FUTURE RELIABLE RENEWABLE ENERGY CONVERSION SYSTEMS & NETWORKS (FRENS)

UK-CHINA ENERGY COLLABORATION

3RD FLAGSHIP SEMINAR

The Kingsley Barrett Lecture Theatre
Calman Learning Centre
Durham University

EPSRC
Engineering and Physical Sciences Research Council

Research Councils UK
Energy
For a Low Carbon Future

2nd-5th September 2011

CONTENTS

SEMINAR INFORMATION AND SERVICES

Organising committee

Chairman Professor Peter Tavner (Durham University)

Co-Chair Professor Xiangning He (Zhejiang University)
Professor Luowei Zhou (Chongqing University)
Professor Yongdong Li (Tsinghua University)

Secretary Professor Li Ran
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Project partners

China side: Chinese Academy of Sciences, Chongqing University, Nanjing University of Aeronautics and Astronautics, Sichuan University, Tsinghua University, and Zhejiang University

UK side: Durham University, Edinburgh University, Newcastle University, Nottingham University, and Warwick University

Supporting universities and institutions

Aalborg University, Huazhong University of Science and Technology, University of Strathclyde, and Wuhan Optoelectronics State Laboratory.

Sponsors

Energy Programme of Research Council UK

Industrial sponsors

Control Techniques, Converteam, EM Renewables, GE Research, Goldwind, Mott MacDonald China, National Grid, NaREC, and Siemens.

Seminar venue

The Kingsley Barrett Lecture Theatre (CLC407)
on the top floor of the Calman Learning Centre, Science Site
Durham University
Durham DH1 3LE
UK

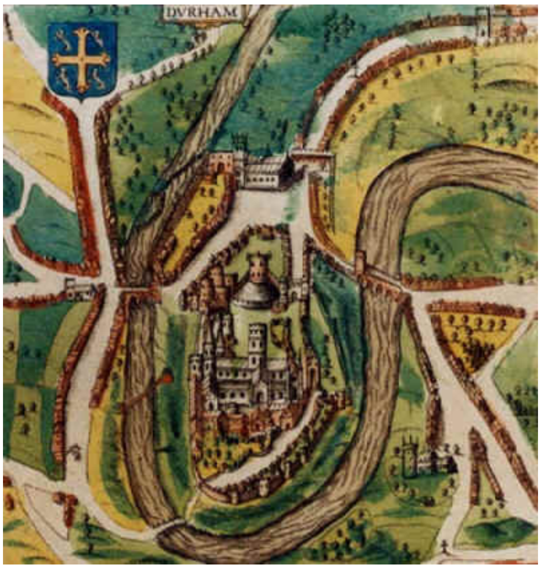
Calman Learning Centre is numbered 43 on the map on page 25.

About FRENS

Sponsored by Engineering and Physical Sciences Research Council (EPSRC) of UK, the third FRENS flagship seminar will be held in Durham, UK on 2nd – 5th September, 2011. It will include some regular sessions on the major aspects of circuit theory, simulation analysis, system considerations and applications on the reliability and networks for future renewable energy conversion. It provides an opportunity for UK and Chinese PhD students to exchange their experience and ideas in their related research projects, in addition to speeches by leading industrialists and academics on the forefront of reliability research and applications.

About Durham

Durham is in the North East of England. It is a World Heritage site and has a number of notable beautiful landmarks, including a Cathedral (completed AD 1092) and a Norman Castle constructed by William the Conqueror, which is now the centre of the University. Durham has good access from Europe via Newcastle and Durham Tees Valley Airports, which are within 20 km of the city.



Durham in 1610

About Durham University

Durham University is the third oldest university in England and is a place of international reputation. Durham University is distinctive - a Collegiate University with ancient traditions and modern values. It seeks to achieve the highest distinction in research and scholarship which make a real difference to societies world-wide. The World Heritage Site at the heart of the City of Durham has been a leading centre of scholarship for over 1000 years, while its cosmopolitan Queen's Campus in Stockton is at the leading edge of Teesside's transition from an industrial to knowledge economy.

Accommodation

Collingwood College
South Road
Durham
DH1 3LT
Tel: +44 (0)191 3345000

Collingwood College is numbered 6 on the map on page 25.

How to get to Collingwood
By Bus: The number 6 bus runs every 15 minutes from Durham Bus Station and stops outside College.
By Train: Durham Train station is in the centre of Durham and 5 minutes walk to Durham Bus Station.
By Car: Please check Google map.

Tour to Lake District and Barnard Castle

This is optional trip to Lake District and Barnard Castle on Saturday, 3rd September. Delegates who showed interest in the tour please check the list on registration. More details can be found on page 25.

AGENDA

Day 1 9:00 – 17:25 Friday, 2nd September 2011

Chairman: Prof. Peter Tavner (Durham University)

09:00 – 09:30	*Coffee reception*
09:30 – 09:50	**Introduction and welcome by Chairman** Prof Peter Tavner, Durham University
09:50 – 10:15	**Keynote: Wind Technologies – Siemens's Vision** Rodney Jones, Siemens Wind Power
10:15 – 10:40	**Keynote: Requirement for Reliability** Carl Johnstone, National Grid
10:40 – 11:00	*Coffee break*
11:00 – 11:25	**Keynote: Smart Grids** Prof Phil Taylor, Durham Energy Institute
11:25 – 11:50	**Keynote: Renewable Power in China** Prof Xiaoming Yuan, Huazhong University of Science and Technology, formerly Chief Engineer of Electrical Engineering at GE Global Research Centre
11:50 – 12:15	**Keynote: Research at the centre of reliable power electronics Aalborg** Prof Stig Munk-Nielsen, Aalborg University, Denmark
12:15 – 12:45	**Discussions and Chairman's Remarks**
13:00 – 14:00	*Lunch*

Chairman Prof. Xiangning He (Zhejiang University)

