Energy Systems Study Group with Industry
8th - 10th January 2018

Innovate UK
Knowledge Transfer Network

University of Sussex

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# Contents


1 Study Group Information 3
1.1 Background 3
1.2 Who will be attending? 3
1.3 How does it work? 3
1.4 Agenda 5
1.5 Do I need to pay? 6
1.6 Pre-Study Group Actions 6
1.7 Check-in, Accommodation and Dinners 6
1.8 Conference Dinner 6

2 Problems 7
2.1 Electric Vehicle Battery Degradation Study 7
2.2 Spectral Analysis of Power System Frequency to Determine Real-time System Inertia. 8
2.3 Algorithms to Devise Optimal Power System Control Actions 9

3 Participants 10

4 University of Sussex Information 12
4.1 Travel to the University of Sussex 12
4.2 Campus Map 13
4.3 Floor Plan 14

5 Supporting Organisations 15
5.1 Knowledge Transfer Network 15
5.2 School of Mathematics, University of Sussex 15


Problems posed by:

WILLIAMS ADVANCED ENGINEERING

nationalgrid

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# 1 Study Group Information

The Study Group is an opportunity for industry to gain access to UK excellence in the fields of mathematics, statistics, engineering, and computer science. The structure of the Group allows for this to be done in a structured, intense session over three days. This Study Group with Industry is being run by the School of Mathematics, University of Sussex, and the **Knowledge Transfer Network (KTN)**.

## 1.1 Background

Future energy networks will be characterised by much greater variability and uncertainty: inputs to electricity networks from renewable and solar generation are naturally highly intermittent, while new patterns of demand, e.g. that are required for the recharging of electric vehicles, are likely to be variable and are currently not well understood. Against this, there are significant new technologies available for the management of future systems. These include the management of demand, storage, generation and the networks themselves [1]

It is estimated that 50% of vehicle production by 2030 will be electric or plug-in hybrid electric. There will need to be completely different business models developed around how energy is stored and used [2].

## 1.2 Who will be attending?

The Study Group will consist of researchers from various fields, including, but not limited to mathematics, statistics, computer scientists, and engineers. As well as university researchers, we strongly encourage registrations from Ph.D students, postdoctoral researchers and early-stage researchers.

As well as these researchers, the Study Group will be attended by industrial representatives limited to those offering problems to the group. **We are not accepting registrations from any industry not directly involved in the problems**. In addition to these attendees the Study Group will host a number of Public Sector representatives from the Research Councils, and Department of Business, Energy and Industrial Strategy. We expect to host around 60 people to this Study Group from across these sectors. Attendees can be found in Section 3.

## 1.3 How does it work?

The format of the Study Group will be following the highly successful European Study Groups with Industry. Industry present their problems on the morning of the first day to the Group. The researchers ask questions and choose which group they may be able to help with.

The groups (10 - 15 researchers per group) will move to their own working space. An academic Project Lead will be nominated. They will discuss with the group what aspects of the problem should be addressed, and how these may be approached. It is likely that the group will subdivide, but this will depend on the problem.

It is expected that the industry representatives will be on hand to answer questions, provide access to codes, data and generally ensure that the problem context is clear throughout the Study Group.

1 http://www.icms.org.uk/workshop.php?id=480
2 https://innovateuk.blog.gov.uk/2017/07/24/the-faraday-challenge-part-of-the-industrial-strategy-challenge-fund/

Conversations often continue during the evening, and as such the Study Group provides dinner for all delegates. This often provides an environment for cross-fertilisation of ideas between groups and disciplines.

Group work continues until the Wednesday afternoon for final presentations. It is likely that the Project Lead will provide these presentations. Following the Study Group, the industry presenters will receive a report detailing what was done during the three days. Again, the Project Lead will coordinate this and draw on assistance from members of their team. The Project Lead will aim to get this report to the industrialist by the end of March 2018.

After review from the industrialist, we wish for this report to be made public as the Sponsoring parties have a responsibility to distribute good practice to the wider community. Thus, it is important for the industrialists to check for sensitive outcomes to be redacted within a month of receiving their report.

