrium model, it is conclude that the amount of adsorbent material estimated with activated carbon requires two or more rotary wheels, of approximately 24 m diameter and 2 m long, to achieve 97% selective CO2 transfer efficiency [1]. To minimise the amount of solid required, the development of new materials is proposed. Therefore new carbon based materials are investigated in this work, along with a rigours model including kinetics of adsorption.

Results and discussion

In cooperation with the University of Saskatchewan, the performance of activated carbon materials is investigated experimentally under a range of operating conditions possible in NGCC plants with SEGR. The so obtained equilibrium and kinetic parameters and properties then feed back into process simulations of large scale selective CO_2 transfer rotary adsorption system for a 800 MWe NGCC with post-combustion capture.

A parametric study through performance modelling is then conducted to optimise both operating parameters such as rotation speed, residence time and flue gas velocity, and kinetic parameters.

This work will show the readiness of activated carbon as adsorbent under real flue gas conditions for this type of large scale deployment application. It then provides guidelines for the development of improved materials targeted for typical operating conditions with SEGR.

References:

[1] L. Herraiz Palomino, 2016, *Selective Exhaust Gas Recirculation in Combined Cycle Gas turbine power Plants With Post-Combustion Carbon Capture*, Ph.D. Thesis, University of Edinburgh

Session: Posters

Name: ABEL ARREDONDO-GALEANA

Title: The leading edge vortex in thin three dimensional spinnaker inspired wings

Abstract: Lift enhancement and stability of the leading edge vortex (LEV) is of paramount importance for yacht racing since it can provide a steady increase in the thrust force, whereas if periodically shed it can lead to undesirable force fluctuations. In 2014, Viola et al. (Ocean Eng., 2014; 90:93-103) predicted numerically a stable and attached LEV on an on an asymmetric-spinnaker-type yacht sail. This PhD research is a continuation of that finding and we have now experimentally observed and confirmed the existence of the LEV on a 1:115th spinnaker scale model with PIV and vortex detection algorithms. The experimental prototype was 3D printed in ABS and measurements were performed at a Reynolds number of 1.7 x 104 in a water flume at the University of Edinburgh. Three cross sections parallel to the oncoming flow (1/2, 3/4, 7/8) were recorded with PIV and forces measurements recorded. We found that the LEV grows in diameter from the root to the tip of the sail. Separation occurs at x/C=0.4 at the bottom half of the sail and at the top half, separation occurs at the leading edge followed by reattachment behind the LEV region. Vortex detection was done through the γ_2-criterion and γ_1-criterion. The core of the vortex was found at the leading edge, coinciding with regions where streamlines are concentric.

Pressure contours have been derived from PIV data with use of a marching integration scheme and pressure troughs indicate the core of the LEV. Modelling of the flow and the vortex has been done with the use of complex potential flow and lift enhancement is shown to be within 10% according to the model. Future and ongoing include carrying on experiments on spinnaker geometries with three different twist angles. So far, the current findings open up new sail design techniques and strategies to control and monitor the LEV to improve performance in yacht racing and apply the concepts to micro air vehicles and tidal energy devices.

Name: Donald R Noble

Title: Combined wave-current scale model testing at FloWave

Abstract: Physical scale model testing is an important part of the marine renewable energy development process. FloWave is a state-of-the-art ocean energy research facility, designed to conduct these tests, with the unique ability to provide combined multi-directional waves and currents in the circular tank. As a new facility, it is important to fully understand the performance characteristics, in terms of recreating both waves and currents individually and combined.

Initial work focussed on the characterisation of the spatial variation of mean flow throughout the test volume, using electromagnetic current meters, and an acoustic Doppler velocimeter was used to measure 3D flow and turbulence in the tank. This validated the design stage computer models as well as mapping and characterising the test volume.

