School of Computing and Technology
University of East London
Docklands Campus
4 - 6 University Way
London
E16 2RD
020 8223 3000

Author John Cowsill
johncowsill@gmail.com
07905665213

In What Ways can Electric Vehicles Assist the UK Renewable Energy Strategy?

Preface

The latest (June 2008) UK Renewable Energy Strategy (Consultation) document, has called for 30 – 35% of electricity to come from Renewable sources by 2020

As the current level in 2008 of renewable electricity production is 4% (excluding hydro) this is a challenging target.

With the Government then, floating the idea of generating 32% of UK electricity by 2020 using wind, it is clearly urgent and important to look for and investigate ways of achieving this.

This paper examines the possibility and possible benefits and costs of utilising electric vehicles as storage for the UK electricity grid as a means of harnessing intermittent wind power and hence of assisting with the UK Renewable Energy Strategy.

Potentially, the infrastructure use described here could both not only deliver a way of permitting large scale penetrations of intermittent renewable sources in the UK electricity grid but also allow for a significant reduction in the consumption of oil based fuel by the countries' 32m vehicles and at the same time help to deliver secure electricity from intermittent renewable sources.

With input from data provided by the Met Office and by National Grid and with further input from a questionnaire designed to obtain vehicle use patterns, a mathematical model using Microsoft Excel was constructed.

Using the model and sample data from 2002 Various scenarios were examined including 20% penetration of wind in 2020 and 32% penetration of wind in 2020.
The possibility of 100% wind was also examined.

Acknowledgements
I would like to thank all the staff and students at CAT for all the enthusiasm and encouragement I received whilst studying there.
I would particularly like to thank Mike Thompson the course leader, Joan Randle the CAT courses Director, Damian Randle my thesis supervisor, Judith Thornton my seminar tutor and Gerry Jones and Melissa Taylor the thesis coordinators.
I would like to thank Rob Gwillim for introducing me to the delights of data modelling.

I would also like to thank the Met Office and the National Grid Company for supplying me with the relevant data.

Contents

List of Abbreviations

AR4 Assessment Report 4

DEFRA Department for Environment Food and Rural Affairs

ICE Internal Combustion Engine

IPCC Intergovernmental Panel on Climate Change

INDO initial demand outturn.

ppkWh pence per kWh

TSO - Transmission System Operator

V2G Vehicle to Grid

List of Illustrations

Chapter 1 Introduction

Overview

In a world where previously undeveloped heavily populated countries are becoming consumer societies rapidly expanding their energy consumption and with the twin problems of climate change and the increasing global oil price clearly evident, world attention is now urgently focussed both on reducing greenhouse gas emissions and on bringing down the costs of energy.

Primarily concentrating on an expansion of offshore wind renewable electricity generation for the UK electricity grid and how to ensure a secure supply from this intermittent power source, this paper investigates and evaluates a system which, potentially, could contribute to achieving success in both of the aforementioned quests and in doing so assist with the UK Renewable Energy Strategy which places emphasis achieving energy security and challenging climate change.

Essentially the system involves using fleets of electric vehicles as storage for the UK electricity grid. This system has been called Vehicle to Grid Power (V2G).

The prospects and feasibility of harnessing and using storage this way are examined and discussed.

A mathematical model has been developed which sets up future scenarios by using hourly National Grid electricity demand data set against hourly wind data from Met Office buoys situated in British waters.

With data from 2002, the model examines the performance of a future UK generating system when increasing proportions of intermittent wind power generation are assimilated by the current mix of conventional electric power generators and compares results running with and without the support of electric vehicle storage.

Using the model, this paper attempts to analyse any advantages or disadvantages this system may or may not have in terms of the following criteria:

1. The feasibility of increasing the penetration of intermittent or variable renewable generation in the UK electricity mix to 32% and beyond whilst maintaining a secure electricity supply and thus assist the UK Renewable Energy Strategy.

2. Whether the system is able to reduce Net CO_2 emissions and again thus contribute to the UK Renewable Energy strategy.

3. Whether the system will be able to achieve reductions in oil consumption which may in turn tend to lower oil prices and increase energy security, again, in line with UK Renewable Energy Strategy.

1 Chapter Outline:

The subject under study is interdisciplinary in nature and, as a result, in order to include all relevant areas and to provide the right focus it is necessary to have an extensive introductory discussion.
This chapter sets out the factors making the study relevant and important, examines the literature for examples of related relevant research, introduces some of the concepts and technicalities that will be expanded upon in later chapters and outlines the structure of the report.

1.1 Factors making the study relevant and important.

1.1.1 Climate Change

According to the IPCC, 'most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations'[Intergovernmental Panel on Climate Change, Climate Change 2007: The Physical Science basis p10]
In the IPCC AR4 Synthesis Report [DEFRA website], the IPCC highlight that 'Global emissions must peak in the next decade or two and then decline to well below current levels by the middle of the century if we are to avoid dangerous climate change'

This means there is a limited amount of time in which to start to put into reverse the factors leading to the global warming now evident.

There is no 'silver bullet' that we can use to start bringing emissions down, but it is arguably necessary to investigate any systems that plausibly will assist in the task spoken of above. This investigation attempts to examine Vehicle to Grid Technology to ascertain whether it may be of some value in that regard.

1.1.2 Energy Security

If the climate change problem were not enough, there is another severe Global challenge.

A year ago, the price of a barrel of North Sea Brent was $56.97, one day ago its price was $129.00[www.worldoil.com website].

The increasing uncertainty about oil prices is forcing governments to reconsider their energy policies and to investigate alternative methods of achieving energy security.

Economists are not all in agreement about what exactly is causing the rise, but the price volatility is forcing people all over the world to look for other ways of securing energy supplies.

There is a need to turn to alternative fuels or traction modes. If there is a turn to electric drive vehicles (which seems already to be happening in fact [e.g. see www.tnt.com website]), the arguments for using electric drive vehicles will alter in that the economics may become more favourable for investments in a technology that has never quite been in the mainstream (mainly because of competition from fossil fuelled cars). More favourable economics for Battery Electric Vehicles (BEVs) is likely to mean more favourable V2G economics.

1.2 Concepts and technical issues

1.2.1 Offshore Wind

This report is concerned with examining whether electric vehicle storage can provide any support to the introduction of renewable generation technologies to the UK.

The most promising renewable energy resource and technology for Britain is wind since Britain and its seas are some of the windiest areas in Europe and indeed in 2008 Britain is due to overtake Denmark in having the largest installation of offshore windpower worldwide at 400MW [UK Renewable Energy Strategy (Consultation) 2008), p5].

The Crown Estate has recently announced Round 3 of the offshore wind program and with the Government looking to produce possibly 19% of the UK's electricity from offshore wind by 2020 it looks clear that there is set to be a very large expansion of this industry.

There are a number of reasons for siting windfarms at sea. Marine wind speeds tend to be higher than onshore wind speeds and as the power obtainable from a turbine is proportional to the cube of the wind speed, significantly more power can be obtained at sea. Also, the power of a wind turbine is proportional to the square of the rotor blade radius which means the bigger the area swept by the blade, the more power can be obtained and this necessarily means larger wind turbines. Since there are fewer obstacles to siting very large structures at sea rather than on land, siting at sea is a favoured option.

The current largest Wind Turbine operational is the RE 5MW turbine – which has a blade length of 61.5 metres and this is the turbine mainly used in the model described in this report.

There are larger turbines being developed with Clipper Wind building a prototype 7.5MW turbine. The model is able to use this size turbine when setting a scenario for beyond 2020.

The wind data from four separate sea areas have been used as the basis for the wind data input to the model. The reason for using four inputs rather than simply one is to model the effect of more or less aggregation or geographic dispersion of windfarm sites. Greater dispersion leads to a smoothing of the total, aggregate, output.

1.2.2 The Grid

System operators are concerned about positive correlation in output across windfarms since the probability of a 'loss of load' occurring increases if there is a risk of all turbines being becalmed and stopped, or shut down because of excessive windspeeds. If the turbines are clustered in one sea area then the system operator is exposed to that risk.

The electricity grid copes with fluctuations all the time because of the constant variability in demand and so small numbers of wind turbines connected and delivering electricity to the grid present no additional problems to the grid system operator and can, with positive correlation between demand and supply, be advantageous. With larger proportions of intermittent wind power connected however, the operator will need to schedule reserve capacity to be available to ensure no loss of load is possible.

1.2.2 Intermittency

The wind does not blow all the time and when it blows its strength varies in a seemingly random manner. This 'intermittent' or 'variable' nature of the wind means that, from any one wind turbine, the amount of power delivered at any given time cannot be predicted in advance with confidence.

A great deal of study and research time has been spent on how intermittency affects the costs of windpower and on the integration of wind generated power into the National Grid.
One report [Gross et al, 2006, pp 50-58] - investigating the costs and impacts of intermittency - reviewed more than 200 reports focussed on how the intermittency and variability of wind affects electricity generation and concluded that there would be additional reserve requirements arising from the intermittency of wind up to 20% penetration - supporting the view that wind generated energy can not deliver secure electricity and needs a reserve on standby.

Of the more than 200 reports examined by Gross et al, none suggested that wind variability or intermittency would be an obstacle to the integration of wind power to the grid up to a penetration level of 20%. The vast majority however (>90%) did not report on penetration levels above 20%.

As the Governments has set an ambitious 32% penetration level for intermittent Renewables it is necessary now to examine levels of penetration higher than 20% and to look for ways of providing a secure renewable electricity supply

The terms 'intermittency' and 'variability' are both used, in the academic discussions of wind energy
Some authors make the point that wind is 'variable' not 'intermittent' and make comparisons with descriptions of thermal or nuclear power which can shut down without warning and therefore argue, plausibly, that nuclear is 'intermittent'

[e.g. Laughton, M. (2007), p32]

When 1000MW is lost suddenly to the grid because Sizewell B suddenly shuts down, more problems are caused to the operator than when, say, one 5MW wind turbine changes output when the windspeed changes to 7m/sec from 8m/sec.
However if the wind speed changes from 24m/sec to 26m/sec and a 1000MW windfarm stops delivering power because all the turbines have shut down due to excessive windspeed, this will cause similar disruption to the conventional power station failure.

The above example highlights the risks to reliability that wind could present to a system operator if the wind generators are not widely dispersed, and/or have a high proportion in the generation mix. If the surplus power from the windfarm could be stored however, the risk could be considerably lower, as surplus power from earlier generation could fill the gap in output caused by the heavy squall.

1.2.3 Storage

At all times the all power generated by the electricity system must be exactly balanced by an exactly equivalent load. If there is not a balance then, if the load exceeds the generation, a loss of load will occur somewhere on the system and sometimes this has been contracted for and is built in to the system operators plan or schedule (for instance a steel works may be able to turn off electric furnaces for a short period with little prior warning). At other times it may mean an unplanned shutdown as happened in May 2008 when two major power systems apparently failed within two minutes of each other and there was a power cut in some parts of South East of England which lasted for about an hour[BBC website].

If the generated power is more than the load, the energy can be stored and there are a number of large storage devices connected to the grid which enable energy to be stored when there is an excess of power. The largest of these is the pumped hydro power station at Dinorwig in Wales which can store 9100MWh energy and can supply 1788MW power for up to 5 hours within 16 seconds.