## 1.4 Agenda

| | Sunday 07 | Monday 08 | Tuesday 09 | Wednesday 10 |
|---|---|---|---|---|
| 09:00 onwards | | **Registration** (Fulton Reception) | **Group Work** (See Floor Plan) | **Group Work** (See Floor Plan) |
| 10:00 | | **Welcome, Introductions and Problem Presentations** (Fulton Building Rooms) | | |
| 11:00 | | | **Tea and Coffee** | **Tea and Coffee** |
| 11:30 | | **Group Work** (See Floor Plan) | **Group Work** (See Floor Plan) | **Group Work** (See Floor Plan) |
| 13:00 | | **Lunch** | **Lunch** | **Lunch** |
| 14:00 | | **Group Work** (See Floor Plan) | **Group Work** (See Floor Plan) | **Final Presentations** |
| 15:30 | | **Tea and Coffee** | **Tea and Coffee** | **Tea and Coffee** |
| 16:00 | | **Group Work** (See Floor Plan) | **Group Work** (See Floor Plan) | **FINISH** |
| 17:00 | | | | |
| 18:30 onwards | **Drinks Reception** (Pub in Town) | **Dinner** (Fulton Building) | **Dinner** (Brighton Harbour Hotel) | |

## 1.5 Do I need to pay?

The sponsoring parties are grateful to Innovate UK who have sponsored the Study Group as such we are pleased to cover for **all** delegates accommodation on the 8th - 10th January, including breakfast and lunches. We do however ask for a nominal payment of between £15 - 40 depending on the length of your stay. Additionally, we do ask that researchers and industrialists cover their own costs for travel to and from the venue.

## 1.6 Pre-Study Group Actions

To make sure the group progresses well, it is important that researchers read and study the problem statements provided by industry prior to the Study Group. It would be helpful for the researchers to have ideas on how they might approach **all** of the problems and be willing to work in any of the groups in case adjustments need to be made to balance capability and numbers in each group.

## 1.7 Check-in, Accommodation and Dinners

The organisers have arranged for a number of rooms to be held for Study Group members, for the Sunday, Monday, and Tuesday nights - requests for these should be indicated at Registration. These (en-suite) rooms include breakfast. Check-in time on the Sunday is 14:00 and delegates should go to the Ibis Brighton City Centre. Buffet lunches will be provided at the venue, dinner will be available on the Monday night on campus (details to be finalised) and a conference dinner will be held on the Tuesday evening at the Brighton Harbour Hotel (below).

For those traveling down on Sunday, there will be an informal reception in the evening starting at 18:30 at Brighton Pub (details to follow) where drinks and light snacks will be available. It will also be a good opportunity to discuss research ideas and how problems may be addressed in an informal manner.

## 1.8 Conference Dinner

The dinner on Tuesday will be held at the Brighton Harbour Hotel. There is no dress code, and no cost associated with the dinner. We would ask that people arrive promptly by 18:00 (for a 18:30 start). Additionally, if you have not indicated to the organisers in your registration any allergies, we request that you do so as soon as possible.

# 2 Problems

## 2.1 Electric Vehicle Battery Degradation Study

WILLIAMS

**Presenting Institution:** Williams Advanced Engineering

**Problem Presenter:** Robert Millar, Wasim Sarwar

**Abstract (Technical Topics and Desired Outcomes):** Williams Advanced Engineering is the technology division of the Williams Formula 1 team. It provides world-class technical innovation, engineering, testing and manufacturing services to deliver energy-efficient performance to the motorsports, automotive, defence and healthcare sectors.

Williams have developed high power density batteries and electric motors for a range of applications and market sectors where high performance, endurance and predictability are key customer requirements. They have expertise in the design and manufacture of the Battery, Motor Generator Unit, Inverter and Battery Management System.

**Objectives:** This challenge is comprised of three related sub-problems:

- **Examining the Correlation Between Track Events and Battery Degradation:** In performance electric vehicles, many of which may be used for non-standard driving such as track days, many different events may occur and much data can be collected. We wish to understand the rate of degradation as a function of different events (track characteristics, environmental conditions etc). Ultimately, we would like to develop an effective cost function for degradation given the different nature of each cycle for individual cells and individual modules to each battery unit to its limit and also to inform the optimal design of the modules.