Water waves and currents interact in a complex non-linear manner. Waves become shorter and higher with an opposing flow, but longer and lower on a following current. The presence of waves also increases turbulence, and imparts cyclic loading on submerged structures. Measurements have been conducted of the combined wave-current field in the tank, firstly to explore the interactions, particularly the non-collinear case. Methods have also been developed to produce the 'correct' desired wave properties after interaction with the current in the tank.

Whilst much guidance has been published on the subject of tank testing, and this has been extended over recent years to include the particular challenges of testing marine renewable energy devices, there is still not much specifically on advanced testing in a multi-directional wave-current environment. To remedy this, considerations for testing in these conditions at the FloWave facility are being collated. This will assist with developing test plans and making best use of the facility capabilities. This research will assist more advanced tank testing of marine renewable energy devices, which will facilitate development within the industry.

Name: Tamás István Józsa

Title: Turbulence control based on in-plane motions for tidal turbine blades

Abstract: Nowadays the marine energy community faces the challenge to design efficient and robust tidal turbines in order to harvest the energy of the tidal streams, and provide a sustainable solution to the increasing energy demand of our society. The development of efficient tidal turbines is challenging, especially given the potential for fatigue damage associated with exposure within an aggressive marine environment. An immersed body in a flowing liquid experiences drag force and lift force. In case of a tidal turbine blade, the sum of these forces has an axial component, the so-called thrust, and a tangential component, which is responsible for the generation of torque rotating the turbine. Damping the turbulent fluctuations near the blades would result in decreased friction drag, which means decreased thrust and increased torque, so more energy harvested.

Both active and passive flow control strategies, aimed directly at reducing the turbulent fluctuations, were examined via in-plane wall motions in turbulent boundary layers. Direct numerical simulations were undertaken, using a relatively simple geometrical configuration, the turbulent channel flow. Initially the work focused on the independent validation of the results of Choi et al. (1994, JFM, 262:75-110), where controls were suggested by sampling the velocity fluctuations in the fluid at a fixed distance from the wall. Such controls require sensors in the fluid, and actuators on the wall, which would make the realisation cumbersome. In order to overcome this difficulty, wall motion controls, based on the wall shear stresses measured at the wall, are considered. Finally, the simulations carried out in this study will, for the first time, indicate that friction drag reduction may be possible with a compliant coating which is deformed by the wall shear stress.

Name: Rodrigo Martinez

Title: Effects of oblique waves and current on the loadings and performance of tidal turbines

Abstract: Tidal energy is at an early deployment stage but some companies and funding bodies find it a risky investment. Some of the high cost of tidal turbine is due to load uncertainties and associated high Factors of Safety implemented in the design. Among the most important sources of uncertainty are the extreme loads imposed upon the rotor. So far, most of the experiments with horizontal axis turbines investigating this issue have been carried out with collinear wave and current interaction both with and against the flow. In the work presented herein, the flow is yawed by 0, 10 and 20 degrees with respect to the rotor axis. For each of these flow angles, regular waves are generated at 0, 45, 135 and 315 degrees. Tests were performed with a 1.2m diameter turbine in the FloWave basin at Edinburgh University. 15 physical quantities were measured including flow, blade, rotor and foundation loads and turbine speed. The experiments were carried out in early April and preliminary results are presented. Thorough attention has been paid to the quality control of the data to ensure all the follow up work is reliable.

Name: Guangming Li

Title: The use of Underwater Acoustic Tomography in Fluid Velocity Measurement over the Flow Basin

Abstract: Measuring the flow patterns in the basin is critical to understanding the interaction of waves and currents with tidal and wave energy machines. Currently technologies exist for point testing and small area measurements such as Acoustic Doppler Velocimetry (ADV), Particle Image Velocimetry (PIV) and Acoustic Doppler current profiler (ADCP). These methods suffer from some problems: small scale, low efficiently and disturbing original fluid. This project aims to develop wide area current measurement techniques that could be implemented in Laboratory test basins. This method will allow a detailed characterization of the flow patterns in test basins, particularly involving the interaction between waves and currents. This work contains following aspects:

1. Fluid dynamic simulation of circular tank
2. Fluid velocity profile reconstruction and monitoring by underwater acoustic tomography
3. Comparison analysis of CFD simulation, point test and Underwater Acoustic Tomography

Due to the good experiment environment of Flowave TT (2m deep and 25m in diameter circular wave/current basin), vertical inverse could be achieved first. After further testing, horizontal current profile in the circular tank could be obtained by adding transducers and control systems. The 3D mapping of fluid velocity in the basin is the final target of this work.