14:00 – 14:25	**Keynote: Advancing Renewable Technologies through Research, Development and Validation** Mr Paul McKeever, Narec
14:25 – 14:45	**The control strategy for asymmetrical LVRT in DFIG system** Lie Xu, Tsinghua University
14:45 – 15:05	**A DC-DC converter topology for voltage equalisation of series connected Li-ion capacitors** Simon Lambert, Newcastle University
15:05 – 15:25	**Recent development and prospect of concentrated solar power (CSP) technology in China** Dr Chao Xu, Chinese Academy of Sciences

15:25 – 15:45	**Modelling of electrical generators in the marine environment** Isaac Portugal, University of Edinburgh
15:45 – 16:05	*Coffee break*
16:05 – 16:25	**Multiple renewable energy resources based micro-grid system for offshore island area** Quanwei Liu, Zhejiang University
16:25 – 16:45	**The use of fault-tolerant modular multilevel converters to improve the availability of offshore wind power** Dr Max Parker, University of Strathclyde
16:45 – 17:05	**PEC thermography for inspection of carbon fibre reinforced plastic samples** Liang Cheng, Newcastle University
17:05 – 17:25	**DC-based Integrated & Smart PV Module System with High Step-Up Converter** Wuhua Li, Zhejiang University
19:00 – 22:30	*Dinner at Lakeside Dining Room in Van Mildert College* *Van Mildert College is numbered 4 on the map on page 25.*

Saturday, 3rd September 2011

Day trip to Lake Windermere in lake district and Barnard Castle. More detail is on page 26.

18:00 – 19:00: **Evening workshop on future collaborative projects.**
Chairs: Professor Tongguang Wang (973 WindPower Chair, Nanjing University of Aeronautics and Astronautics) and Professor Guiyun Tian (Newcastle University)

19:30 – 21:30: Dinner at restaurant "Capriccio Ristorante Italiano" in Durham city centre

Sunday, 4th September 2011

There will be private transport to Newcastle Metro Centre (shopping) or to South Shields seaside.

18:00 – 19:00: **FRENS Management Meeting**.
Chair: Professor Peter Tavner and Professor Li Ran (Durham University)

19:30 – 21:30: Dinner at local pub "Court Inn" in Durham city centre.

AGENDA

Day 2 8:45 – 17:30 Monday, 5th September, 2011

Chairman: Prof. Luowei Zhou (Chongqing University)
Prof. Yongdong Li (Tsinghua University)

08:45 – 08:55	Introduction of the day
08:55 – 09:20	**Keynote: Challenges of Marine Renewables** Professor Ed Spooner (EM Renewables)
09:20 – 09:40	**Multi-objective Design Algorithm and Numerical Simulation of Wind Turbine** Long Wang, Nanjing University of Aeronautics and Astronautics
09:40 – 10:00	**Wind Turbine Generator Bearing Failure** Matthew Whittle, Durham University
10:00 – 10:20	**Thermal stress of power devices in multilevel converters for 10 MW wind turbine** Ke Ma, Aalborg University
10:20 – 10:35	*Coffee break*
10:35 – 10:55	**Lifetime prediction for power converters** Hui Huang, Warwick University
10:55 – 11:15	**Electrothermal Modelling for Power Converter Reliability** Peter Wyllie, Durham University
11:15 – 11:35	**A Multi-Parameter Method for Prognostics of Insulated Gate Bipolar Transistors** Shengqi Zhou, Chongqing University
11:35 – 11:55	**A time-domain physics-of-failure model for the lifetime prediction of wire bond interconnects** Li Yang, University of Nottingham
11:55 – 12:10	*Coffee break*
12:10 – 12:35	**Keynote: Mechanisms of Device Failure and Design for Reliability** Prof Sheng Liu, Wuhan Optoelectronics State Laboratory
12:35 – 13:00	**Keynote: Condition Monitoring Power Electronics for Reliability – Temperature and Harmonic Techniques** Profs Phil Mawby and Li Ran, Durham University
13:00 – 14:00	*Lunch*
14:00 – 17:30	**Visit National Renewable Energy Centre at Blyth**
18:00 – 20:00	Dinner at Newcastle

The **first International Seminar of Health Monitoring of Offshore Wind Farms** (HEMOW) will be held at Newcastle University on 5th and 6th September 2011. Anyone who is interested in the seminar please request further information from Professor Guiyuan Tian through g.y.tian@newcastle.ac.uk.

FRENS
3rd Flagship Seminar

ABSTRACTS

The control strategy for asymmetrical LVRT in DFIG system

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This presentation focuses on the control algorithm of the asymmetrical LVRT for DFIG system, and developed a novel direct power control (DPC) for a 1.5MW DFIG system.

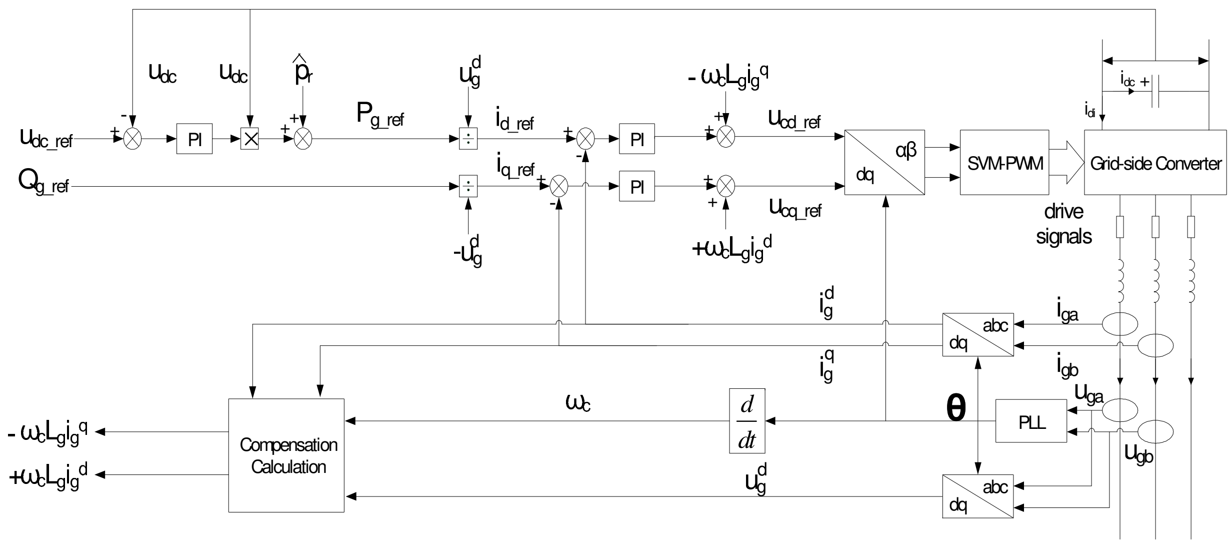
The content includes: Characteristics of Asymmetrical Voltage, Asymmetrical LVRT with Vector Control, Asymmetrical LVRT with Direct Control and Asymmetrical LVRT with Auxiliary Equipment.