- **Fast Charging of Batteries:** After operation batteries are often warm when they are connected for recharge. To control degradation effects during fast charging application, cooling prior to or during recharge may be required. The challenge here is to derive a cost function and an optimal strategy for fast charging and cooling of car batteries. This could be done either combining existing empirical degradation models or starting from first principles.

- **Cost Models for V2G Applications:** In V2G applications, the degrading effect of grid load balancing on individual vehicle batteries will be very important. There is the need for robust models which capture monetary costs to the effects of battery degradation due to this load management..

**Resources Available for this Problem:**

- Experts from Williams Advanced Engineering.
- We will have access to 12 data sets, each of around 20 minutes for a single battery in a high performance cycle from full to empty, around 250 minutes in total. Each battery has 165 cells in it. Data will be progressively released.

## 2.2 Spectral Analysis of Power System Frequency to Determine Real-time System Inertia.

**Presenting Institution:** National Grid

**Problem Presenter:** Martin Bradley

**Abstract (Technical Topics and Desired Outcomes):** The growth of renewable generation has resulted in a significant fall in power system inertia. National Grid needs to keep the inertia of the power system above a certain threshold to ensure that it can ride through the most severe disturbances, and this is now costing tens of millions of pounds a year. These costs are incurred because, at times of low system inertia, it is necessary to stop renewable generation and replace it with thermal generation (mostly gas-fired) which has a large spinning mass.

At present there is no way to actually measure system inertia before a serious disturbance happens, so National Grid has to forecast it based on expected generation and demand conditions. These forecasts are used to decide which actions need to be taken to keep system inertia above the threshold.

**Objectives:** National Grid believes that it may be possible to determine system inertia in real time based on analysis of the short-term variations in the 50Hz power system frequency. This exhibits continuous "noise" across a whole range of frequencies, and it is possible that the characteristics of this noise may provide information on the actual system inertia. Analysis of historic frequency data may also provide a range of other useful insights, so project objectives could include:

1. Spectral analysis (or other types of analysis) to determine the characteristics of the grid frequency "noise".
2. Explore any correlations between this "noise" and National Grid?s historic forecasts of system inertia.
3. Analyse historic frequency data over several years to see how the behaviour of system frequency has changed with the growth in renewables. Explore the data for other interesting phenomena, for example try to develop methods to:
4. automatically identify "interesting" events in historic data, so that historic and recent events can be compared;
5. See if it is possible to identify differences in frequency management practices between different shift teams, which may help to identify best practice;
6. Explore whether there are noticeable regional differences between system frequency measured at different locations
7. Explore limited amounts of high-speed measurement data of system frequency (one measurement every 20ms compared to one every 1s or 0.1s in the main dataset) to see whether there are interesting phenomena in the data.

## 2.3 Algorithms to Devise Optimal Power System Control Actions

**Presenting Institution:** National Grid

**Problem Presenter:** Martin Bradley

**Abstract (Technical Topics and Desired Outcomes):** National Grid controls the power system in real time by issuing instructions to power stations. However, these instructions have unique constraints on the form they can take, which are currently solved by humans but which are very challenging for conventional optimisation algorithms to solve. For example, instructions must have a minimum amplitude and duration, must ramp up and down at prescribed rates, and cannot change ramping direction instantaneously. It is desirable not to issue instructions too early because of uncertainty on the power system, but if instructions are left too late then an unmanageable "bow-wave" of instructions may be created.

A rule-based solution to this problem has proved too complex, and mixed-integer linear programming is likely to be too slow (even if the problem could be formulated accurately).

**Objectives:** National Grid would like to investigate alternative algorithmic solutions which may be able to turn "unconstrained" control actions (determined by a conventional optimiser) into practical instructions that meet the various hard and soft constraints described above.