Name: Ross Calvert

Title: Sediment Transport by Shoaling Wave-Groups

Abstract: Globally, beach erosion is an increasing problem. The obvious example is coastal cities and infrastructure, but beach morphology also has a significant effect on both natural and artificial sea defences, which protect from floods that have a much larger inland effect. Sea level increases and more frequent storms are expected, thus understanding how these changes will affect beach morphology is required to enable us to assess the effectiveness of sea defences. The poster will outline a strategy to create an analytical and a numerical model for beach erosion under shoaling wave-groups. Wave-groups are used to model the largest probable wave in a storm to reduce complexity and cost, compared with probabilistic or full time simulations of random seas. Three different analytical approaches to calculate the undertow associated with shoaling wave groups will be discussed. Two approaches solve the Laplace equation with non-linear boundary conditions by using perturbation analysis and frequency sum respectively, whilst the third approach uses radiation stresses and mass and momentum continuity. An outline for a numerical model of shoaling wave groups, using Smoothed particle hydrodynamics (SPH), will also be presented. SPH is a Lagrangian meshless particle method and thus models free-surfaces with ease and improvements of sediment modelling have recently been achieved.

Name: Gareth Wakelam

Title: Current models and tools used in the design of tidal stream devices

Abstract: Current models and tools used in the design of tidal stream devices have primarily been adapted from wind energy industry use, and due to a relative lack of detailed understanding of tidal flow characteristics have resulted in lower confidence and overly conservative designs. Of particular concern is fatigue loading over the operating life of the machine, with onset turbulence being a critical part of this. Waves have also been found to have a significant effect on tidal flow characteristics, however their interaction with tidal currents and turbulence is not well understood.

Work will be undertaken to improve understanding by interrogating site data from the ReDAPT and FloWTurb projects, contributing to a 'toolbox' of methodologies and models for use in characterising tidal channel flows that have been developed and experimentally validated during the project. These will be appropriate for industry use regarding device design and modelling, in addition to enhancing academic understanding of tidal stream energy and providing a basis for further work. Specific aspects of the effect of non-uniform 'real' flow on device loading and operation may also be investigated experimentally or numerically as an extension of this work.

Name: Susan Tully

Title: The Flexible Blades Project: Unsteady Loading of Tidal Turbine Blades.

Abstract: Tidal turbines must operate within an unsteady flow environment. The combination of diurnal currents, sheared current profiles, high levels of turbulence and wave-current interaction leads to highly variable flow across devices, with an associated variation in the loads experienced. Whilst this has ramifications both on the ability of a turbine to generate power efficiently and on the expected lifespan of a device, a lack of understanding of unsteady turbine hydrodynamics has lead developers to over-engineer their devices. Of particular note is the effect of cyclical wave-induced loading on devices since their cyclical nature means that blade and rotor fatigue becomes an increasingly important issue. This poster presents a study into the loading effects of wave-current interactions on a blade section of a horizontal axis tidal turbine. Wave-current interactions were calculated based on 2nd order linear wave theory and a numerical model for estimating loads on both rigid and flexible blade section is presented, based on a quasi-steady analysis. Results from this model are compared with load measurements on two constant cross-section hydrofoils, one rigid and one flexible, in combined waves and currents in order to assess whether a flexible blade can lead to lower load fluctuations. Particle image velocimetry was used to investigate the flow field surrounding the hydrofoils throughout a wave period in order to better understand the underlying hydrodynamics. The flow experienced by each hydrofoil is found to be highly unsteady with hysteresis effects resulting in different loading profiles than the quasi-steady analysis predicts. The experimental results indicate that the oscillating pressure field, associated with an oscillating free surface, significantly changes the hydrodynamic behaviour of the hydrofoils. The flexible blade was found to reduce the magnitude of load fluctuations by 30% in addition to achieving 25% higher lift to drag ratio as compared to its rigid counterpart.