Novel Direct Power Control algorithm for the grid side converter:

The grid-side converter is controlled for the following two objectives:

- To regulate the power factor on the grid side, which is desired to be unity power factor under normal grid conditions?
- To maintain the constant dc-link voltage as desired.

The grid-side converter is controlled by the traditional external-voltage-loop and inner-current-loop structure as following



Novel Direct Power Control algorithm for the Rotor-side Converter:

- To regulate the stator active power and reactive power independently.
- To connect the stator to the power grid smoothly.

Advantage:

- Eliminating the inner-current-loop, it controls the stator active and reactive power directly by a simple structure of a single-layer loop, which means a faster transient response.
- It's very easy to observe the stator power, the merits of which will be featured more prominently when the grid voltage is asymmetrical.

A DC-DC converter topology for voltage equalisation of series connected Li-ion capacitors

Simon Lambert
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Fluctuations in energy flow associated with renewable energy such as wind speed variation can cause stress to the drive train of the generation plant. This stress can cause failure resulting downtime or destruction of the generation plant. Flywheel energy storage can help to alleviate the stress on the generation drivetrain and therefore reduce downtime and increase lifespan of equipment. High capacitance devices have been used in many applications as energy flywheels to increase the reliability of plant.

As technology incorporating high capacitance devices such as supercapacitors, ultracapacitors and more recently, Li-ion capacitors have become more common a number of methods for equalisation of series connected devices have been published. The equalisation schemes which have been published to this point often have significant drawbacks such as restricted energy paths, complex multi-winding transformers, large numbers of components and poor equalisation rates.

Presented is a new equalisation scheme which provides the maximum energy path possibility, reduced component count, reduced mass and volume without significantly affecting equalisation rate.

Recent development and prospect of concentrated solar power (CSP) technology in China

Chao Xu*, Zhifeng Wang

Key Laboratory of Solar Thermal Energy and Photovoltaic System, Institute of Electrical Engineering, Chinese Academy of Sciences

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In the current world, electricity is still dominantly generated by burning conventional sources such as coal, oil and natural gas, which not only have a limited life but also release gaseous or liquid pollutants during operation. Because solar energy is an inexhaustible, clean and safe source of energy, it has received much attention as one of the most promising candidate to substitute for the conventional fuels for electricity supply. Recently, rapid development occurred worldwide in the basic technology and market strategy for the concentrating solar power (CSP) technologies, including parabolic trough, power tower, and dish/engine. This presentation will give a brief review about the developments of various CSP technologies in China, with emphasis on the state-funded research infrastructure of CSP in China.

China has plenty of solar resources, and research on CSP technologies in China began in 1979 and was accelerated since 2003 with pressure on energy resources and environmental concerns. After 30 years of research and development, great progress has been made in China on a wide range of technologies, including solar materials, solar thermal-electrical conversion materials, solar energy storage materials, solar concentrator equipments, evacuated tube solar trough collectors, solar thermal receivers, solar dish-Stirling systems, solar high-temperature air power generations, and solar power tower system. The first 1MW CSP demonstration plant based on power tower technology developed at the Institute of Electrical Engineering, Chinese Academy of Sciences, is nearing completion in a suburb outside of Beijing. The first commercial-scale CSP plant using the commercially proven parabolic trough technology has also been projected in Inner Mongolia of China. Large-scale commercialization of CSP systems in China is expected to be realized in the next 10 years, which will provide strong support for China’s economic development.

Modelling of electrical generators in the marine environment

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Reliability of marine energy converters represents a key challenge for engineers, as high-energy density places in the sea are typically located some kilometres away from the shores where the harsh weather conditions could limit the maintenance accessibility. Moreover, the nature of the marine resources (i.e. turbulence and wave spectrum) could create high-load patterns that could jeopardise the reliability and economic feasibility of entire projects.

Additionally, most marine energy devices are being designed to allow the usage of off-the-shelf electrical generators. This allows developers to concentrate their efforts in optimising the hydrodynamic and aerodynamic performance of the devices at the cost of dismissing potential benefits of especially designed machines.

This presentation will outline the endeavours' taken in the attempt of modelling the behaviour of a generator in a marine energy converter with the aim of obtaining a "typical" in-service load profile for the selected machine. These stress-levels will be further used in reliability studies using previously developed deterioration models.

The stress-levels seen by the electrical machine are very device dependant. The work here exhibited will be focused on an oscillating water column, which is a system that comprises a semi open chamber with one opening semi submerged under the sea and the other one directed to a duct, the air pushed and sucked by the waves is forced to pass through an air turbine that extracts energy from the moving fluid, the turbine is then attached to an electrical generator for a final energy conversion.

The key aspects of this modelling work is translating the highly variable wave pattern into torque at the shaft of the electrical generator, and then, translating this torque into electromagnetic and thermal stresses inside the electrical machine. Although the focus of the study is on electrical generators, the dynamic interaction inside the chamber plays a significant role, as well as the modelling of the air turbine and the control of the entire system.