# 3 Participants

| First Name | Surname | Institution | Capabilities |
|---|---|---|---|
| Stephen | Ashton | University of Sussex | Mathematical modelling. Statistical analysis. Stochastic modelling. Mathematical biology |
| Martin | Bradley | National Grid | |
| Matt | Butchers | Knowledge Transfer Network | Organiser |
| Alan | Champneys | University of Bristol | Maths modelling |
| Michael | Coulon | University of Sussex | Mathematical modeling of energy markets; quantitative finance techniques |
| Chris | Dent | University of Edinburgh | All round mathematical modelling expertise, combined with significant energy systems experience. Thus in addition to proposing solutions I can help make links between other mathematicians and the energy systems challenges. |
| Andrew | Duncan | University of Sussex | |
| Bertram | Düring | University of Sussex | Applied and computational partial differential equations, including modelling, analysis, numerics and control |
| Peter | Giesl | University of Sussex | Dynamical systems |
| Maldon | Goodridge | Queen Mary University of London | Statistical analysis |
| William | Holderbaum | University of Reading | Control Theory, Mathematical Modelling and forecast |
| Max | Jensen | University of Sussex | |
| Dante | Kalise | Imperial College London | Computational Mathematics, Optimisation, Optimal Control, Agent-Based Modelling |
| Sara | Merino | Imperial College London | Mathematical analysis, in particular: Analysis of Partial Differential Equations, kinetic theory, linking micro dynamics with macro dynamics, modeling. |
| Rob | Millar | Williams Advanced Engineering | |
| Geev | Mokryani | Bradford University | |
| John | Moriarty | Queens Mary University of London | Expertise in applied probability and experience in working with both startups and large energy companies to deliver algorithms |
| Ioannis | Papasthopoulis | University of Edinburgh | Statistical modelling and inference, time series analysis, extreme value statistics |
| Athena | Picarelli | Imperial College London | Optimal control theory, numerical analysis. |
| Nazanin | Rashidi | Knowledge Transfer Network | |
| Wasim | Sarwar | Williams Advanced Engineering | |

| First Name | Surname | Institution | Capabilities |
|---|---|---|---|
| Enrico | Scalas | University of Sussex | Probability theory/Stochastic processes |
| Nick | Simm | Univrsity of Warwick | Expertise in probability theory, random matrices, mathematical physics. |
| Venessa | Styles | University of Sussex | Numerical analysis |
| Hayley | Wragg | University of Bath | Previous study group experience at the international problem solving workshop in Montreal and the European study group with Industry. Research areas included mathematical modeling for high frequency wave propagation. As well as numerical solutions to partial differential equations. |

# 4 University of Sussex Information

## 4.1 Travel to the University of Sussex

**Train:** You can reach the University of Sussex directly from Brighton Station and Lewes Station. Falmer Station is directly opposite the campus. You can walk to the campus from the station through a subway under the A27. Follow signs for the University of Sussex (the University of Brighton also has a campus at Falmer). You can get from Brighton to Falmer in nine minutes by train. Four trains an hour go to Falmer during the day. If you are travelling from London and the west, take a train to Brighton and change there for Falmer.

The journey time from London to Brighton is just under an hour. You can also change at Lewes for Falmer, if you are coming from the east.

**Car:** The University is at Falmer on the A27 between Brighton and Lewes, about four miles (six kilometres) from the centre of Brighton. Follow signs for the University of Sussex, which is on the north side of the A27. The University of Brighton also has a campus at Falmer, on the south side of the A27.

If you are coming from London and the north, take the M23/A23 road towards Brighton. Before you enter Brighton, join the A27 eastbound signposting Lewes. If you're travelling from the east or west take the A27 direct to the University.

**Parking on campus:** Parking on campus is limited and there is normally a daily parking charge for visitors. This does not apply for open and admissions days or any visits arranged through the Student Recruitment Services Office.

There is designated visitor parking, which is signposted on campus. Car parks are not attended and you should not leave objects of value in your vehicle.

