APPLICATIONS OF MATHS IN ENERGY 25th June 2009

Participants

Industry

Ray Hunter	Renewable Energy Systems Ltd (presented Problem 1)
Deryck Brown	Zi-Lift Ltd (presented Problem 2)
Mat Thomson	Garrad Hassan (presented Problem 3)
Craig Brand	Scottish Power
John Cosgrove	Associate of Energy Invest (Edinburgh University)
Dario Ghazi	Centrica
David Hall	Plurion
Nigel Harper	Energy Invest Group (plus colleague Tim)
Adrian Kirby	Centrica Ltd
Angela Mathis	ThinkTank Maths
Hannu Rajaniemi	ThinkTank Maths
(Oliver Rix	Redpoint Energy – registered but had to cancel last minute)
(Philip Tracey	Cairn Energy – registered but had to cancel last minute)

Total: 12 attended

Academics

Euan Barlow	Strathclyde
Julio Bros-Williamson	Napier
Andrew Coles	Strathclyde
Christopher Coles	Strathclyde
Graham Copeland	Strathclyde
Samia Cunningham	Heriot-Watt
John Fletcher	Strathclyde
Roger Fletcher	Dundee
Eric Grist	ERI (Thurso)
Andreas Grothey	Edinburgh
Meetu Gupta	Strathclyde
David Hill	Strathclyde
Hassan Khalid	Strathclyde
Nigel Mottram	Strathclyde
Andrew Richards	Heriot-Watt
Lukasz Szpruch	Strathclyde

Total: 16

Organisers and others

Helen Bridle	ICMS
Irene Moore	ICMS
Tony Mulholland	Strathclyde
Alasdair Rose	EPSRC
John Toland	ICMS

Total: 5

Total: 33 attendees

Programme

11:00 *Registration / Coffee*

11.30 *Welcome & Introduction*
(Helen Bridle, ICMS and Tony Mulholland, University of Strathclyde)

11.45 *Overview of Applications of Maths in the Energy Sector*

12:00 *Industry Problem 1: Optimising the ratings, cost targets and operating strategy for energy storage at a wind farm*

13:00 *Buffet Lunch*

14:00 *Industry Problem 2: Sensor reduction in down-hole linear permanent magnet machines*

15:00 *Coffee*

15:30 *Industry Problem 3: Understanding marine turbulence for development of robust tidal turbines*

16:30 Mechanisms for funding collaborations
(ICMS, Smith Institute, Bridging the Gaps, RenewNet)

Discussions continued over dinner.

Problem Abstracts

Optimising the ratings, cost targets and operating strategy for energy storage at a wind farm

Wind energy is largely stochastic although it has clearly defined statistical attributes and general daily and seasonal trends.
For much of the time, power levels from a wind farm are well below rated power, although in annual terms a significant proportion of overall energy is delivered at higher powers.
This results in relatively poor use being made of grid assets where asset usage broadly matches the capacity factor of the wind farm.
However, grid assets(available capacity) are often in short supply.
Storage is seen as a method of smoothing the delivery of power from a wind farm to a network which would make better use of network capacity - rather than linking a 30MW wind farm to the network using a 30MW rated connection, one idea might be to only use 20MW of network capacity but to have a local energy store with a 10MW transfer capacity.
The problem I'd like to pose is:
for a given financial structure epitomised by an energy income tariff and by a network capacity charge, what would be the optimum energy capacity and power transfer ratings for the store and what control algorithm should be employed. As a partial corollary, what should the cost targets be for energy storage devices before they could generally be regarded as being commercially attractive in this application.
All of this could be sorted out using oodles of time domain simulation, but is there a more analytical, statistical approach that will give greater insights?

Sensor reduction in down-hole linear permanent magnet machines

Traditional applications of a linear permanent magnet motor have required accurate position feedback to the variable-speed drive to control the speed and position of the motor. This feedback is often provided by an optically-based sensor that requires many signal wires between the sensor and the drive.

In our application, we aim to use a linear permanent magnet motor to power a pump that will be located 3 kilometres down a natural gas well. Whilst the linear motor and pump are deployed down-hole, the drive unit remains on the surface, and is connected to the motor using a four-conductor cable that consists of the three motor supply cables and one communications cable. In this environment, both the optical nature of traditional position sensors, and the requirement for many connecting wires are impractical for a cost-effective and reliable pumping system.

One possible approach to controlling the motor is an alternative position sensor that can withstand the extreme environment, and send its output signal over the single communications wire to the surface, where it can be used to generate the normal feedback signals to the drive. However, this solution has several disadvantages, not least that a failure of this sensor or its connecting cable would render the entire system inoperative. A better solution would replace this down-hole sensor with various measurements taken at the surface that could estimate the motor position.