Name: Renato Wu

Title: EV charging scheduling for cost and greenhouse gases emissions minimization

Abstract: With the increasing penetration of varying renewable energy and the introduction of new types of electrical loads, current power systems are facing more challenges in the balancing of generation and demand. Electrical vehicle (EV), as a booming entity, becomes more important in the system. Vehicle-to-Grid (V2G) technology can be used to coordinate the EV into the system. It can control the bi-directional electrical energy flow between vehicles and the power grid.

However, due to the unpopularity and technology constraints of electric vehicles at the current state, how a large fleet of electric vehicles stochastic charging will influence power system is still unknown. Meanwhile, people's driving and charging behaviors are also unpredictable. The aim of this paper is using more precise and practical driving pattern of each vehicle with consideration of external variables to optimize electric vehicle charging plan with the wet load category (washing machine, dish wash.ect).

In this paper, low-voltage distribution network model has been built by using the PSS SINCAL power system simulation package, which includes the household demands. It is the first time to simulate travel activities of each household, especially traveling by car, which includes starting time, ending time, and traveling distance for each car. The local temperature also has been regarded as an important input variable affecting the available range of electric vehicles.

The primary charge plan is used to model people's stochastic charging and driving behaviors which assume that all electric vehicles are in a fully-charged state when they leave the home and will be charged as soon as they arrive home in the evening without consideration of other electricity demand in the distribution network. The simulation results show that the uncontrolled integration of electric vehicles in distribution network will cause many challenges such as the time shift of peak demand, unexpected surge of power demand, more power losses and voltage drop on power lines, etc.

At the same time, uncontrolled charging will probably lead to high charging price in the peak hours which could add unnecessary extra cost on electric vehicle's owners. Based on simulation results, some smart charging scenarios and battery management systems will be proposed by multiple objective optimizations. The proposed optimization algorithm of this paper is shifting electric vehicle charging load to minimize the combined cost which includes electricity cost and greenhouse gas emissions in 72 hours household demand profiles. However, in reality, not every electric vehicle owners are happy to delay their charging time. The penalty factors will be introduced in this optimization which set the allowable maximum time delay of a given load. Two objectives will be fixed in the optimizations such as the low cost for customers and peak demand reduction. Low cost for customer model will take into account cost of energy consumption, queuing time and charging time to measure comprehensive cost customers will spend. Peak demand reduction model is aimed to reduce the difference between demand and generation at the peak time by controlling electric vehicle charging. According to previous research, time series of wet loads share lots of common features with uncontrolled electric vehicle charging. Similar optimization methods can also be applied with electric vehicle charging. Due to the unbalanced distributions and various loading conditions, the voltage drop at each bus is different in radial distribution networks. Therefore, various penalty factors will be used to decrease the pressure of large-scale electric vehicle charging for the power system.