**Bus**

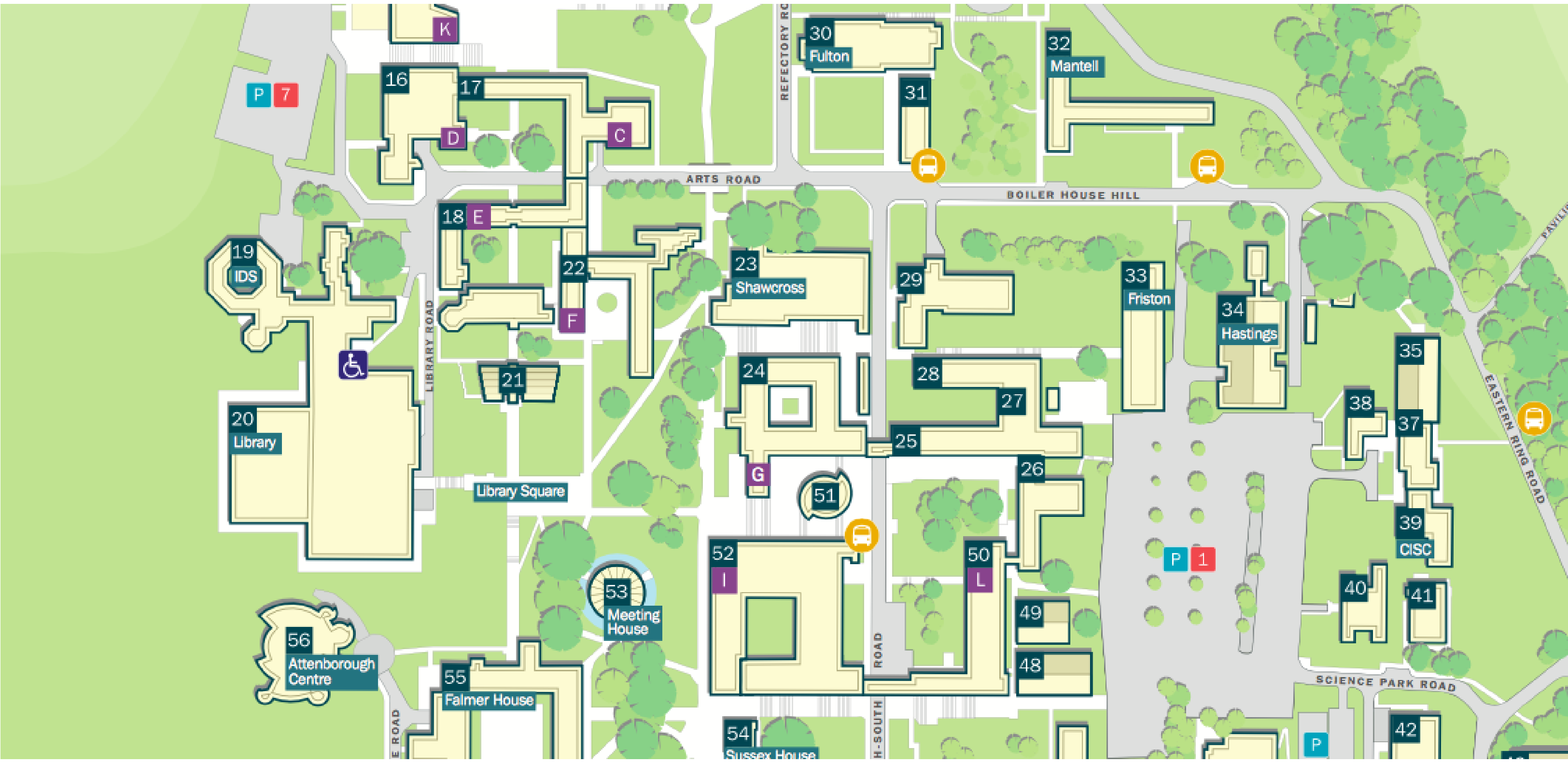
- The 23, 25, 25X, 28 and 29 buses run between the centre of Brighton and the campus.
- The 25 buses run from Palmeira Square in Hove, through Churchill Square and the Old Steine in Brighton, into the campus.
- The 23 route runs from Brighton Marina in the east, through Hanover, into the campus.
- The 28 and 29 go from Churchill Square and stop outside the University campus.
- Some 5B (Hollingbury) and 50 (Hollingdean) buses also run to the campus.
- Travel time between the campus and Brighton is about 20 minutes. See bus timetables and information.