Recent work on permanent magnet motors has considered the theoretical aspects of various sensor-reduction techniques. These techniques use a mathematical model to estimate the motor position, using various parameters including the voltage, current and induced back EMF on each of the three motor supply conductors. Unfortunately, this work has tended to focus on rotary rather than linear motors, and has ignored the problems that would arise from the large distance between motor and drive in our application.

Our problem is to develop a suitable mathematical model of sensor reduction that can be applied to our linear motor over a long cable length, which could be used in practice.

Understanding marine turbulence for development of robust tidal turbines

Tidal stream devices offer an attractive source of renewable energy due to the predictable nature of tidal currents. But whilst the prediction of the mean tidal flow velocity is an established science and can provide estimates of steady power capture and device loadings, the understanding of the higher frequency flow fluctuations is limited.

If cost-effective design solutions are to be achieved then it is a prerequisite to have a detailed description of the environmental conditions. Initial analysis at typical sites suggests that the level of ambient turbulence intensity will have a major impact on device loading and performance. Hence there is a need for a good understanding and robust representation of the incident flow on to the device.

The problem is twofold. Firstly we need to better understand the intensity, length scales, frequency spectrum and spatial correlation characteristics of the turbulent flow, so that we can then go on to develop better representations as the basis of more reliable calculations of the hydrodynamic loading of tidal stream devices.

The emerging tidal energy industry is reliant upon the input of expert knowledge from many different disciplines and there is a clear need for collaborative R&D to move this new area of science forward.

Summary of the discussions

PROBLEM 1

RH described how storage is seen by some as the solution to the periods of low production associated with wind energy. His aim was to characterise, in terms of cost, capacity etc, the requirements that a storage solution needs to achieve for applications in the wind energy sector. He wanted to determine whether storage was a viable solution and promote better communication between the wind sector and the storage community.

AK enquired whether the target of 35% of UK production from renewables by 2020 was feasible and if there were other options, such as improved grid efficiency rather than storage.

RH replied that wind energy could deliver 2/3 of the renewable energy target with schemes already approved. He commented that storage was definitely useful, for example in the electrical vehicles sector and that his interest was in evaluating how useful storage was for wind farms. He agreed that there were other options such as CtCGs or demand side management.

Tim enquired whether linear programming was the same as the hill climbing algorithms RH had mentioned and commented that this approach would give the parameter values.

RH replied that he was interested in an alternative approach looking to find the optimum values and what drives them.

HR suggested that this problem was maybe a 'toy' version since the whole network should actually be considered rather than storage at just one wind farm.

RH agreed that the bigger picture is indeed more complicated but that he hoped the answer to the simple problem would be informative and that he felt his problem represented a useful simplification. Additionally, due to the extent of weather systems averaging across the UK is not enough to give stable production so the problem was not completely facuous.

NM commented that the need for a numerical approach arose because the power data was noisy. He wondered if a simple single frequency model could be utilised and then extended to incorporate several different frequencies.

RH countered that wind is not like that and that a model only using a few dominant frequencies probably wouldn't work since wind contains a very broad spectrum of different frequencies.

NH thought that if you added in storage and smoothing such an approach could work.

RH wondered whether it would since variability is observed even over long time scales of 30 days or more.

JBW enquired about the use of fuel cells as storage, for example H fuel cells.

RH said he had looked at these and in his opinion, in terms of electrical storage, batteries were much closer to market than H fuel cells. He commented that one outcome of a better understanding of the use of storage in the wind sector could be to drive investment and guide policy in developing new storage solutions.

AR saw it as a stochastic optimisation and thought that the cost of intermittency should be included into RHs basic model.

RH agreed there was a missing term which would influence the lifting off the bottom effect (i.e. no periods with no delivery to the grid).

AR and RH then discussed the back up, i.e. how much reserve would be needed when using renewables.

TM mentioned the possibility of spatial averaging.

AR mentioned studies performed by ETT in Finland where smoothing was not shown and commented that even if it did smooth how do you transport the power?

RH agreed that high efficiency DC transmission systems were needed.

NM wondered if the model developed would influence where to situate wind farms.

DG enquired about the feed power to the turbine at high speed and whether it could act as storage.

RH replied that the storage implicit in the inertia of blade rotation could last only a few seconds and was not enough for the timescales he was interested in.

TM asked whether a cost-benefit analysis had been done and RH replied that it was related to power quality, in terms of whether the local grid would be messed up.

AG enquired whether or not pumped storage was possible for 30 days.

RH agreed that although it was the best option and would last a long time the difficulties were that location of such pumped hydro storage was inflexible and required lots of space.

TM commented that RH was mainly interested in the inverse problem, i.e. what would the parameters from the model tell him about the needs of storage.

RH agreed and said he was meeting a storage company the next day who considered that renewables was one of their prime markets. He wasn’t sure if his company was and at the moment he was quite negative but would be interested in seeing the results of any mathematical modelling.