The importance of storage to clean energy and the grid is clear and is evidenced by the discussions in the following papers:

‘A major R&D effort on energy storage and storage systems will be crucial for the achievement of a low-carbon energy system’ [p 255, Stern. N, 2006] (The Stern Review)

‘Electricity generation from fossil fuels with carbon capture and storage will … be unable to enter the transport markets unless improved and lower cost forms of hydrogen storage or new battery technology are developed’ [op cit p 423]

‘The immediate conclusion is that until new solutions emerge that will add substantially to the overall capacity credit of a more varied combination of variable energy sources, perhaps including very substantial energy storage capacities, much otherwise uneconomic conventional plant will need to be retained or replaced' [Laughton, M. (2007) p28]

'if cheap and effective storage were to become available, it would be widely used in electricity generation systems … if the storage could be small and distributed, this would have the added benefit of reducing the capacity requirements of both the transmission and distribution systems' [Infield, D., Watson, M. (2007) p 201]

The storage looked for in the above papers and in many others not referenced here is that without any more R&D effort, large quantities of economic, small and distributed forms of storage are may potentially be available now – in the form of electric vehicles.

For at least a decade, studies have been carried out on the concept of using vehicles as storage, although for a reason not yet identified (but see chapter 5 on Policy Analysis), these studies seem not to received widespread attention as, apart from some exceptions, including those referred to below, when storage is seen as a solution, the 'electric vehicle fleets plugged in to the grid' solution, is not considered.

1.2.4 Storage in Electric vehicles (Vehicle to Grid Technology)

(See box on V2G)
The idea of using electric vehicles to provide storage for and to assist the transmission system operators - the National Grid in the UK - was described initially by two American researchers in 1997. [Kempton, W. and Letendre, S.(1997)]

The basic concept with what has now been called 'V2G' (Vehicle to Grid) power is that a vehicle with a suitable battery and charging and discharging technology can both provide storage for surplus grid electricity and provide power to the grid from a charged battery (as well as providing transport).

There are several services which a suitably connected vehicle can provide to a system operator

a) Provide storage and power (as outlined above) – this could be supplied when the system operator required, for instance at times of unexpected demand when, otherwise, more quickly responding but more expensive thermal plants might behave to be brought in to operation, while less expensive thermal plant is ramped up to be ready for operation.

b) Provide Reserve *Capacity* to assist scheduling
A fleet of electric cars would be capable of supplying a large amount of power almost instantaneously. The system operator could contract for this capability, i.e. it could pay the owner of the vehicle (or an agent for a group of vehicle owners) to have the vehicle

connected to the grid at certain agreed times and on stand-by to provide power and/or storage services.

c) Provide System Balancing Services.

The frequency and the voltage on the grid are constantly fluctuating from minute to minute and from hour to hour. The system operator attempts to keep them within agreed limits. (50 Hz +/_0.2) If a power generator drops out for some reason (there are many reasons – overheating coolant plant, mechanical breakdowns etc), this means there is a sudden loss of a lot of power on the grid. The system operator has numerous ways to cope with the sudden loss. Some generators are kept on half power ready to be turned quickly up to full power within a few seconds (about 20 seconds). The operator has arrangements with other plant to shutdown at short notice in order that at all times the operator can ensure that generated power is matched exactly with the demand.

These services are arranged for in advance.

The different services can be ‘Regulation Up’ - supplying power, or Regulation Down being able to accept power. Equivalent to the storage of electricity by Dinorwig pumped hydro scheme. Regulation down is accepting power, Regulation up is delivering power. When power is delivered on to the grid, the system frequency goes up as a result, and similarly if a plant stops operating or a pumped hydro station accepts power, the frequency will go down.

The system operator can thus regulate the frequency by contracting to buy Regulation Up or Regulation Down. This service can be provided by a vehicle equipped for V2G because they can respond very quickly for demands to store or to discharge electricity.

V2G

V2G was first described by Willett Kempton and Steven Letendre [Kempton and Letendre, 1997]
The idea behind V2G (or vehicle to grid technology) is based on the fact that for most of the time, vehicles stand idle and that while they are not being used for their primary purpose (of being driven), the expensive technology in the vehicle could be used for other purposes thus getting more value out of an expensive investment.

The possibility of doing this comes about because the vehicles’ battery not only holds the charge for driving the car forward but it is also a valuable electricity storage device.

The battery can be used to buy electricity at night, say, when the spot price of electricity is low (this is usually called charging the battery). When the spot price of electricity is high, the electricity can be sold back to the grid. The vehicle owner can in this way make a small profit on the transaction.

The fact that this vehicle is connected to the grid is also of value to the electricity network system operator (National Grid in the UK).

One vehicle on its own plugged into the grid would probably not be of much use to the system operator. But tens of thousands or greater numbers could be of great value to the system operator.

A lot of money was spent building the Dinorwig pumped hydro power station (£450m in 1982)
The money was spent because storage for the electricity grid is very valuable - it is a very useful way of managing excesses and shortfalls of power; for instance, nuclear power stations are generally run at their maximum capacity and can not be shut down quickly very easily; if the system is generating more than is required (at night for instance when there is not so much demand as during the day), rather than close down a large thermal power station, the system operator can quite easily arrange for Dinorwig (or one of the smaller pumped hydro schemes) to pump water from its low level reservoir up to its high level reservoir using the excess power on the system. The pumping of water from a low level to a high level has created a store of potential energy. (This facility can be called 'negative reserve') [see Strbac and Black 2006, p5]

The system operator needs reserve generators to be on standby (this is sometimes called 'spinning reserve') in case of a power failure so, when a generator failure occurs, the reserve generator can be started up to replace the failed generator and thus keep the system as a whole running reliably. Alternatively, if the system operator so decides, pumped hydro storage (now reversing the process described above by allowing the water to travel down from the upper reservoir, through the turbines to the lower reservoir) can be used to provide power to replace the failed generation. (This facility of pumped hydro can be called 'positive reserve')

The 'positive reserve' service or facility can be provided by spinning reserves. However spinning reserves cannot supply the 'negative reserve' service.

A Battery electric vehicle plugged into the grid could supply both 'positive reserve' and 'negative reserve'. This 'positive' and 'negative' storage capacity would be of value (as indicated above) to the system operator and, given the right policies and tariffs etc in place the vehicle owner (or an agent for a number of owners) would be able to contract with National Grid to provide that service in return for a revenue

Dinorwig, the UK's largest pumped hydro storage power station can hold 9100MWh of energy and can deliver 1728 MW of power (for 5 hours).

If 1 million Smith Ampere vans (each with a 25kWh battery) were to be available and plugged into the electricity system, they could store 25,000MWh energy and could deliver (with a 16A connection) 4000MW of power. (ie more than twice the storage capacity of Dinorwig and about twice the power capability)

Currently there are 32 million registered vehicles on Britains' roads.
Most of the vehicles are parked at any one time (on average people who are driving will drive for 38 minutes a day [www.statistics.gov.uk]
For the rest of the day (more than 23 hours) the vehicles are parked somewhere.

It would be possible to set up a V2G infrastructure without any intelligent communication devices by using grid frequency or radio signals to control remote vehicles (see section 2.7 in Chapter 5), however, more benefit might be derived by providing intelligent communications as it would then be possible to set up revenue and tariff structures that didn't rely on home charging.

Given that at some time in the near future, electric cars become more common, then, even if a fraction of them had the necessary power electronics and connections, then this type of storage could start playing a role as a new kind of storage on the electricity network.

The reason this is important is because of the variable or 'intermittent' nature of renewables.

PV panels do not provide power at any time we want. They only provide power when the sun is shining on them. If we want power at night, PV cannot provide it. The same is true of wind. The wind does not blow all the time or at a constant rate. When there is no wind, or not enough wind to turn the rotor blades of a wind turbine, or if the wind is too excessive for the turbine to generate power, no electricity will be generated.
The opposite phenomenon is also true. If the wind is blowing but there is no need for electricity or there is no load, any energy produced by wind turbines will be wasted.

Storage is therefore of great value for intermittent renewable generation because it can make the electricity available when its needed, and it also allows for the output to be 'smoothed' and made less intermittent and more reliable.

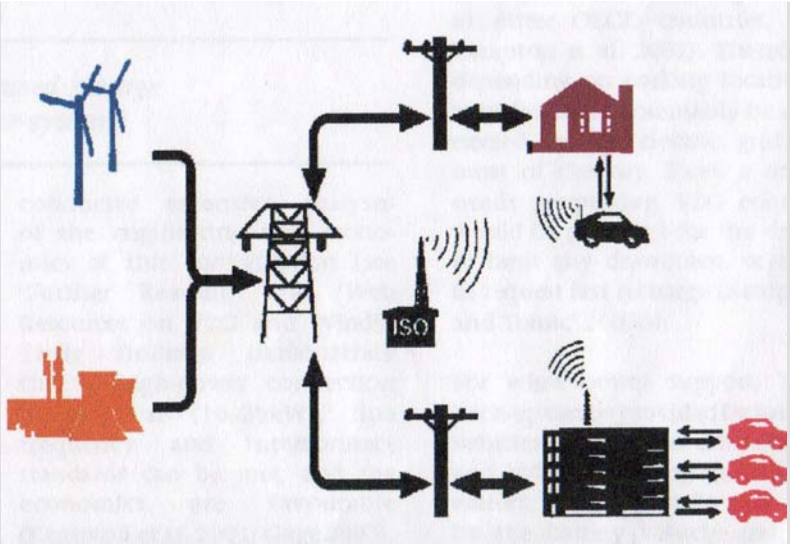

Fig 1 Graphical description of V2G
Source Kempton et al 2006

1.2.5 Electric Vehicles

Vehicle to Grid Power technology can in theory be applied to all electric drive vehicles. Fuel cell vehicles and plug in hybrid vehicles are vehicles which could be plugged in to the grid and provide service to the system operator. Both of these can in effect act as 'mini generators' and could supply power indefinitely providing there was fuel on board.

The fuel cell vehicle would not be able to provide regulation/system balancing in 'down' mode - it could not easily absorb electricity - the plug in hybrid with its battery could provide service 'up' and 'down' but to more limited extent than a pure Battery Electric Vehicle which would tend to have a larger battery pack.

[The terms 'positive reserve' and 'negative reserve' are also used for the equipment that provides regulation up and regulation down]

As, in this investigation, focus is on the storage service which Battery Electric Vehicles can, then, best provide, this investigation is considering solely BEVs.

Of course, the primary purpose of the car is for driving; the V2G concept allows for, though, the car to be put to additional use. Most vehicles are driven for less than about 1hour out of 24 in the day [www.statistics.gov.uk]; for 23 hours out of 24, the vehicle, an expensive piece of technology, is sitting idle. If this large investment could provide a service to the system operator, and revenue to the vehicle owner at the same time, this is a synergy that is arguably worth investigating thoroughly.

A Vehicle to Grid demonstration project was carried out for the California Air Resources Board with a battery Electric Vehicle (BEV) in 2002 [Brooks, A., 2002,Vehicle to Grid Demonstration Project, California Air Resources Board]

The Brooks project was undertaken to test the V2G concept with an existing Battery Electric Vehicle equipped with a power system that allowed for power to be discharged to the grid as well as charging from the grid. A 60kWh lead acid battery was installed in the vehicle. The study did not consider the value that such a system might prove to be to the intermittent renewable power industry, the aim was to examine whether ownership costs could be reduced whilst providing useful services to a grid operator and help them maintain reliable operation.

The results showed that the value created exceeded the battery wear out costs. The annual revenue, calculated by the Brooks team, for all services to the grid (supplying 'peak power', system balancing and regulation, and providing reserve capacity – also called 'spinning reserve') was between $3,038 and $5038.
Most electric grids are now operated under a market system and, although there are differences between the way the Californian Grid is run, and the UK National Grid model, it is feasible that similar results would be attained if similar testing of such a system were to be carried out under UK conditions.

1.2.6 Patterns of Vehicle Use

According to UK government statistics, the average time spent travelling in a car per day, by residents of Great Britain, is around 38 minutes [www.statistics.gov.uk].
That means that most of the time, most of the cars are parked.
In order to get a better idea of when people were actually driving and when the car was parked, a short survey was undertaken and the results fed into the model.