Multiple renewable energy resources based micro-grid system for offshore island area

Quanwei Liu, Yan Deng, Wuhua Li, Xiangning He
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liuquanwei@zju.edu.cn

Renewable energy resources, such as wind power, solar arrays and ocean current energy are effective supplements to the main grid, especially to those remote areas or islands, which are not economical for the conventional grid stations. Those renewable energy resources are studied for grid connected power generation or independent resident power supply as micro-sources, and they are usually united as a micro-grid for the better control and manage of the energy. These renewable energy resources call for energy storage elements, such as super capacitors, batteries or flywheels, to provide reliable and constant power supply due to their intermittent nature.

A multiple renewable energy resources micro-grid system with the total installing capacity of 4.8MW is introduced for offshore island area. The system consists of 3MW wind turbine, 300kW ocean current energy, 500kW photovoltaic arrays, 500kWh energy storage batteries with 1MW maximum power and super capacitors with 200kW maximum power. All the renewable energy resources are connected to the AC bus of the micro-grid through the inverters or AC-DC-AC converters, and the Li-ion batteries and the super capacitors are connected to the ac bus through the bipolar converters. The micro-system is connected to the grid through a static switch. Normally, the micro-grid is running with connecting to the grid, and the micro-grid runs independently with the main grid cut off when it fails. In this project, the challengeable problems will be summarized and the first-level research topics will be carried out. Novel advanced converters for multiple renewable energy resources and energy storage elements will be investigated, and the smart monitor system and effective energy manage strategies will be developed.

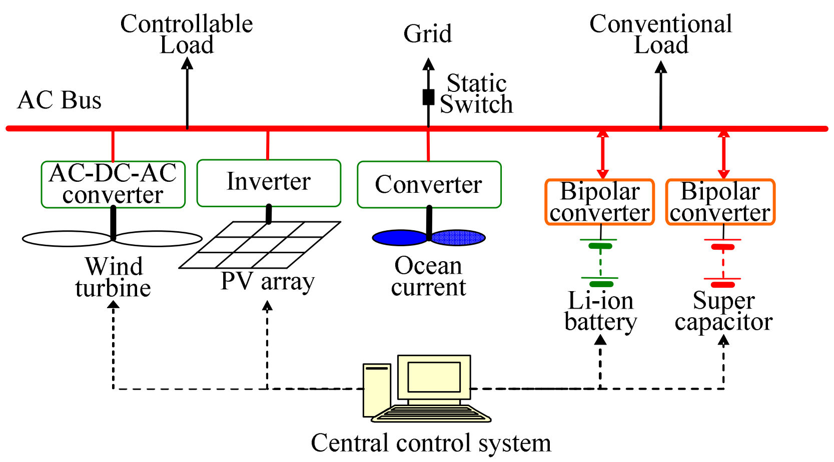

Fig: The micro-grid system configuration

The use of fault-tolerant modular multilevel converters to improve the availability of offshore wind power

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A modular cascaded multilevel inverter is proposed as a grid interface for direct-drive generators in large wind turbines. Multilevel inverters are able to provide a high voltage output, while using cheap low voltage switching devices, and produce an output waveform with low distortion while minimising the switching frequency of the individual switching devices. The cascaded multilevel inverter, if built to a modular design, provides a high level of tolerance to component failure, which is particularly important in the offshore wind industry, where accessing the turbine for repair is difficult and costly.

Each leg of the cascaded multilevel inverter consists of several h-bridges, each with its own voltage source, and these h-bridges are cascaded to form the inverter. The issue in such an inverter is providing the separate isolated voltage sources, and regulating the DC voltage of these sources.

Existing medium voltage drives based on such a converter use isolating transformers and diode rectifiers to provide the isolated voltages, with the inverter output driving the machine. It is proposed that the isolated voltage sources could be provided by multiple isolated coils on a direct drive generator, through boost rectifiers. In this case, the inverter would be connected to the grid side, operating at a voltage of 3.3kV or higher. It would be built out of modules each consisting of a boost rectifier connected to several generator coils, a DC-link capacitor, and an h-bridge output. The boost rectifiers are controlled independently to regulate the DC-link voltages of the modules.

A prototype system has been built, based on a single phase 12-module 23-level inverter, producing 2.5kW at 230V. Each module is connected to two coils of an axial-flux permanent magnet generator. The system has been shown to produce a low distortion voltage waveform, and is able to tolerate faults in one or more modules by raising the DC-link voltage of the remaining modules to compensate for the lost module.

PEC thermography for inspection of carbon fibre reinforced plastic samples

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There is currently a requirement in many industries to inspect carbon fibre reinforced plastic (CFRP) components, such as those used in wind turbine blades to identify issues leading to potential failures. Based on failure models, three different kinds of defects on CFRP materials are summarised as crack, delamination and impact damage. To detect and classify them, pulsed eddy current (PEC) thermography is proposed and investigated, allowing the operator to observe the heating developed from the eddy current distribution in a structure using infrared imaging, detecting defects over a relatively wide area within a short time. In this presentation, a PEC thermography inspection system for CFRP materials is reported. Using the system, the directional electrical conductivity and fibre orientation of the CFRP material is observed through the surface heating pattern and modelled. Then, surface heating pattern and transient temperature variation are investigated in both simulation and experiment and features are extracted and validated to classify these damages or defects. The advantages compared to other thermography approaches are also provided.