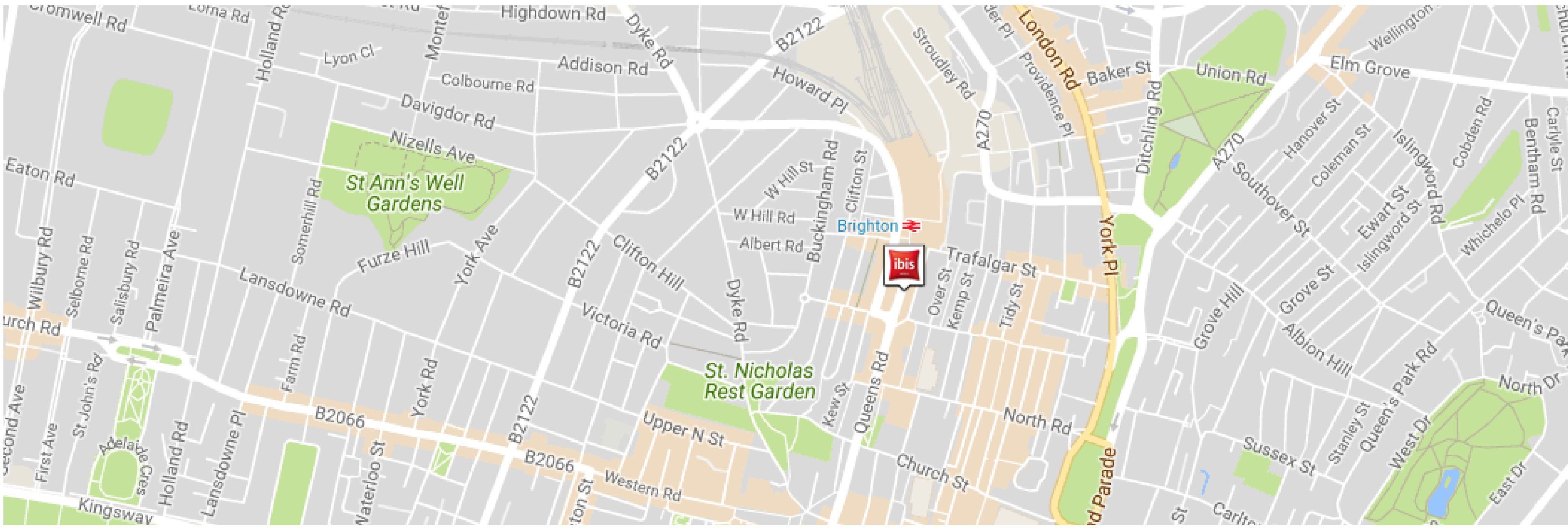
**Bicycle:** If you're a cyclist, you can benefit from purpose-built bike lanes along Lewes Road connecting the University to the centre of Brighton. It takes about 25 minutes to cycle to the campus and there is plenty of bike parking.

**Taxi:** Taxis are available at central taxi ranks and Brighton and Lewes train stations. The campus is about four miles (six kilometres) from central Brighton but it is often quicker to catch the train to Falmer from Brighton or Lewes