1.2.7 The Model

For this study, an excel spreadsheet has been developed which attempts to model a future UK system which is enabled for V2G in order to examine how this form of storage might assist with the integration of intermittent renewable sources to the UK electricity grid.

Wind speed data for a number of geographically spread marine anemometers (mounted on buoys at 3.3m) was obtained from the Marine Department at the Met Office. A whole year's data (8760 readings for each buoy) was added to the spread sheet.
Demand data for the same year (2002) was obtained from the National Grid and this was synchronised with the wind data on the spreadsheet.

The first questions asked of the model were:
If, in 2002 there had been grid connected offshore wind turbines installed in the 'sea areas' in which the buoys were located, how would the system have coped?
How many wind Turbines would have been needed to provide a reliable service
– at 20% penetration, 32% penetration, 100% penetration?
How does geographical dispersion affect the reliability?

The second questions asked were:
With a fleet of V2G cars connected to the Grid, how would that change the performance?
What is the optimum number of V2G vehicles?

If V2G were to be taken up, this would mean that internal combustion engined (ICE) vehicles would be gradually replaced by electric vehicles and this in turn would result in the electricity demand on the grid to rise accordingly. In the scenarios 32% penetration in 2020 and 32% penetration in 2020, this extra demand is added to the model.

It is assumed, for the scenarios, that there is no general growth in demand from an expanding economy (other than from the extra electric cars mentioned above)

The results are shown in Chapter 3 – Model and Results

1.2.8

The structure of the rest of the report is:

Chapter 1 Introduction

Chapter 2 Literature review

Examines some of the relevant publications on Intermittent Renewables and on V2G

Chapter 3 Model and Results.

This chapter describes the results and details the ‘experiments’ carried out with the model

Chapter 4 Building the model - Calculations

This chapter details the way the model was constructed and examines the inputs and outputs of the model

Chapter 5 Policy Discussion

A discussion of some of the major policy items that need resolving for V2G to succeed

Chapter 6 Conclusion

This chapter brings together the various facets of the report and summarises the results

Summary Chapter 1

1 This Chapter has looked at why an investigation into vehicle to grid storage and power is important and relevant. It has attempted to cover all of the widely disparate subjects that need to be discussed when V2G is studied.

2 This was started by examining some of the current issues related to climate change and noting how, with the adoption, quickly, of appropriate renewable technology, it may be possible to avoid serious global warming and also at the same time relieve pressure on global oil demand, an issue which has arisen as a problem for human society in tandem with the threat of global warming. Both of these issues are very high on the priorities of the Governments Renewable Energy Strategy.

3 It has looked at offshore wind, selected because of its particular relevance to the UK renewable generation ambitions.

4 What intermittency is, and its impact on power generation, was included in the introduction.

5 The electricity grid and the risk to reliability posed by varying levels of new wind generation were examined in the context of the intermittency of the wind resource.

6 A brief survey was undertaken of the current amount of national grid connected storage (i.e. mainly pumped hydro storage of the type found at Dinorwig).

7 What other academic papers had concluded on the importance of storage was noted

8 The concept of vehicle to grid power and how, in the right context, it could assist renewable power generation was introduced.

9 The testing of a standard Volkswagen car converted to an electric vehicle to grid demonstration project was examined.

10 The model developed for this report was examined.

Chapter 2 Literature Survey

Overview

The papers reviewed include:
Those primarily related to V2G (1 – 7)
Bridging both fields (8 and 9)
And those primarily related to intermittency of wind ,large storage and the grid (10 – 12)

1.1 V2G related:

1) Kempton, W. and Letendre, S. (1997)

2) Brooks, A. (2002)

3) Kempton, Tomic, Letendre, Brooks and Lipman, 2001.

4) Kempton, W and Tomic, J, 2004[a]

5) Kempton, W. and Dhanju, A., 2006

6) Tomic, J and Kempton, W. 2007

7) Turton, H and Moura, F., 2008

1.2 Bridging both fields

8) Helweg-Larsen, T. and Bull, J., 2007

9) UK Renewable Energy Strategy (Consultation) 2008

1.3 Primarily intermittency and the grid

10) Gross, R., Heptonstall,P., Anderson,A., Green,T. Leach, J.and Skea,J.,2006

11) Black, M. and Strbac, G., 2005,

12) Strbac, G., Shakoor, A., Black, M., Pudjianto, D., and Bopp, T. 2006

2 The Reviews

2.1
Kempton, W. and Letendre, S.,1997, Electric Vehicles as a New Power Source for Electric Utilities

Concept
This paper laid out for the first time, the concept of connecting a vehicle to the grid for the purposes of not only charging the battery, but also to provide power to the grid.

Most of the issues relating to V2G were encapsulated here and the other works on the subject (a great many by Kempton in collaboration with others) are refinements of Kempton and Letendre's original work.

Zero Emission Vehicles (ZEVs)
The trigger for the work was the policy of the California Air Resources Board to require that manufacturers of mass market vehicles must sell Zero Emission Vehicles (ZEVs) as an increasing fraction of their output. (That policy was weakened in 2003 to include low emission vehicles).

Managing the grid
The V2G storage concept was compared to other mechanisms for managing grid loads – such as Direct Load Control – where the system operator is able to control the scheduling of a customers electrical equipment – and other storage such as pumped-storage hydro-electric plants.

Communications
The paper describes how a vehicle owner might be provided with a mechanism for indicating, for instance, how many miles they wished to drive for this day?, how much charge they would like to have left in the vehicle battery? at what specific times?, What is the time of the next trip? What is the the distance needed for the next trip?
All the above would be carried by an onboard computer which would then calculate the required times of discharge and charge and communicate this information to the transmission system control.

Values and Costs
The paper calculates the cost of discharge to the owner, concluding that '(battery) cycle life is the biggest cost factor for the vehicle owner'

The value to electric utilities from customer-owned storage is also derived

They found that the value exceeds the costs for all vehicles studied

Renewables
They make the general point that:
'Distributed storage from EVs could facilitate the introduction of intermittent renewable sources into the power system'

2.2 Brooks (2002)Vehicle to Grid Demonstration Project: Grid regulation ancillary service with a battery electric vehicle.

This project takes a logical step for V2G – by testing the concept with an actual vehicle.

A number of comprehensive tests were carried out to find out the net value obtained from utilising the car as storage for an electric power utility.
For this study, the only costs considered were the wear out costs of the battery due to extra cycling.

They found that the value of regulation (or 'system balancing') did exceed the battery cost but stated that until real extended testing of batteries under the same cycling conditions are performed, that the results they obtained should only be considered an estimate.

It was also suggested that, if the life of the battery was limited by calendar time rather than by actual usage, that the cost of adding regulation on top of driving could actually be zero.

The author recommends that a Home or 'Champion' be found for V2G. The concept spans transportation, the environment and energy and is relevant in the fields of a large number of research or government agencies, but because it is interdisciplinary, V2G has no home or champion.

2.3 Kempton, W., Tomic, J., Letendre, S., Brooks, A. Lipman,T, - Vehicle-to-Grid-Power: Battery Hybrid and Fuel Cell Vehicles as resources for distributed electric power in California

This report analyses V2G performance for BEVs, Hybrids and Fuel Cell vehicles in the context of three electricity markets:
Peak Power, Spinning Reserves and regulation services (see Box1)

The technical requirements needed, such as the on board power electronics requirements, plug to vehicle connections and communications facilities are described

They make an observation which may prove to be important for policy on V2G; there are two types of charging methods possible, currently, for recharging vehicle batteries, - on board conductive charging and inductive charging. Onboard conductive charging can be used for V2G whereas inductive charging cannot.

In terms of availability of vehicles for V2G, they calculate that 92% of vehicles are parked even at the height of the rush hour (of 3pm-6pm in California)

There is a comprehensive analysis of costs to the vehicle owner including capital costs of any required equipment together with any fuel costs, shortening of battery pack life and, for the hybrid vehicles, internal combustion engine lifetime due to additional use.
For each vehicle combination and power market, they calculate the value of the power in the market.
Assuming that V2G is incorporated at the manufacturing stage, they calculate that the added costs due to V2G over and above a standard electric car would be in the low hundreds of dollars per vehicle.
As an add on, V2G, due to the possibility of a complete upgrade of the power electronics, might have ‘an extremely high cost’
They recommend that it is essential that the two separate industries, (electricity and vehicles) and the associated organisations, apply some coordination across the two areas if V2G is to develop.

2.4 Kempton, W and Tomic, J, 2004[a], Vehicle to Grid Power Implementation: From stabilising the grid to supporting large scale renewable energy

This article suggests strategies and business models that can develop the symbiotic relationship that could exist between electricity system operator and vehicle owner.

It notes that, if development occurs, after an initial high value of V2G, the market will quickly reach saturation and the value of V2G will subside.

They suggest that V2G could ‘stabilize’ one half of the US windpower with 3% of the fleet dedicated to regulation for wind, and with between 8 and 38% of the fleet providing operating reserves.

The method employed was to take the annual wind output from 8 geographically dispersed sites and disaggregate the data into hours of higher or lower power.

Setting a 20% firm capacity (i.e. providing storage enough that the firm capacity would be two thirds of the capacity factor of the windfarm (see Box1)), they found in the 6916 hours of valid data in the study year, 1,109 hours in which the power was under 20% of rated capacity. A graph was plotted of shortfall events v elapsed hours showing the duration of events under the contract amount of 20%.

2.5 Kempton, W. and Danu, A., 2006, Electric Vehicles with V2G: Storage for large windpower

Referring extensively to the methods used by Kempton, W and Tonic, J, 2004[a] this report clearly restates the findings of previous reports on electric vehicles with V2G and additionally finds that V2G would serve the majority of need for integrating wind into the electrical system even if wind becomes half or more of total electrical generation...

It also notes the potential for V2G power from a number of countries.

2.6 Tonic, J and Kempton, W., 2007, Using Fleets of electric–drive vehicles for grid support, Journal of Power Sources

Looking at two fleets existing of electric drive vehicles as test cases (100 Think City Vehicles and 252 Toyota RAV 4 vehicles) the team developed a method for calculating the value of V2G for regulation.
With Vehicle characteristics and patterns of use (egg hour of day parked up and the hour of day the vehicle is started up and driven for the next trip) and assuming various power electronics fitted at the work end of fleet travel and at the home end one important finding is that regulation up and down was the most profitable service (compared to regulation down only or regulation up only) since it provides twice as much regulation due to the battery not filling up or being completely drained to 80% DOD.

They found the major criteria are:
The market value of regulation services
The power capacity of the electrical connections and wiring
The energy capacity (kWh) of the vehicles battery

2.7 Burton, H. and Maura, F. 2008, Vehicle to Grid systems for sustainable development: An integrated analysis

In this report, the authors develop a number of global scenarios using a proprietary computer model (ERIS).

The premise behind the report is to examine whether V2G can help to begin a transition toward electric drive vehicles (fuel cell, hybrid or BEV) and away from conventional vehicle drive trains by delivering V2G specific benefits.

The paper claims to be the first to examine V2G technologies in a long term dynamic data model

The ERIS model was calibrated to the year 2000 and V2G parameters (wiring, safety systems, metering) were fed into the model.

They conclude that V2G benefits can only be realised with:
1) Regulation
2) Metering and Wiring in Buildings
3) Electric Drive Vehicles
4) Fuel production and distribution systems
- All available

With that proviso, the model indicates that V2G technologies are potentially attractive and cost effective over the long term, and hence warrant further investigation.

2.8 Helweg-Larsen, T. and Bull, J., 2007, zerocarbonbritain: An alternative energy strategy

This work describes an alternative energy strategy for Britain.