PROBLEM 2

DB described how Zi-Lift aim to use a linear permanent magnet motor to remove water from gas wells to allow for the extension of well production lifetime and for a greater quantity of gas to be recovered. The challenge with linear motors is that the alignment is very important so the drive requires position feedback. Down-well sensors are difficult for many reasons so an alternative could be to measure voltage and current at the surface. Models for this have been developed for rotary motors but how do they apply to linear motors (lower error tolerance) and how do they cope with the extremely long cable lengths?

NM wondered why rotary pumps couldn’t be utilised instead.

DB mentioned that space was one issue but that the bigger problem with rotary pumps was that gas locking could occur in a multiphase fluid whereas linear motors could still completely displace even if gas gets in.

SC asked if acoustic transmission could be used for sensing.

DB thought that the data transmission rates would be too slow and also wondered if it could achieve sub mm accuracy. He knew that acoustic sensing had been applied in other areas of Ziebel (the parent company) and assumed that this option had been considered before he started the project.

TM commented that since you will always need the cable it made sense to utilise it in sensing. He asked about sending an electrical signal down the cable.

DB replied that there could be significant voltage drops along the long cable length.

NM asked about the working of the linear magnet motor and whether the 3 magnets move independently because if so the device could readjust and correct for any positional error.

DB replied that they would prefer not to have to alter the VSD since Zi-Lift don’t manufacture the motors themselves and therefore VSD changes would be a commercial decision for the manufacturers.

AC suggested moving the sensor back down the hole for high frequency.

DB replied that there were problems having the electronics at high temperatures and remote from any possibility of repair.

TM enquired as to whether lab testing would be possible to acquire data to compare to the existing models.

DB agreed this could be done using cable simulators.

Tim asked about metal expansion and DB agreed that there would be expansion but that it wouldn’t be extreme enough to result in deformation.

PROBLEM 3

MT is interested in using mathematical modelling to develop a better understanding of marine turbulence. Garrad Hassan has converted a time domain simulation for wind turbines for use with tidal energy and has made an assumption about the turbulence which they are unsure about. The resulting software is used to drive device design (i.e. how the device copes with both extreme and fatigue loads) and to validate performance so it is important that the turbulence is well understood. One difficulty is collecting data from tidal races as the device currently utilised (acoustic dopplar current profiler - ADCP) gives data from points 15m apart which is a large scale.

SC enquired whether chargability had been considered in the models as it might result in density fluctuations. NM agreed that given the proximity of the waves and the seabed there would be lots of disturbed sediment which could influence viscosity and the load.

MT replied that the flow was at very high Reynolds numbers that these effects would be of second order compared to the turbulence. Tidal races move so fast that blades remain really clean.

SC disgreed and thought that chargability would be very interesting in relation to blade fatigue.

MT thought that there could be an effect on the surface of the blades and blade degradation but that he was much more interested in trying to understand the turbulence which he believed to be a more important effect.

GC asked how the data was reconstructed in the current model.

MT replied that it was a turbulent model in 3D which was then applied onto the rotar. The model was von Karman and specific input parameters were applied.

GC suggested using a process model to collate the data and collocate the 15m apart measurements.

AR wondered about scaling the ADCP and tightening the beam to provide closer together data points or using simultaneous readings of ADCP data and flow measurements.

MT agreed that the ADCP beam could be tightened but that vertical accuracy would be lost. Flow measurements were regarded as difficult since it is tricky to mount such devices in the sea although this could be worth considering.

NM enquired whether multiple sources were used and MT agreed that they were necessary.

TM asked about the frequencies used in the measurements and also whether measurements from the blade could be used to understand the turbulence.

MT replied that the measurement frequencies were 300-600kHz. Another possibility would be to cross beams from different devices but that the manufacturers were nervous about this and there were problems with post processing. In terms of the blade local sensors placed there would give information on the length scale of eddies. However, MT would prefer to ignore the turbine at present and develop a good understanding of the actual flow.

NM wondered about the difference between the wind and tidal models and if the only difference was in compressibility of the fluid and possibly the effects of sediment.

MT commented that their model was probably valid but that there was no evidence and that the situation was different since the dominant length scales were different and the tidal situation was more complex due to the narrow depth and the interaction with waves.

RH asked if using CFD in a recurvise way could be the optimal solution.

MT agreed that such an approach has its place for, e.g. design validation, and that a CFD model of turbulence could probably be well applied to study extreme events. However, when considering fatigue many simulations would need to be run and thus it may not be optimal in this case.

GC suggested that a data assimilation method could be applied, i.e. a small volume CFD could be used to recover boundary conditions. A similar method was used to bring info together in generating large scale weather models. Data assimilation could be used to back calculate and find the correct parameters. MT agreed that this appeared to be a sensible approach and their discussion continued after the end of the presentation slot.

A follow-up sheet was circulated after the final talks for people to register their interest in the different problems. These people will be contacted to investigate how we can work together to solve the above problems.

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