## 4.2 Campus Map

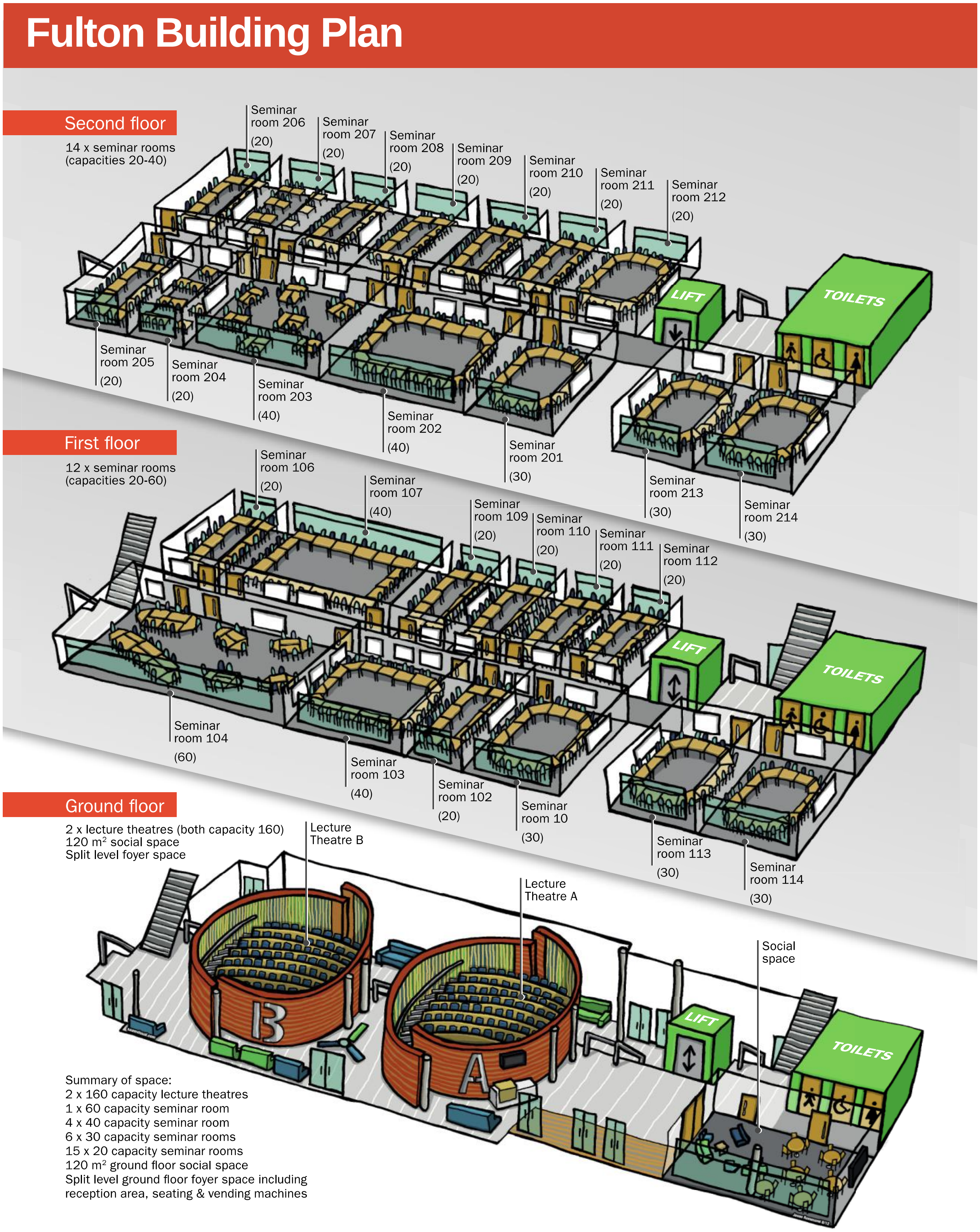
The Study Group will take place in the **Fulton Building** - Building 30 on the upper Campus Map below. Accommodation will be at the Ibis Brighton City Centre - the marker on the below map below.



## 4.3 Floor Plan

The main rooms for the Study Group will be First Floor, Fulton 103, 104 and 107.



# 5 Supporting Organisations

## 5.1 Knowledge Transfer Network

KTN Connects people. To speed up innovation, solve problems and find markets for new ideas. Established to foster better collaboration between science, creativity and business, KTN has specialist teams covering all sectors of the economy - from defence and aerospace to the creative industries, the built environment to biotechnology and robotics. KTN has helped thousands of businesses secure funding to drive innovation. And we support them through their business cycle to see that investment through to success.

**Contact(s):** Matt Butchers
**Website:** http://www.ktn-uk.co.uk

## 5.2 School of Mathematics, University of Sussex

The University of Sussex is a public research university in Falmer, near Brighton in Sussex. The university received its Royal Charter in August 1961,and was a founding member of the 1994 Group of research-intensive universities promoting excellence in research and teaching.

**Contact(s):** Enrico Scalas, Max Jensen, and Andrew Duncan
**Website:** http://www.sussex.ac.uk/maths/