Arguing for a 'cap' to be put on the global emissions of CO2 and
using the idea of 'Powerdown' meaning to use the energy we have more efficiently, and then 'Powerup' meaning gradually replace the conventional generators with renewable generators, the team drew up a scenario to achieve a Zero Carbon Britain by 2027 – i.e. a Britain which was not contributing to increase in atmospheric CO2 emissions

V2G was employed in the scenario to assist in both 'Powerdown' and 'Powerup'

2.9 UK Renewable Energy Strategy (Consultation) June 2008.

This UK government document suggests V2G technology may help mitigate some of the issues of intermittency of renewable electricity (eg p173)

2.10 Gross, R., Heptonstall,P., Anderson,A., Green,T. Leach, J.and Skea,J.,2006, The costs and impacts of intermittency

This paper is concerned with the intermittency of wind

It addresses the question ' What is the evidence on the impacts and costs of intermittent generation on the British electricity network, and how are these costs assigned?'

Over 200 international studies were reviewed for the report.

The report states that wind generation means that the output of fossil fuel plant needs to be adjusted more frequently to cope with fluctuations in output due to intermittency and that some power stations will be operated below their maximum to facilitate this, and that extra system balancing will be needed.

The report concludes that intermittent generation adds to system balancing costs,
and that for intermittent renewable penetrations of up to 20% of electrical supply, the costs are about 5-10% of wind capacity

2.11 Black, M. and Strbac, G., 2005, Value of storage in providing balancing services for electricity generation systems with high wind penetration

This report asked how intermittent wind generation would be affected by increasing the storage in the form of pumped hydro storage.

They found that providing a greater part of the increased reserves needed from standing reserve in the form of pumped hydro storage increases the efficiency of system operation and reduces the amount of wind energy that cannot be absorbed.

A proprietary software (Dash Xpress) was used to simulate the operation of a system similar to the British electricity network

They also show that, reductions in fuel utilisation in the system with storage are directly reflected in the improvement of CO_2 performance of the system.

For example, a storage system of 3GW installed in a generation system of medium flexibility would save 3.2 million tonnes of CO2 per annum (equivalent to a 900MW plant running at full output for a year)

2.12 Strbac, G., Shakoor, A., Black, M., Pudjianto, D., and Bopp, T. 2006, impact of wind generation on the operation and development of the UK electricity systems

This survey is concerned about the extent to which wind can replace the *capacity and flexibility* of conventional plant, with regard to winds intermittency, rather than the extent to which wind can replace the *energy* of conventional plant.

With regard to storage, they note that it can provide both upward (‘positive’) and downward (‘negative’) reserve, whilst an OCGT plant can provide only upward regulation. ‘The ability of storage to provide this (‘negative’) reserve will be of *critical importance* when low demand conditions coincide with a high level of wind generation’ (my italics)

They also note:
The penetration of intermittent wind generation will increase the need for *continuous frequency regulation* (my italics) and ‘at the level of 25GW of wind the requirement for additional continuous frequency regulation is likely to double’.
As they have not considered V2G storage, only pumped hydro, this indicates another way in which V2G can be used and this is considered in the Chapter Policy Issues.

They argue that Demand Side Management (reducing or increasing loads in response to fluctuations in demand) and pumped hydro can enhance the capacity of intermittent sources and give a figure for the value of (pumped hydro) storage in supporting intermittent renewable energy. They also note that the capacity provision of storage is modest, given the size of bulk storage required; V2G has thus not been considered as the potential capacity of V2G is considerably larger (and at a lower cost) than that of the pumped hydro facilities currently available.
The value put on pumped hydro storage is between £470 and £800/kW

No figure was given for the energy cost, only for power.

So, with 27 million vehicles Smith Ampere Vehicles each with a 25kWh store then:.

If we assume the vehicle discharges its 25kWh in 7 hours, then the power available

is 25/7 * 27million

96 million kW

The value, then, if we assume that V2G storage has an equivalent value to pumped hydro is £96 * 800, the value of the V2G fleet in terms of storage would be:

£76.8 Billion

Of course, the value would decrease as more became storage became available.

Black et al also derive some figures for how capacity credit of intermittent renewables is improved by storage. The analysis did not consider V2G, and has not been quantified here but it is arguable that V2G will improve the intermittent capacity credit of wind in a similar way to pumped hydro

Chapter 2 Summary

This looked at several studies concerned with the capability of V2G storage equipped systems, examining storage at the 'micro' level and how in the later reports this storage would allow for significant wind on the electricity network. (2.1 – 2.7)
Two reports are concerned about the UK system as a whole and how the twin problems of climate change and the energy security crisis can be solved

Other studies were concerned with the intermittency of wind and how it can be integrated into the electricity network (2.8 – 2.9).

Report 2.10 made several conclusions regarding intermittent wind being introduced up to a penetration level of 20% based on a review of 200 studies.

Finally, two reports concentrated on how different levels of intermittent wind could be assimilated on to the national electricity network with the aid of large 'macro' level pumped hydro storage (2.11 – 2.12).

Chapter 3 - The Model and results

Overview

A mathematical model is set up to analyse the performance of the electricity grid with intermittent wind generation.

The findings are broadly in agreement with previous work.

The use of four sites for windpower generation follows [Kempton and Tomic, 2004]. However, Tomic and Kempton used the disaggregated wind data statistics, whereas in this study, the real wind speeds were matched to synchronised National Grid Demand figures.

Finding 2 supports the synthesis of Kempton et al work on V2G [Kempton and Dhanju, 2006]

Finding three notes the work of Black and Strbac [Black,M and Strbac, G, 2005] and [Strbac et al, 2006], on pumped hydro storage and intermittent generation.
This study finds similar results with V2G

Main Findings

1 With the necessary infrastructure and policy in place for V2G, using electrical vehicles for storage could provide significant assistance to windfarm developers and to the UK governments' Renewable Energy Strategy in terms of increasing the security of supply from large scale wind.
(Section 1.8.2)

2. It has been shown that electric vehicles fitted with V2G storage technology would be able to replace the UK's entire ICE vehicle fleet, and thus contribute to the removal of CO_2 emissions, this is another way that electric vehicles can contribute towards the Governments Renewable Energy Strategy.
(Section 2.6)

3 Wind generation that would otherwise have been lost will be taken up by the V2G electric vehicle fleet, thus reducing alternative generation, and, since that generation is mainly fossil fuel, reducing CO_2 emissions.
This is another way that (V2G) electric cars can assist the UK Renewable Energy Strategy (Section 2.7)

Other Findings

1 None of the windfarms, individually, had wind suitable (ie with windspeed < 25ms $^{-1}$ or > 4ms $^{-1}$) for power generation in each and every of the 8760 hours in 2002.

This also applied to the four windfarms combined, and so no matter how many windturbines were commissioned in these four areas, there was no possibility of having reliable power generated throughout the whole year without storage support.

2. It was shown that a V2G system is capable of delivering secure electricity at penetration levels of 32% and beyond.

Operation of the model

The two main data inputs are windspeed data and the INDO data

The expected variations in output due to wind intermittency are modelled
a) with no storage
b) with storage from electric vehicles.

The numbers of hours with a power shortage due to the intermittency is recorded.

The model is then set to run with varying amounts of V2G storage to examine the effect this has on system performance.

The relationship between the amount of wind power on the system (from 20% to 32% to 100%) and the number of connected V2G electric vehicles required to deliver a service with no shortfalls was recorded and tabulated.

The model examines how well V2G performs at reducing the intermittency of wind by reducing or removing the power shortfalls

The examination is carried out in the context of how V2G contributes to security of supply and to emissions reductions - the primary objectives in the UK Renewable Energy Strategy Consultation.

The following question is also asked of the model:

V2G storage has the capability of acting both as ‘positive’ reserve and ‘negative’ reserve (see V2G Box in Chapter 1).

Will increasing the proportion of V2G storage on the electricity network, in place of conventional ‘positive’ reserve, allow for more wind generated electricity to be harnessed (for a given number of wind turbines) than would be the case with ‘positive’ reserve alone?

The model was used to resolve and quantify these issues.

1 Strategy

In order to show if or how V2G has an effect on the performance of wind generation in respect of intermittency, it is necessary first of all to examine the intermittency effects on wind generation – to find out what specific problems there are in relation to wind intermittency. Once the effects or effect have been established, it can be possible to make comparisons with a system where V2G is an added component to see whether the effect or effects remain or have been altered in some way.
Therefore first, the intermittent wind generation without V2G storage is modelled.

1.1 The model, experiments and results

Four hypothetical windfarms were located at dispersed locations in the seas around the UK. (Fig1) Using wind data kindly supplied by the marine department at the met office from buoys collocated with the windfarms the model shows how much power could be produced by each windfarm and what level of correlation there is between the windfarm outputs.

Assumption

The little squares on the fig 1 map indicate Round 1 and 2 windfarms that were allocated by the Crown Estate for windfarm development. (A lot of effort was made to obtain windspeed data for these areas, but none apparently was available). However, although the windspeed data obtained from the Met Office marine department originates from, in the main, areas further from the coast, it is assumed that it is valid to use the met office data because,
a) Further rounds are planned to be further out anyway

b) It is assumed that the patterns of wind found at the Met Office buoy sites are broadly similar to the patterns of wind found nearer Round 2 sites (the round 2 sites are further out than the round 1 sites).

c) The wind factors being studied relate to the winds variability; any conclusions derived from data that may or may not have a little more or a little less variability will not detract from any general conclusions since, where conclusions will be made, they will be made on the basis of questions about flattening or smoothing out the variability. It is assumed any differences in variability will be reduced in significance by this smoothing out of the data.

The real hourly windspeed data from the whole year of 2002 is synchronised with the INDO data for the whole year of 2002 in order to see how the windfarms would have performed had they been installed.

Fig 2 Windfarms (marked with an x).

Windfarm (Met Office buoy)	Latitude	Longitude
6026	55.4	1.2
62109	57.0	0.0
62301	52.3	-4.5
62303	51.6	-5.1

Table 1 Locations of the (hypothetical) windfarms

1.2

An experiment was carried out to see if each of the windfarms could supply secure power all year round.

In this section, section 1, the model assumes that 100% of the electricity is being supplied by wind. The following sections - section 2 and section 3 - will examine a 20% and a 30% scenario respectively.
*All results from the model will be indicated by shading

An experiment was carried out to see if each of the windfarms could supply secure power all year round.
The results are in Table 2

Windfarm	62303	62301	6026	62109
No of hours in 2002 without suitable wind	1229	2569	841	485

Table 2

None of the windfarms, individually, had wind suitable (ie with windspeed < 25ms $^{-1}$ or > 4ms $^{-1}$) for power generation in each and every of the 8760 hours in 2002. Windfarm 62109 would have provided the most hours with power (8275 out of 8760 hours). In other words, if windfarms had been installed in any one of the single sea areas only, no matter how many windturbines were commissioned, there was *no possibility* of having reliable power generated throughout the whole year. [Finding 1]

1.3

If windfarms were installed in more than one of the four ‘sea areas’ it would be expected that the geographical dispersion would lead to a reduction in the number of hours with no wind or too much wind.
This was found to be the case; with two areas combined, the number of hours with no suitable wind are shown in Table 3.

windfarms	62109 with 6026	62109 with 62301	62109 with 62303	6026 with 62301	6026 with 62303	62301 with 62303
No of hours in 2002 without suitable wind	144	192	99	335	173	926

Table 3

It might be expected that the two areas with the greatest geographical separation might be the most likely to have low correlation. The fact that this has actually occurred in this instance with the two areas the greatest distance apart north v south and east v west

(62109 and 62303) showing the least number (99) is not taken as significant due to the fact that only four different wind areas have been sampled.