DC-based Integrated & Smart PV Module System with High Step-Up Converter

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The increasing threat of the fast depletion of the resources pushes people to seek the renewable energy sources. Photovoltaic (PV) energy based micro-grid system is taken as one of the most promising solutions to save the natural resources and solve the environmental problems. The state-of-the-art PV grid-connected architectures have been investigated to explore the potential gaps among current PV system techniques. A novel architecture named as DC-based integrated & smart PV module system is proposed to satisfy the stringent high-performance and low-cost requirements for next generation PV grid-connected systems. The clear advantages of the DC-based integrated & smart PV module can minimize the hot spot effect in the conventional solutions with PV cell series configurations. Furthermore, the light-to-electric energy conversion efficiency is quite high because each PV cell can insert an independent maximum-power-point tracking (MPPT) control strategy. Moreover, the proposed solution has advanced extendibility, easy maintenance and high reliability due to its module configuration. How to derive high step-up and high efficiency converters is one of the most significant research topics. The major challengeable problems on isolated and non-isolated high step-up converter deduction are summarized and the universal topology derivation principle is generated to make a clear picture on the general law and framework for the next generation DC-based integrated & smart PV module systems. Some high step-up converter derivation rules with detailed experimental results are employed as examples to verify the effectiveness of this presentation.

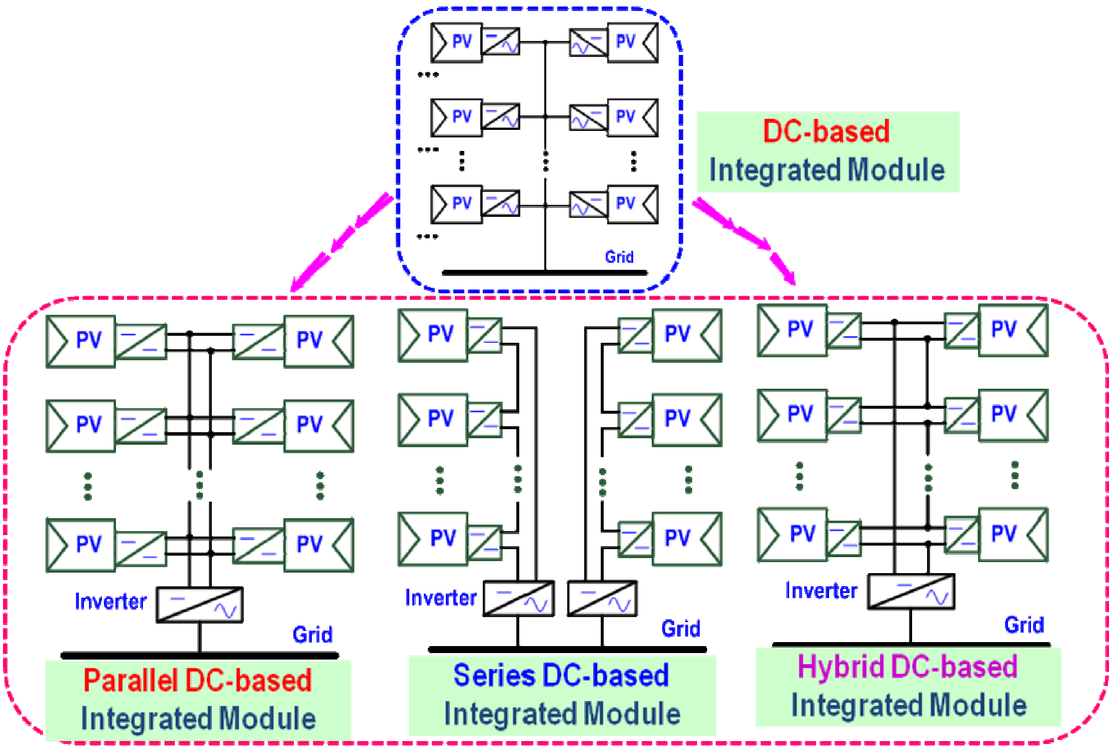

Fig: Proposed DC-based integrated module

Multi-objective Design algorithm and Numerical Simulation of Wind turbine

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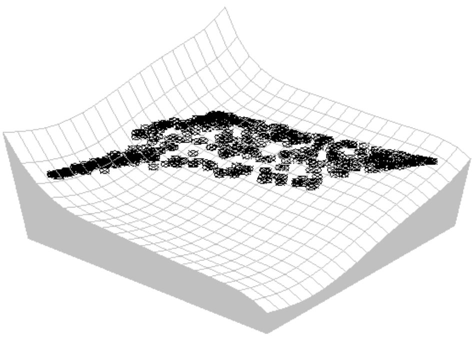
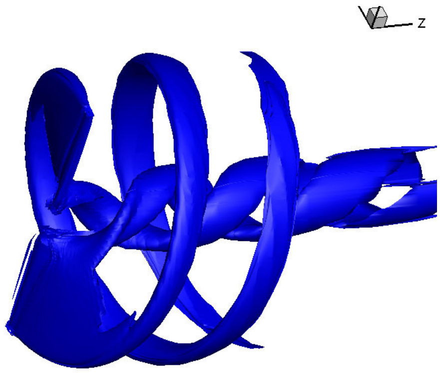
Based on a fast and non-dominated sorting genetic algorithm，an improved NSGA-II, incorporating the controlled elitism strategy, the dynamic crowding distance strategy and effectively constraint-handling approach, is applied in the field of multi-objective optimization design of wind turbine. This improved algorithm can be used to handle the problems with any number of objectives and equality or inequality constraints. As an example of the algorithm, taking maximum annual energy production, minimum blade mass, and minimum blade root thrust as the optimization objectives, a series of 1.5MW wind turbine blades are designed with both two-objective and three-objective conditions. The results indicate that the Pareto-optimal solutions of two-objective conditions distribute on a curve, and the solutions of three-objective case are approximate on a five-order surface with evident boundaries. Compared with the traditional methods for wind turbine design, the improved NSGA-II has been proved better in maintaining diversity and authenticates its potential to solve multi-objective optimization problems of wind turbine. In additional, the Phase VI wind turbine is also studies by Computational Fluid Dynamics (CFD) simulations, using 3-D, unsteady, incompressible, parallel, finite volume flow solver. The solutions are obtained using unstructured sliding mesh and Reynolds-averaged Navier-Stokes solver (SST k-ω turbulence model). Three different flow cases with different wind speeds (7m/s, 10m/s and 13m/s) and wind yaw angles are investigated. Results for these three cases and comparisons with the experimental data are presented. The results turn out to agree well with experimental data at incoming wind speed of 7 m/s. However, when the wind speeds are 10m/s and 13m/s, some deviations exist due to the relative large flow separation and 3D spanwise flow over the suction surface of the blade.