Name: Kevin Kails

Title: Superconducting generators for large wind turbines

Abstract: The biggest challenge the wind energy sector faces is to reduce the cost of energy. For several decades now there has been a trend towards higher power-rated wind turbines which help to reduce the cost of energy through lower installation and maintenance costs per kilo-watt hour. Projections indicate that 85% of offshore wind turbines will be rated above 5MW in 2020. However, one critical issue with large wind turbines is the tower head mass problem. The tower head becomes extremely heavy for large wind turbines, this leads to a need for more robust foundation towers for support which in turn dramatically increase the cost of the whole system. To solve this issue a novel lighter topology of power generators based on superconductor technology is required which would enable 10MW and even higher rated wind turbines. Based on previous research done at the *Institute for Energy Systems* of the *University of Edinburgh* a reduction of weight of at least 30% when compared to conventional power generators is possible. It has also been shown that superconducting machines remain extremely efficient even when only operating under partial load. There are several other superconducting power generator designs for wind turbines available however many use an excessive amount of superconducting tape, often several hundreds of kilometres making them economically unviable. The closest comparable design to the double claw pole generator developed at the *IES* is *AMSC*'s 10MW superconducting generator which uses 36km of YBCO tape. This is still 10 times more than the design developed at the *IES*. One issue with the claw pole generator is however that it is too heavy to satisfy the needs of the future wind industry market.

To reduce the mass of the double claw pole generator, further investigation into the design of superconducting machines was required. A new initial design based on the double claw pole machine was developed and it is expected to be lighter and use less superconducting tape than the original claw pole machine. Detailed multiphysics modelling will be performed throughout the PhD project in order to further optimize the design and prove its feasibility.

Name: Renaldi Renaldi

Title: Multiple time grids in operational optimisation of energy systems with short- and long-term thermal energy storage

Abstract: As a vital part of future low carbon energy systems, storage technologies need to be included in the overall optimisation of energy systems. However, this comes with a price of increasing complexity and computational cost since the presence of storage means that decisions between time steps are now coupled and the optimisation problem has to be solved over the entire time horizon. The increase in complexity can be limited by using simplified time series formulations in the optimisation process, e.g. typical days or multiple time grids. This in turn will affect the computational cost and quality of the optimisation results. The trade-off between these two aspects has to be quantified in order to appropriately use the simplification method. This study investigates the implementation of the multiple time grids approach in the optimisation of a solar district heating system with short- and long-term thermal energy storage. The multiple time grids can improve the optimisation computational time by over an order of magnitude. Nevertheless, this is not a general rule since it is shown that there is a possibility for the computational time to increase with time step size. This has to be considered in the time step size determination in the optimisation using multiple time grids. Furthermore, the benefits of multiple time grids become more evident in optimisation with a longer time horizon, reaching almost two order of magnitude improvement in computational time for the case with 6 years time horizon and 5% MIP gap.

Name: Krisna Pawitan

Title: Scaling Effects on Performance of an Oscillating Water Column Wave Energy Converter

Abstract: Wave energy is one of the most promising marine energy resources for renewable energy, however it's not without difficulties. There are many wave energy converter that have been developed over the year and oscillating water column stand out the most by its simplicity and low maintenance cost relative to other wave energy converter devices. The concept of OWC (oscillating water column) in wave energy converter (WEC) is usually combined with a breakwater structures to split the cost between energy sector and coastal defence sector. One major problem encountered during the design of OWC-WEC was the uncertainty of the wave loads. One of the best way to tackle this problem is by using a small scale model to see the performance of the OWC design first before the full scale construction. Currently there are two kind of scaling methods widely used, cauchy scaling and froude scaling. Cauchy is very useful to scale down the air elasticity or compressibility, while Froude can be used to scale down the gravity force acting on the structure. Both properties in very crucial for an OWC's structure due to the air column located inside the chamber and the wave load hitting it from the sea, however it is not possible for one model to use both since some parameters needed in the scaling methods contradict each other. So, other than using both scaling to make two models, one scaling method is selected and a factor to compensate the other scaling effect need to be established. The current research mainly focused in finding the compensation factor for Froude scaling due to air compressibility in a small scale physical model. The method used in this research is multiple scale measurement comparison of an OWC-WEC design. After the scaling effect can be concluded, the performance characteristic of the designed prototype can be estimated using the data receive from the test using the small scale model inside the laboratory, thus helping in designing a better OWC-WEC structure.