1.4

Combining three wind areas would be expected to lead to more reduction in number of hours with no suitable wind: The results for these permutations are shown in Table 4.

windfarms	62109, 6026 and 62301	62109, 6026 and 62303	62303, 62301 and 6026
No of hours in 2002 without suitable wind	54	25	146

Table 4

As might be expected now, the ‘marks’ for all the windfarms have come down – with greater geographical dispersion, there are less hours with ‘no suitable wind’ and it could be said that from the above that they all work better in combination with other windfarms.

1.5

Finally, when windfarms from all four sea areas combine, the number of hours with unsuitable wind are shown in Table 5.

Windfarms	All: 62109, 6026, 62301 and 62303
No of hours in 2002 without suitable wind	19

Table 5

What this is showing is that with windfarms in four different sea areas, there were periods (19 separate hours) in 2002 when the wind across all windfarms was either too strong (>25ms $^{-1}$) or too weak (<4 ms $^{-1}$) to drive wind turbines, and that therefore these windfarms would not have produced a secure power supply in 2002.

Again then, as stated in section 1.2, no matter how many windturbines were commissioned in these four areas, there was no possibility of having reliable power generated throughout the whole year.

1.6

With windspeed data available for more sea areas, then this type of experimentation could have been taken further to quantify to some extent the amount of dispersion necessary to achieve a situation where wind could produce power in 100% of the annual hours (in 2002).

However, the following chart of ‘number of windfarms in combination’, v average number of unsuitable hours, derived from the above numbers (fig 2) gives a *very rough*

or approximate indication of the effect of increasing the geographical separation of windfarms.
The chart roughly indicates that the more the dispersal, the lower the number of hours with unsuitable wind there are. It gives no idea of how many windfarms would *definitely* have provided secure power generation from the wind (in 2002)

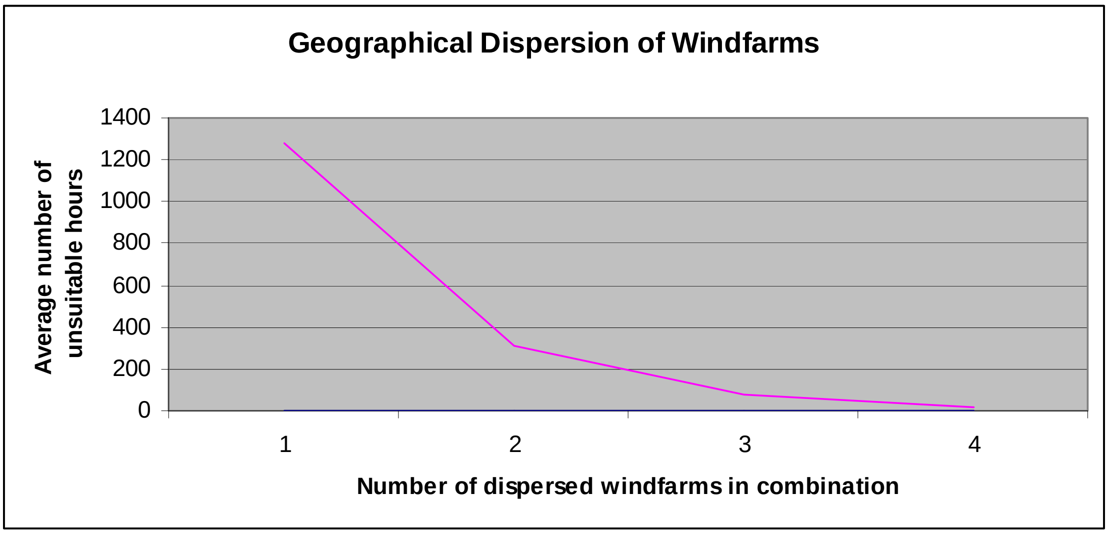

Fig 3 Geographical Dispersion

1.7 INDO

The previous experiment (sections 1.2-1.5) was examining the system purely from the point of view of windspeed data alone.

This section introduces the INDO data and begins to calculate the power from the windfarms.

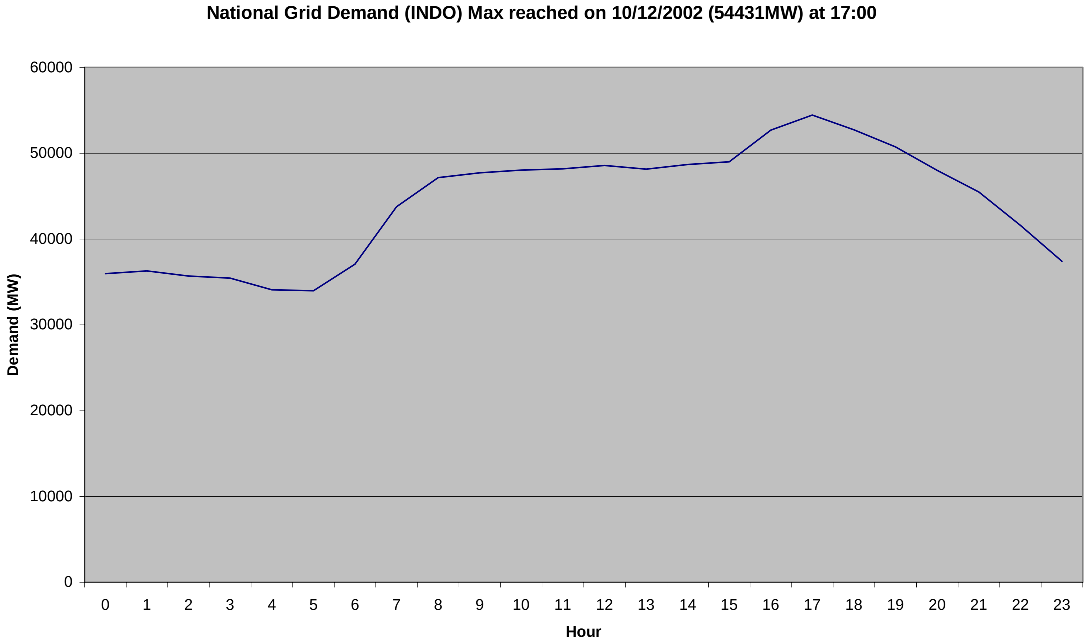

Fig 4 (above) National demand (INDO)

The initial demand outturn (INDO) is the average megawatt value of demand for a settlement period. It is a measure from hour to hour of the power demand on the national electricity grid.

The above chart (Fig 4) shows the INDO for 10/12/2002. The peak demand for 2002 was reached on that day (at 1700 hours approx)

This day will be used throughout in order to provide for consistent comparisons.

There is very little correlation of the wind variability with demand (although windspeeds tend to be highest in the colder months of the year when demand is higher.

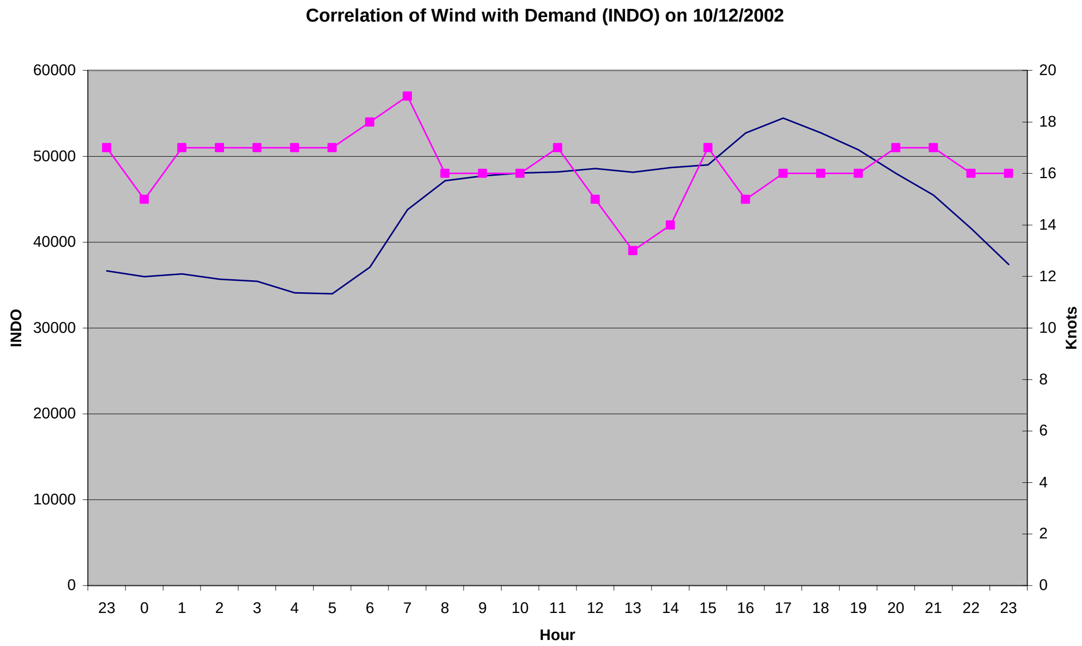

Fig 5 Random wind pattern

Fig 5 shows the random wind pattern (at windfarm 62109) with no correlation with Electricity demand

It can be deduced from the above chart (Fig 5), that if enough wind turbines had been installed in sea area 62109 to enable the annual peak electricity demand to be met, which happened to occur on 10/12/2002 at 1700 hours, excess power would have been generated at other times of the day. (This is shown below below in fig 5 and fig 6 when the wind pattern from buoy 62109 is used to generate power)

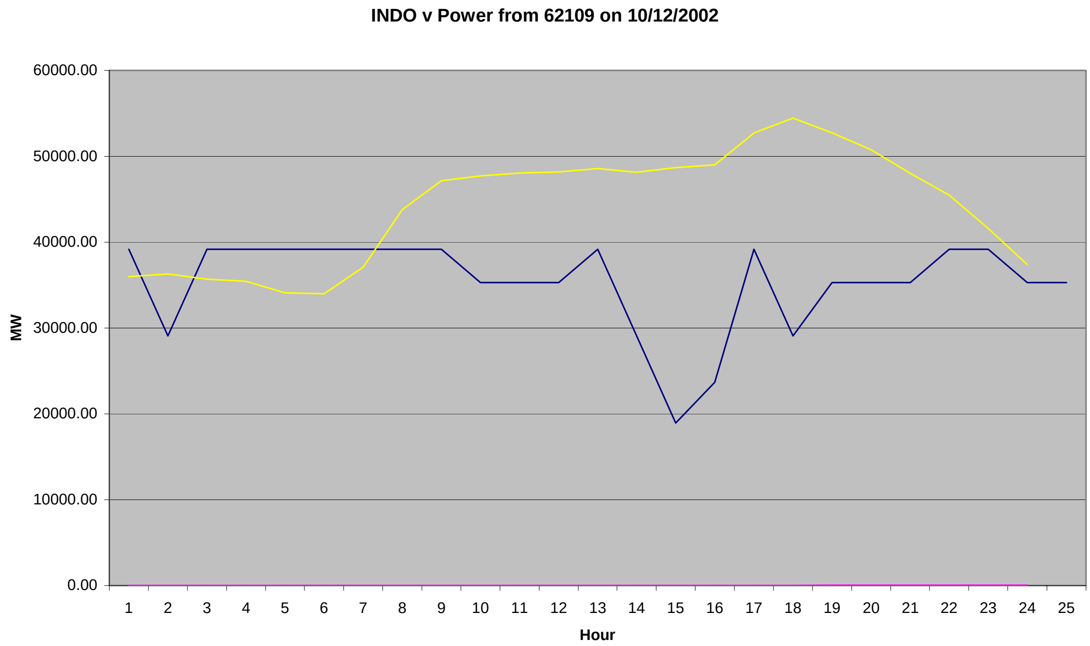

Fig 6 (above) 100% wind (35 GW)

Fig 6 is showing windfarm 62109 now producing output. It does meet demand between 0300 hours and 0900 hours, but fails to meet the peak demand occurring at 0700 hours. A 35 GW windfarm was required. This is with 100% wind for illustrative purposes.