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Wind Turbine Generator Bearing Failure

Matthew Whittle
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Improving the reliability of wind turbines is an essential component in the bid to minimise the cost of energy, especially for offshore wind due to the difficulties associated with access. Numerous studies have shown that wind turbine generator failure rates are unacceptably high, particularly given the long downtime incurred per failure. However, generator failures have, to date, received relatively little attention in the wind industry with the focus generally having been on the blades and the gearbox. There is evidence that the bearings are the most important source of generator failures. This situation in the industry provides the motivation for the current research focused on understanding the modes and, crucially, the root causes of wind turbine generator bearing failures.

A 'bottom-up' approach (i.e. seeking a general understanding by beginning with particulars) has been adopted to complement the higher level reliability studies in the literature. Two failure modes have been identified which, because of the particular integration of technologies in wind turbines, are of importance and have to date received relatively little attention in the industry. Firstly, premature rolling contact fatigue failure caused by system misalignment and, secondly, bearing failure due exposure to electrical stress caused by the common-mode voltage of the pulse-width modulated (PWM) switching of the power electronic converter.

The sensitivity of the generator, and gearbox high speed stage (HSS), bearings to parallel misalignment and flexible coupling tilt stiffness has been investigated using proprietary software to analytically compute the bearing contact stresses. It was found that the generator bearings were especially sensitive to misalignment, and that under certain operating conditions could be expected to fail prematurely. The value of performing integrated system analyses has been demonstrated.

The second failure mode stated above was failure due to exposure to electrical stress. In this case the parasitic capacitive coupling, by which high frequency (HF) leakage currents give rise to bearing currents, has been investigated and the general principles are now quite well understood.

A range of coupling models has been proposed in the literature, but all incorporate a very simplified model of the bearing. An improved model of the bearing capacitance is presented here by using both Hertzian contact mechanics and the Hamrock-Dowson film thickness equation. By considering a typical 2MW DFIG the capacitances of the HF stray circuit were calculated from the machine geometry and a range of simulations and sensitivity studies were undertaken.

Thermal stress of power devices in multilevel converters for 10 MW wind turbine

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As the power level of a single wind turbine is continuously pushed up even to 7 MW, the wind power generation system are required to be more reliable, and able to withstand extreme grid disturbances. Moreover, it is becoming a need that the wind power generation system should be more active, and able to contribute to the grid recovery by injecting reactive current during grid faults. Consequently, the full-scale power converter solutions are becoming more and more popular to fulfill the growing challenges in the wind power application. Nevertheless, the loading of the power devices in full-scale power converters, especially during grid faults may compromise the reliability performance and further increase the cost of the system. Three promising multilevel converter topologies for the next generation 10 MW wind turbines are proposed and basically designed as case study. The operation status, as well as loss and thermal distributions of power devices are investigated, simulated and compared aimed at both normal and grid fault conditions. It is found that the all of the proposed converter topologies will suffer from higher junction temperature in some heavy loaded power devices especially the diodes under grid faults, and both of the three-level and five-level H-bridge topologies show more potential to reduce the device stress than the well-known three-level Neutral Point Clamped topology.

Lifetime prediction of power converters

Hui Huang
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Power converters are used in most electrical applications due to their high conversion efficiency. Therefore, their reliability is an important issue to manufacturers. All power converters have a limited lifetime. However, it is difficult to determine a general lifetime for all power converters, since their working conditions may vary in different applications. From the design point of view, it is valuable to develop a lifetime prediction tool for power converters which can predict the converter lifetime according to various working conditions. This is extremely important for the applications that require high reliability, such as off-shore wind farms.

In order to predict the lifetime of a power converter, it is essential to understand the physics of various device failure modes. During converter operations, IGBT modules are subjected to a complex sequence of service loads which leads to fatigue failures. Fatigue is a process leading to the failure which is caused by repeated stress cycles below the tensile strength of the material. The two most common fatigue failures of IGBT modules are bond wire lift off and die solder cracking. Both of them are caused by the temperature cycling and the mismatch of coefficient of thermal expansion (CTE) between silicon and aluminum/copper.

This presentation will introduce a novel lifetime prediction method based on the electro-thermal models and thermo-mechanical failure models of power semiconductors. This method could predict the lifetime of converters according to different operating conditions (current, voltage, switching frequency and so on). With further modifications, this method could also be used for condition monitoring of power converters.

Electrothermal modelling for power converter reliability

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Introduction

Fluctuating power in a wind turbine (WT) results in cyclic thermal loading on the generator and converter. The semiconductor components (diodes and Insulated Gate Bipolar Transistors (IGBTs)) used in the back-to-back converter will suffer accelerated aging effects. These effects will have consequences for both reliability and lifetime of the converter. An accurate thermal model is required in order to improve reliability prediction and allow insight into likely failure modes. Methods for mitigating the effects of thermal cycling, such as advanced cooling techniques or by control of losses during operation will be investigated.

Background

Wind power is set to play a crucial role in allowing government targets on reduction of carbon emissions to be met. The result will be an increased number of installed turbines both onshore and offshore. The remoteness of these wind farms, particularly those at offshore locations at which maintenance is costly, places an increased significance on reliability. Conventional steam turbogenerator units can outlast WTs by as much as 20 years: given the considerable research effort in the area of wind generation over the past 20 years this is a significant concern. A key distinguishing feature between the two operating environments is the fluctuating load developed by the stochastic nature of the wind. An understanding of the reliability implications of this stochastic mode of operation is crucial to allowing accurate prediction of turbine availability and lifetime energy yield. These turbine characteristics, of course, contribute to the cost of energy to the end user and thus the viability of wind generation of electricity.