To supply power for the whole day would have been possible, illustrated by the chart below (Fig 7) but it would have required 18,000 5MW turbines, 90 GW, and, as shown above – section 1.2, even with 90GW of wind, there would be 485 hours in the year when there was no generation at all and consequently several power cuts.
This illustrates in a graphic way the problem of intermittent wind power.

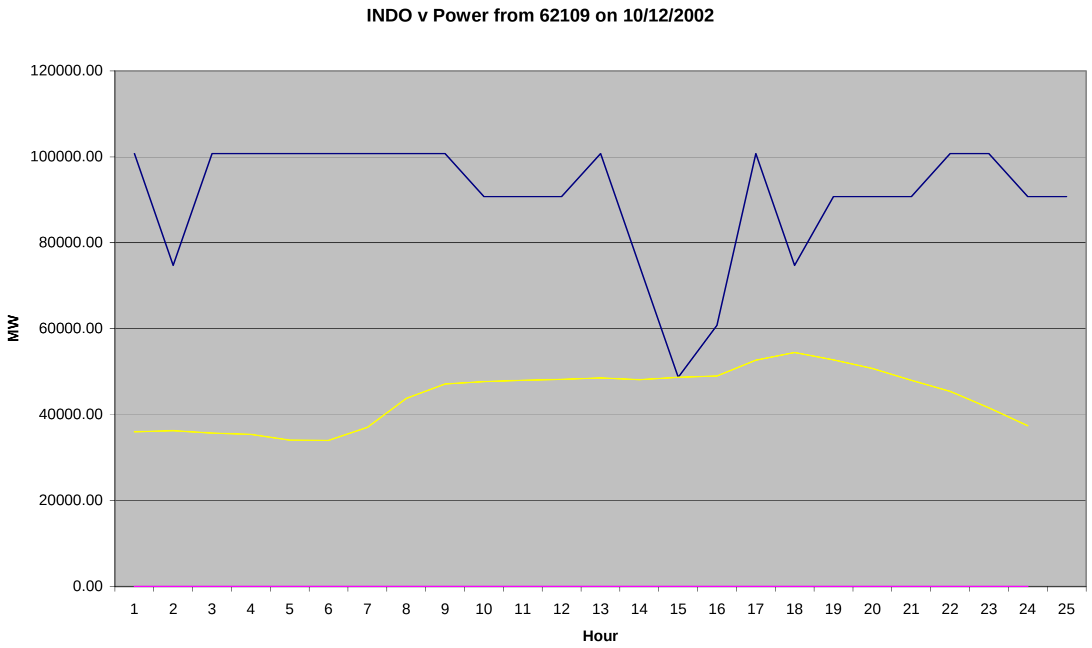

Fig 7(above) illustrative with 100% wind, 90 GW of windpower generated at the 62109 windfarm would have provided enough power to balance demand all day on 10/12/2002, but produced more energy than could be used. (There were still 485 independent hours in 2002) when there was no generation due to too little or too much wind)

Fig 7 shows that in order to just have enough power at around 1500 hours to provide the power to meet the demand on the 10/12/2002, excess power has to be generated for all the other hours in the day. This energy would probably be lost.
(Unless there is a way of storing it – and that is where 'negative' reserve V2G may be able to assist)

Fig 8 (below) shows the amount of excess power generated by the windfarm on
10/12/2002

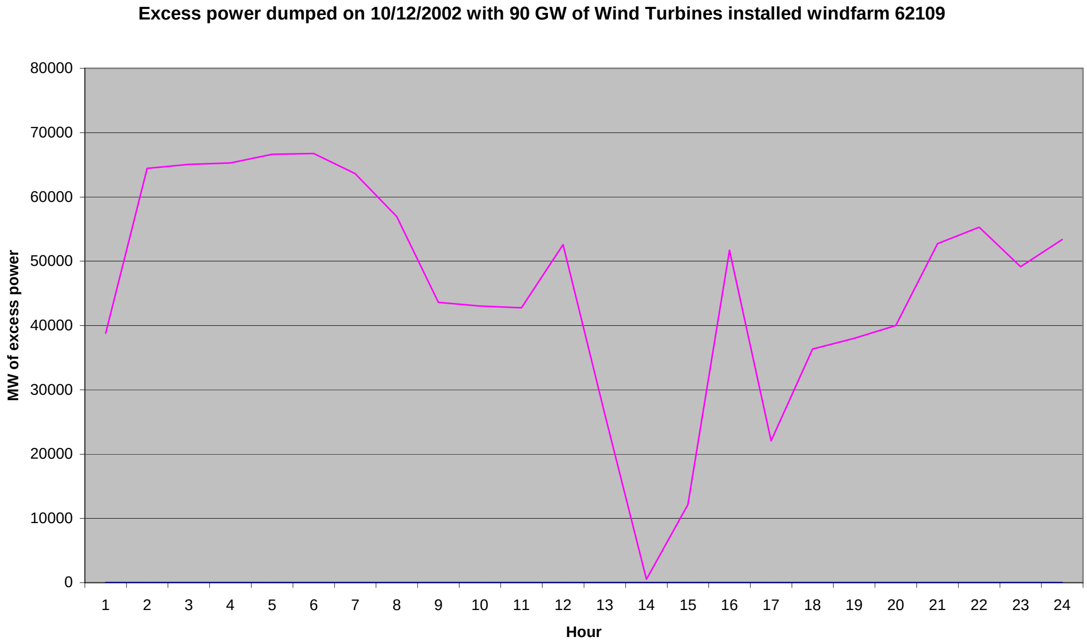

Fig 8 (above) Excess power generated but not used (or stored) (MW)

1.8 Model with V2G

The model is now set to report on: what assistance can V2G make to this system? Firstly, with windfarm 62109 on its own

Can the 485 'Loss of Load' situations be removed?

1.8.1 Keeping the 90GW of turbines.

The model indicates that with 182,000,000 Smith Ampere vans, the single (buoy 62109) 90 GW windfarm would have provided an uninterruptible supply of power for the whole of 2002.

Clearly, this is a simply huge number of vehicles and is not viable for the UK, but what it shows is how storage (pumped hydro or V2G) can smooth the output, and increase the security of supply. Therefore, it can be said *with certainty* that, with 182,000,000 x 0.025 MWh of storage (4.625 million MWh), the single 62109 windfarm with 90GW of intermittent generation installed would have provided secure power delivery throughout 2002.

It would probably be more realistic to assume that the building of the future windfarms will be done so that a good dispersion of the windfarms is achieved, because, and as we have seen, reducing the correlation between the turbines, by dispersing them, tends to lower the periods with a shortfall.

1.8.2 'No Loss of Load' achieved

Operating all four windfarms together as was seen in section 1.4 led to a 2002 year with 19 separate hours when there was no generation.

Can these Loss of Load situations be removed using V2G?

By 'No Loss of Load' is meant that over the whole of 2002, there was no period when the system operator would have had to disconnect a load from the network due to too little power being generated. In other words a secure supply of electric power was delivered throughout the whole year.

A Smith Ampere van is again used as an example of a suitable electric vehicle.

This van has a 25kWh battery (Li ion phosphate).

Modelling (with 100% wind) shows that:

With 24,000,000 V2G Vehicles and 86,400 5MW Wind turbines (432GW) over all four sea areas, there was no 'Loss of Load throughout 2002.

With a very large geographically spread array of windturbines, then, (about 10 times the number of turbines planned by the UK government to be installed before 2020), wind generators with the wind regime of 2002 as indicated by the four Met Office buoys *would* have supplied secure electricity for the whole of 2002.

(As the INDO figures used are for England and Wales, if Scotlands' demand were included, the number of vehicles required would rise)

This is an interesting result and indicates that, with the necessary infrastructure and policy in place for V2G, using electrical vehicles for storage could provide significant assistance to windfarm developers and to the UK governments Renewable Energy Strategy in terms of increasing the security of supply. [Finding 2] [Way1]

If an equal amount of pumped hydro storage were available, an equivalent security of supply would be obtained but, to provide the same amount of storage with pumped hydro systems would require 475 Dinorwigs.

Even if there were sites available, at 1982 prices this would cost over £200 B, whereas, because cars are being produced anyway, a V2G storage fleet could even generate revenue.

Further analysis, this time using the example of a Toyota RAV4 electric vehicle (discontinued now) which had a 40kWh battery, shows the relationship between number of V2G vehicles and wind generation installed to achieve no 'Loss of Load' in 2002. This relationship is shown in Fig 9.

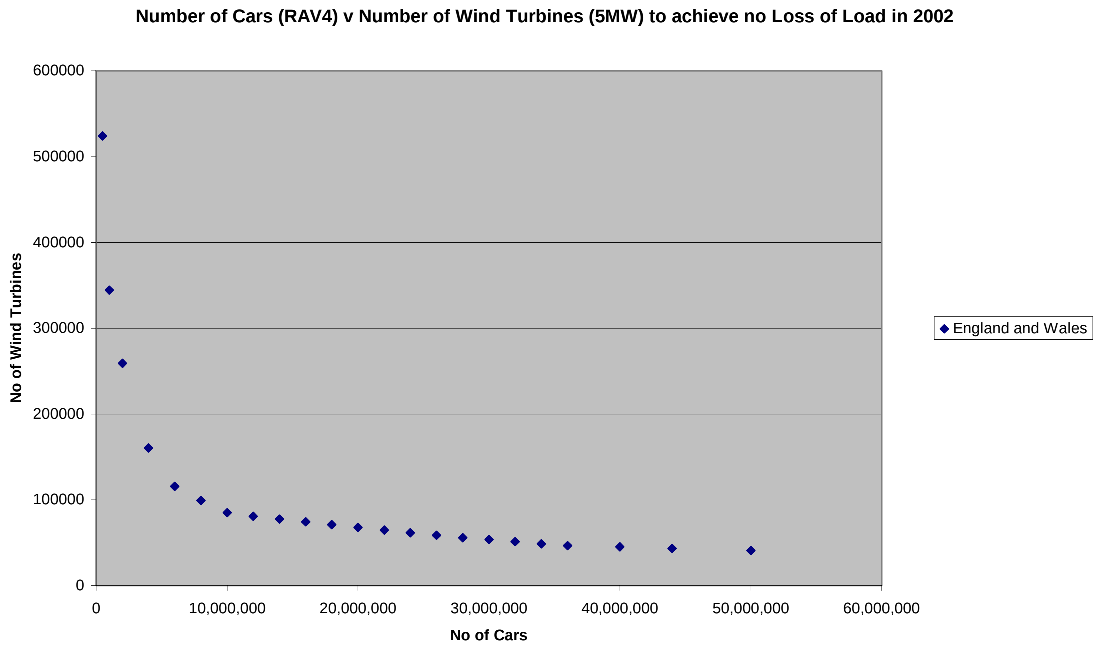

Fig 9 (above) Wind turbines (5MW) v No of V2G cars to achieve secure power

It can be seen that, increasing the number of storage vehicles will decrease the number of wind turbines required.
Increasing the number of wind turbines will reduce the number of storage vehicles needed to be plugged in to the grid.

Fig 10 shows the relationships between storage and wind power that can achieve no 'Loss of Power' in the modelled year (2002) when windfarms were installed in the four sea areas (equal numbers of turbines in each area).

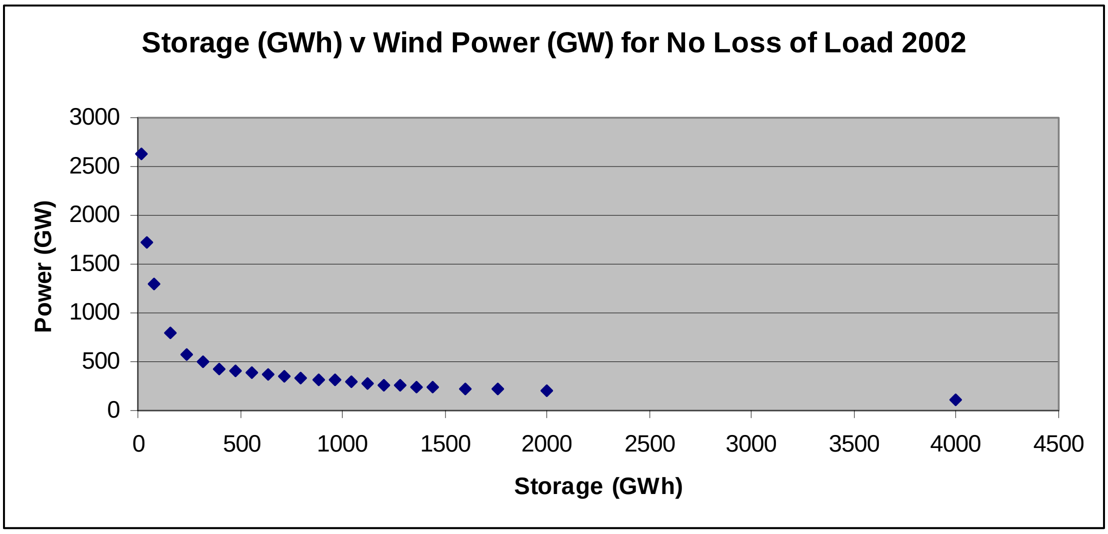

Fig 10

1.9
Up until now, the model assumed wind will provide 100% of the power.

Of course, in reality the generation in the future will not be from just wind, but will come from a whole variety of technologies.

Sections that follow assume the target for wind is, first, 20% (section 2), and then 32% (section 3)

The method used is simply to amend the INDO hourly figure by multiplying each hourly value by 0.2 for 20% and by 0.32 for 32% wind.

This is considered a reasonable approach, since all the variability in demand will be retained and the turbines will need to match that curve by using the varying wind strength.

2.0 20% Wind

This is 20% wind; but it is 20% of the current (2002) INDO, not 20% of INDO plus new load.

A series of tests were carried out to examine the outcome with various permutations of the many possible variables.

The general finding is that it is indeed possible to stabilise the wind output and make it a firm supply with wind supplying 20% of the electricity.

It also seems possible to replace the entire ICE fleet with electric vehicles powered by the wind, backed up with V2G , but on the understanding that the National grid output would have to rise considerably, as is calculated in section 2.3

2.1

With 7000 turbines, which is the governments target for 2020, 26,500,000 V2G equipped Smith Ampere vans would stabilise the wind output.

This is an interesting result as 7000 turbines is one of the government targets for wind and 26,500,000 is about the size of the UK fleet.

2.2

However, the 26.5 million electric cars will need to be charged regularly from the grid, and this is a load that has not been catered for by the system operator in 2002.

By the system operator is meant, in the UK, The National Grid Company.

Perhaps not surprisingly, adding the load from the V2G electric cars, reduces the effectiveness of the smoothing effect of V2G, and more storage and turbines are required to provide no loss of load. (see Model Calculations Chapter for a description of how and why the electric vehicle load is added).

2.3

If the load on the grid is increased by adding 26.5 million electric vehicles with a 25kWh battery with 100 mile range each relying on the grid for their electricity,
an increase in the number of wind turbines will be required to provide that load.
in a secure fashion. If the *storage* does not increase with the increase in numbers of turbines, the resulting mix will no longer provide a secure supply (as shown in Fig 9) Although standard electric vehicles with no V2G do provide ‘negative’ reserve, this is not under the control of the system operator and therefore is not as valuable as storage under the control of the system operator. They provide no ‘positive’ reserve and so can not help with filling power deficits. It seems to follow, that if electric battery vehicles are to be the vehicle for the future, there may be no rationale for not using V2G.

If enough energy for driving just 1 mile were provided by the grid in 7 hours, that would require an increase in power generation each hour of 946 MW. This is equivalent to one large power station. If the charging were completed in 1 hour, the system operator would have to find the equivalent of four large nuclear power stations.

If we assume that on average people use their vehicles to drive 9.4 miles (as found by the questionnaire survey carried out), and that the charging for this is spread across the day evenly, then using a simple equation for Load on the system, L

$$L = N * B/24 * x/R \quad \text{(eq 1)}$$

Where L is hourly load in MW, N is the Number of vehicles, B is the battery capacity in MWh, x is the length of a daily trip in miles and R is the range of the vehicle in miles With a Smith Ampere van, with a 25kWh battery and a 100 mile range,

The extra load each hour will be 2595 MW

So, if V2G (or for that matter, electric cars generally) are to expand, the National grid will have to increase its output accordingly. If its done with intermittent output,

2.4

It was found that the longer the charge time, the better the smoothing (requiring less turbines and storage to provide the whole of 2002 with no Loss of Load)

Charging of the whole fleet in the same 1 hour of the day in real life is not likely to happen (and under V2G could be prevented, by arranging for charging periods arranged at different prices for example)

2.5

Of course, it is probable that the whole fleet would not be V2G by 2020.

So, if only a quarter of the fleet (say 6 million) were to provide storage via V2G, then:

With 6 million V2G vehicles plugged in and charging in 1 hour every day and driving 9.4 miles, 18240 5MW turbines would have provided secure power for 2002

2.6

With the whole fleet of V2G Smith Ampere vans (26.5million) charging in 1 hour every day and driving 100 miles, 100,000 5MW turbines would have provided secure power for 2002.

NB This is equivalent to replacing the entire ICE car fleet.

This is one way in which electric cars can assist the UK Renewable Energy Strategy and is thus part of the answer to the question in this papers Title.

Tackling climate change is one of the two major challenges that the UK Government faces and this is described in the consultation document on climate change [UK Renewable Energy Strategy (Consultation) June 2008.p 4]

Because the ICE car is the main source of CO_2 emissions [IPCC, 2007,'Climate Change 2007 – Mitigation'], if they can be replaced by vehicles that do not emit CO_2 and if that is coupled with a method of stabilising the non fossil fuel wind energy generation, this is one way in which electric cars can assist the UK Renewable Energy Strategy.

Of course if the electricity continues to be, in the main, generated by conventional fossil fuel generators, CO_2 will continue to be emitted.

However, one of the results of this current study is to realise that there may be another way in which CO_2 emissions could be reduced as a result of an adoption of V2G technology.

2.7

When low demand conditions coincide with high wind power conditions, a significant number of part loaded CCGT (Combined cycle gas turbines) plant that are run part loaded (and part load running is not the most efficient mode of running) reduce the amount of wind generation that can be absorbed [Black et al, 2005 p2] and also [Black et al, 2006, p10]

Black et al find that replacing standing reserve with pumped hydro storage increases the efficiency of system operation and reduces the amount of windpower that cannot be absorbed. [Black et al, 2005, p1]

They also show how using a 3GW storage system as reserve would result in a saving of 3.2 million tonnes of CO_2 per annum.[op cit p 3]

If this is the case for pumped hydro, is it also the case for V2G storage?

The model suggests that it is.

With 10,400 5MW Wind Turbines and 26.5 million cars, the wind generation is stabilised and annually the system over-generates (the generation is greater than the load) 176.33 TWh annually.

If the numbers of cars on the system are now increased to 27,000,000 (ie both increasing the load and storage, but leaving the Wind turbines at 10,400, the over-generation figure drops to 176.07 TWh annually.

So, further increases in V2G vehicle numbers decrease the lost wind output.

Fig 11 indicates the pattern

The wind generation that would otherwise have been lost is being taken up by the V2G electric vehicle fleet *(as load),* thus reducing alternative generation, and, since that generation is mainly fossil fuel, reducing CO_2 emissions. [Finding 3]

This is another way that (V2G) electric cars can assist the UK Renewable Energy Strategy [Way 2]

The annual lowering of the ‘otherwise lost’ generation amounts to 2.55 TWh once stabilisation of wind is established and if the fleet expands to 32 million vehicles (the size of the UK total vehicle fleet in 2008) .

This equates to
2551714300 * 0.43 Kg

1,097,237,149 Kg of CO_2

Based on Carbon trust website figure of grid electricity having an equivalence of 0.43 kg carbon/kWh [www.carbontrust.co.uk]

This is a conservative estimate based on the savings to be made in emissions post achievement of security of generation from intermittent wind.

It does not include savings made resulting from V2G wind support in a period when there are V2G vehicles connected to the system but are not as yet sufficient to stabilise the wind generation.

When wind is installed in the generation mix, it contributes to energy savings and thus CO_2 emission reductions anyway [Gross et al, 2006, piii].

V2G additionally allows the wind generation, previously lost due to intermittency, to be captured, by ‘infilling’ unsuitable wind speed, or low power periods, with energy from periods with more suitable wind speeds and thus higher power.

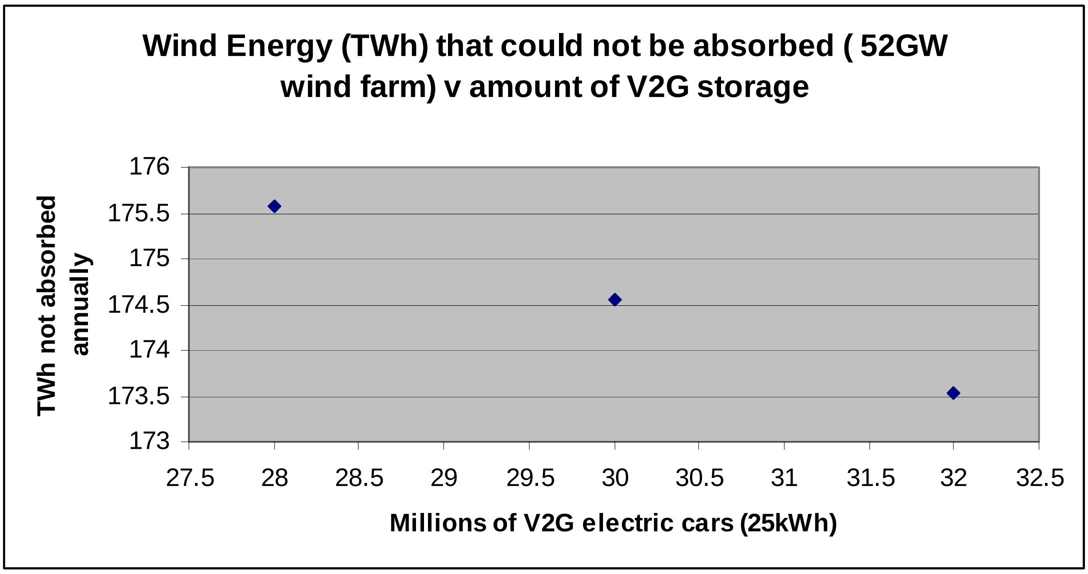

Fig 11 This shows the reduction in the wind energy that could not be absorbed through lack of storage.

3.0

The Governments' ambition to reach 32% of electricity to come from renewable sources by 2020 was set out in the UK Renewable Energy Strategy (Consultation), June 2008 p 8

Of course, not all of this would have to come from offshore wind, however the

Government sees wind energy providing the main proportion of this target.

This section then, will examine the scenario of 32% offshore wind, provided from the four '2002' windfarms in 2020 using the model.