The electrical subsystems (generator, converter and grid connection) have been identified as significant contributors to turbine failure rates and whilst reliability is improving failure rates for large WT generators especially in early life are still high [1]. It is hoped that a control strategy or design adaptation may be developed that will improve resistance to failure mechanisms of thermal origin within these systems.

Method

An electrothermal model of a large wind turbine is needed to allow us to understand the effect the varying wind has on the key electrical systems in the turbine. Reliability of converter and generator will, in part, be determined by the cycling of heat that arises due to varying electrical losses. In the case of a Doubly Fed Induction Generator (DFIG) the magnitude of this thermal cycling has been shown to be greater in the IGBTs that comprise the machine side converter than in those within the grid side converter. This problem may be used as a vessel to carry out research and to develop knowledge that may be applied to other topologies.

An electrothermal model of a 2.5 MW DFIG turbine has been developed using MATLAB-SIMULINK to model the control of the WT and PLECS to model the electrical system. Loss data is extracted with a view to understanding the effects of thermal cycling on semiconductor aging in the converter.

A Multi-Parameter Method for Prognostics of Insulated Gate Bipolar Transistors

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In order to get high power, IGBTs are commonly used in wind turbines, hybrid electrical vehicles and railway traction nowadays. But according to the investigation, IGBTs are easy to fail due to the suffered electrical and thermal stresses while running. So developing methods to detect precursor parameters of faults and prevent costly failures will be very necessary. In this research, a prognostic system using multi-parameter is presented. Electrical and thermal characterizations are performed via power cycling of IGBTs, and deviations of maximum gate charging current ΔI_g , saturation collector-emitter on-state voltage ΔV_{ce} are identified as precursor parameters for intelligence diagnosis based on NN. In addition, ΔT_j which is obtained by online measurement developed form $V_{ce}(T)$ method, is also used in the prognostic framework to predict the remaining useful life of IGBTs. The verification experiment of prognostic system mentioned above is still in progress.

For the sake of detecting of ruptured bonding wires, electromagnetic coupling between gate loop and main loop are used as shown in fig.1. It shows that bonding wires connecting emitter to terminals are regard as common inductance and fed by both gate and power current, so if some bonding wires are lifted, the value of the common inductance will be changed, charging current of gate loop is also correspondingly changed, as shown in fig.2. This phenomenon is valuable that provides a retrograde analysis for diagnostic of bonding wires in IGBTs via deviation of gate voltage oscillations and charging current. By means of developing time series models for gate voltage oscillations and charging current, we can track the change of their approximate entropy and use the deviation as one input data of NN.

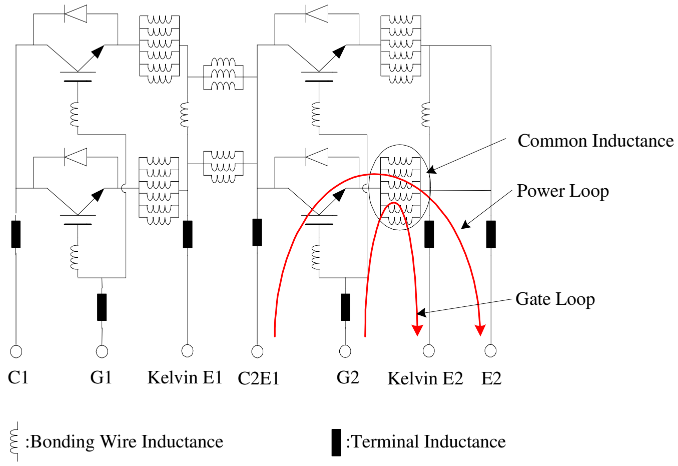

Fig.1 the electrical equivalent circuit of IGBT module

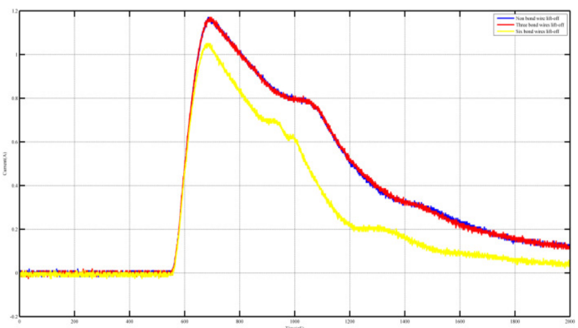

Fig.2 the change of gate charging current

To evaluate degradation of solder and remaining life, ΔV_{ce} and ΔT_j are best choices as precursors, but only if we can get the junction temperature T_j . Under present circumstances, the temperature dependent V_{ce} for a small sense current is particularly suitable method since IGBTs commonly used today have an almost linear negative temperature coefficient. We plan to add a current source to the gate driver board to measure the junction temperature of each IGBT inside equipment below 0.1 ms after turn-off simultaneously, to calibrate ΔV_{ce} and extract the number of thermal cycles.

A time-domain physics-of-failure model for the lifetime prediction of wire bond interconnects

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The move to a low-carbon energy future that is underpinned by electrical energy is driving increased use of power electronic enabled energy conversion technologies. As a consequence a detailed understanding of the factors influencing the reliability of power electronic modules is becoming an increasingly important topic.

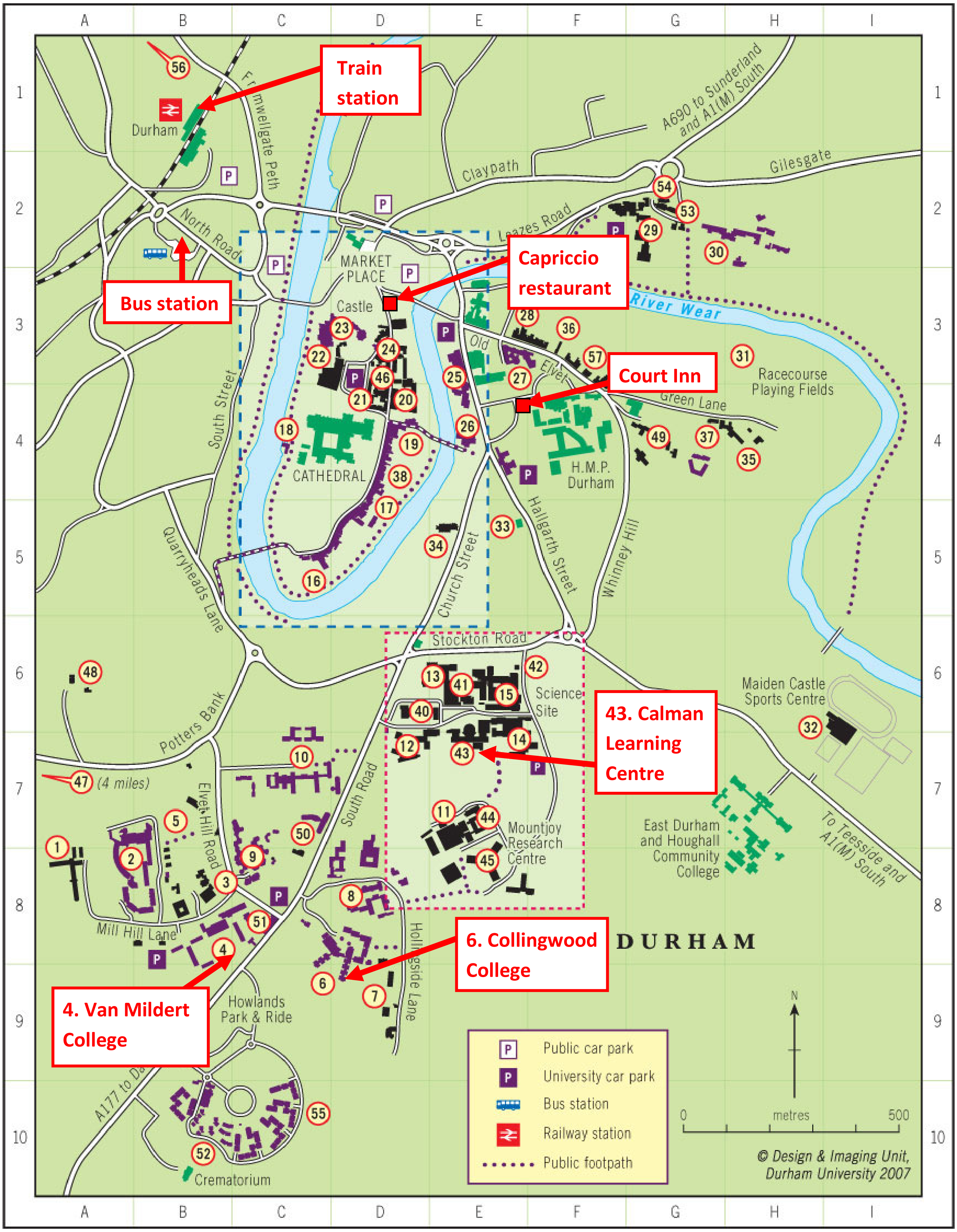
Reliability assessment based on physics-of-failure models aims to identify the root-cause of the potential failures under application conditions. In this method, the specific failure mechanism models are employed to predict the time to failure, which allows the behaviour of the electronic devices to be described at the structural level.

Wire bond interconnect failure is one of the most important life limiting factors to reliability behaviour. In the existing physics-of-failure based models for wire bond interconnects, lifetime is usually accounted for by loading amplitude alone and is usually derived based on a regular thermal cycle of a known duration. The effects of irregular loading and time at temperature are not addressed, leading to substantial errors for thermal cycling regimes with high peak temperatures.

Therefore a new physics-of-failure lifetime prediction model for wire bonds is proposed based on some phenomenological considerations. It discards the usual cycle-dependent modelling methodology and is instead based on a time domain representation. Also, the model accounts not only for the damage accumulation processes but also the damage removal phenomena during thermal exposure.

The bonding interface damage condition is estimated at regular time intervals through a damage model which includes the effect of temperature and time dependent material properties. The bond degradation is indicated in the form of crack growth and shear force reduction which can be predicted by the total interface damage as a function of time. Thus the impact of time at temperature and other rate sensitive processes on the bond degradation rate can be accurately represented.

DURHAM MAP


Train station
Bus station
Capriccio restaurant
Court Inn
43. Calman Learning Centre
6. Collingwood College
4. Van Mildert College
Durham
Framwellgate Peth
North Road
MARKET PLACE
Castle
CATHEDRAL
South Street
Claypath
Leazes Road
A690 to Sunderland and A1(M) South
Gilesgate
River Wear
Old Elvet
Green Lane
Racecourse Playing Fields
H.M.P. Durham
Hallgarth Street
Whinney Hill
Church Street
Quarryheads Lane
Stockton Road
Science Site
Maiden Castle Sports Centre
Potters Bank
(4 miles)
Elvet Hill Road
South Road
Mountjoy Research Centre
East Durham and Houghall Community College
To Teesside and A1(M) South
Mill Hill Lane
Hollingside Lane
DURHAM
Howlands Park & Ride
A177 to Durham
Crematorium
Public car park
University car park
Bus station
Railway station
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N
0 metres 500
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Lake District & Barnard Castle

Saturday, 3rd September 2011

09:00 – 11:00 From Collingwood College to Windermere
11:00 – 14:00 Tour in Lake District
14:00 – 15:00 From Windermere to Barnard Castle
15:00 – 16:30 Tour of Barnard Castle
16:30 – 17:30 From Barnard Castle to Collingwood College
18:00 – 19:30 Dinner in Van Mildert College

Windermere

Barnard Castle