If the car manufacturing companies in the UK this year, altered their production lines to produce electric cars instead of ICE cars (and this might not be a bad idea for them given ICE car sales are falling) and produced V2G ready electric cars at the rate they are producing ICE cars – about 1.5 million per annum [www.statistics.gov.uk] ,

Then with the 16.5 million Battery electric vehicles that would be on the road then

According to the model 19,600 5MW turbines would be required to provide a secure supply and provide the load for the extra 16.5 million vehicles

As the phrase above suggests, the V2G storage is doing a lot more than provide secure electricity, it is also replacing 16.5 million ICE cars and eliminating the emissions those vehicles would have produced.

Of course the fuel now powering the vehicles is coming from the wind and is being delivered via the national electricity grid, not by an oil tanker to the petrol station.

Using Equation 1 and assuming a daily drive of 10 miles in a Smith Ampere van for all the vehicles then, assuming no other power changes, and assuming the same wind regime in 2020 as in 2002, the grid power delivery would have to expand by approximately 1718MW.

The peak demand figure in 2002 of 54431 (occurring on 10 12 2002) would now be (in 2020) 56149 MW

4 Summary

This chapter has covered the investigation of the 'experimental' V2G system in detail The main conclusions are stated at the start of the chapter.

Chapter 4
Model Descriptions and assumptions made.

1
Overview

This chapter explains the detail involved in setting the model up and notes any assumptions that were made.

1 Vehicle patterns of use

The primary purpose of the car is, of course, for driving, so while the car is actually being driven, it cannot be used for providing services to the system operator.

[Kempton et al, 2001, p25] describe three methods of calculating hourly distribution of daily traffic.

They estimate the percentage of vehicles that are, at any one time (including at the rush hour), not on the road driving and hence are available to be plugged in.
The average of their three different calculations is 94.3%

These studies were based on American driving patterns and UK traffic distribution may be different. However, the figures are unlikely to be significantly different since modern cities and roads and traffic are very alike regardless of whether you are in Paris or London or Seattle or any other large city.
Country driving patterns will probably differ significantly although the vehicles will still on average only be driven for 1 hour out of every 24 [www.statistics.gov.uk].

However, in order to get a general idea of the times of day that the cars' owners actually drive them, a number of workplaces were visited and a simple questionnaire [see appendix] was handed out randomly to workers within the workplaces (three banks and a library).

A separate survey was made by asking passers by to answer questions in a shopping centre in Croydon and in a large Tescos car park.

It is not to be expected that this survey covers all the myriad types of ways and times that people drive their cars, but since the way the model is set up requires an idea of patterns of use, although this is not critically important since, as has been established, most of the cars are parked for most of the time, this method will be better than a completely random guess at times of departure and arrival.

Out of the small sample of people asked at the shopping centre, most did not use a car at all (about 60%).

Of the people that did drive and did answer the questionnaire and the questions (23 in total), It was found that the average mileage was 10 miles (counting both work time and leisure time) and 4.7 miles counting just work time.

In order to get an idea of the exact driving times, the time of day figures were converted to numbers and a simple average was taken to give two departure times and two arrival times (to the nearest minute) for each working week day.
This method is not totally satisfactory, since the result will not represent any one actual driver. However, the aim is not to get figures for a real persons driving habits, the object is to arrive at a measure for the electrical impact the vehicles will have on the grid.
Some of the home journeys are considerably shorter than the going to work ones – this explains the shorter average travel home time.

Mostly, the leisure time part of the form was not filled in with times so nothing could be concluded about any patterns for the weekend.

The weekday driving pattern is shown in Table 1

Leave for work	Arrive at work	Leave for home	Arrive at home
07:48	08:29	17:28	17:54

Table 6

This data was added to the model using a Lookup Table.

To get an idea of how the load that the electric cars would place on the system affected the system, the lookup table can be changed to alter the amount of charge being drawn.

Because the INDO and Wind data is hourly, it was not possible to model the exact leaving and arriving times.

The driving distance was used to model average trip lengths

The Smith Ampere will travel 100 miles on a fully charged battery.

As Kempton et al illustrated it [op cit p6] the vehicle will be best charged at the end of a trip, and, if possible at off peak times when the electricity is cheaper.

The model, then, will start to charge at night from the off-peak start time at around 23:30 until 07:47, will discharge from 07:48 until 08:29, and charge (at work) between 08:30 and 17:28.

Only a proportion of the vehicles are disconnected from the grid between the times discussed. The storage capacity available will reduce by 5.7% when the cars are disconnected - the proportion on the road at any one time as calculated by Kempton et al[op cit p25].

As the capacity of the battery is 25kWh, a journey of 4.7 miles will use 4.7/100 *25 kWh = 1.175 kWh
This amount * the number of V2G vehicles plugged in is actually *new demand* that has not been accounted for in the INDO figures yet.

This new demand cannot be added to the INDO as this is simply a measure of the demand that existed in 2002. The new EV load will come direct from the incoming windpower or, if there is not enough wind power, will come from the storage if it has enough charge. This will have the effect using any surplus which would otherwise have had to be dumped.

To compensate for the 'missing' cars which are out driving about! In terms of the storage capacity, the battery capacity is reduced by 5.7%.

2.
Workings of the Spreadsheet

2.1 The Windspeed data

The data was kindly given by the Met Office Marine department.

It consisted of six years of wind data from 4 different buoys and one platform (Leman)

All the buoys had anemometers at 3.3m above sea level and had Year Month Day and Hour readings for wind direction and windspeed (knots) as well as latitude and longitude.

It was not clear what the height of the Leman anemometer was and so, this data was discarded in the interests of being able to compare like with like.

Not all of the data was complete for all of the buoys, and after analysis and one other factor, it was decided to use the 2002 data since that was mainly intact for all of the Buoys, although there were quite a considerable number of erroneous reading and missing periods. When there was a question mark over a piece of data, this was recorded, and an adjacent number was taken to replace the erroneous one.

The basic premise for the work is that it is possible to match the National Grid Demand data with the wind speed data and synchronise them so as to simulate a situation where it could then be demonstrated how a windfarm would have performed both without storage support and when matched to an electronic storage system like V2G.

The synchronisation actually took some time since there were missing and extra entries in both sets of data.

2.2 National Grid data

The National Grid Data
The National Grid data is available on the internet and can be easily downloaded. It is available from 2001 until the current month. In fact it is possible to view the national power system attributes like frequency in almost real time.
In 2005 the National Grid data that is downloadable changed the way it is organised. Prior to mid 2005, the INDO figure refers to England and Wales demand only. After this date it includes to Scotland as well. All the data in the report therefore is relevant to England Wales electricity demand.

There are 48 entries each 24 hours and, of the possibilities – double up the wind or selectively remove every other line in the INDO data or take the average of each pair of INDO figures. In the end it was decided to remove half the INDO data as it seemed the best way keep original data.

There are a number columns of data, all England and Wales demand figures, all slightly different INDO does not include ‘station load’ for instance. Station load is the power used by power stations and is about 500MW but varies continuously. There is also an ‘interconnector’ data feed .It was decided that interconnecter (incoming) and station load were not relevant to this study and so INDO was chosen as it was not affected by the other two feeds mentioned.

2.3 Wind speed calculations

Converting windspeed at just above sea level to windspeed at wind turbine hub height:
The wind speed in knots was first converted to ms^{-1} and then was adjusted with a modelling equation which estimates, from the wind speed at a given point, what the windspeed would be a given distance above or below given various parameters such as the roughness of the terrain (which for the sea surface was assumed equivalent to a smooth surface).   [S Mathew Wind Energy p 48 eq 3.1]

If the wind data is available at a height Z and the roughness height is Z_O then the velocity at a height Z_R is given by:

$$V(Z_R) = V(Z) \ln(Z_R/Z_O)/\ln(Z/Z_O)$$

Where $V(Z_R)$ and $V(Z)$ are the velocities at heights Z_R and Z respectively

In the excel model the two heights are set up as variables to make it easier to vary the hub height for instance.

2.4 Power Calculations

To convert the windspeed to a power figure
The equation below is used

$P_T = Cp * Pa * A_T * V^3/2$
[Mathew, S, 2006, p14]
Where P_T is the power developed by the turbine
C_P is the power coefficient of the wind turbine
Pa is the density of the air
A_T is the turbine blade swept area (cross sectional area of the rotor)
V is Windspeed

Cut in and max wind speeds determine whether the turbine generates energy at all and are entered as variables in an Excel spreadsheet.

2.5 Workings of the model – general

With an excel spreadsheet it is possible to input thousands of figures into a column, line this column up with another column of related figures in a separate column and to then compare the related figures row by row.

This is what was done with the INDO and windspeed data in this study.

8760 readings INDO were set alongside 8760 readings of windspeed data (one column for each of the windspeed sources. 8760 is the number of hours in 2002.

Now, with the calculations for windspeed and for power delivered, set out in sections 2.3 and 2.4 above, Excel makes it possible to calculate the power from one turbine on 2002 on a specific month day and hour and to then calculate how many turbines, x, it would require to generate enough power to equal the total power required by England and Wales on the same date and hour as given in the INDO figures.

Because the windpower generated and the hour by hour electricity demand figures both vary from hour to hour, for a given number of win turbines (x), unless there is an exact balance (which is extremely unlikely) there will either be a shortfall of power on that hour or a surplus. These shortfalls and surpluses are recorded in their own spreadsheet columns, which can then be used to simulate battery storage by beginning to accumulate the surpluses, and discharging the battery back in to equalise the INDO when there is a deficit now with wind generation plus stored power. This is what is meant by ‘smoothing’ the output of intermittent wind.

If there is not enough accumulated energy at any given hour to complement the generated power on that given hour
If there is a deficit between generated supply and demand on any given hour, and if there is not enough available energy in the accumulators to ‘top up’ the generated supply to

meet the INDO on that hour, that hour is marked (m) as one in which there is ‘Loss of Load’.

In running the model to see ‘how many turbines’ combined with ‘how many accumulators’ would be required in order to provide no’Loss of Load’ occurrences for the whole 8760 hours, the total number of ‘m’s are tallied and if not zero, then that combination is deemed not to have provided secure supply for 2002.

In other words, for a combination to have provided for a ‘No Loss of Load’ year, all the 8760 ‘m’s in 2002 would need to be zero.

To achieve that condition, both with accumulators (situation with no V2G) and with numbers of V2G vehicles being used for storage (with V2G), a large excess of power is generated when the wind speed is suitable. This excess generation is also recorded by the spreadsheet.

Chapter 5 Policy and Infrastructure

Overview

1 Introduction

The first outline for V2G was published more than 10 years ago, and numerous surveys have been carried out and reports published on the subject (see Literature review chapter).

There is a recognition that electricity storage is an exceedingly important and necessary component in the development of renewable energy technology (see Introduction (Chapter 1) section 1.2.3)

There is a great urgency now that the development of renewable energy technology proceeds at a rapidly accelerating pace (see Introduction (Chapter 1) section 1.1)

The numerous reports in the literature review and the investigation in this paper suggest emphatically that V2G technology has the capacity to provide assistance in the effort to resolve energy security issues and combat climate change, so the questions arise, why is not V2G more widely known about considering the concept is 10 years old and why has it yet to be taken seriously by the renewable energy industry?

Another important question that needs answering is, what specific policies and infrastructure need to be in place for V2G to progress in the UK?

This chapter attempts to answer these questions.

2 Electric Vehicles

Darren Kell,CEO, unveiling the new Smith Ampere

Fig 12 The Smith Ampere Van is capable of 70mph and has a 100mile range

Electric vehicles have been manufactured since the beginning of the 20thcentury and were originally more numerous than ICE vehicles.

Over the ensuing years ICE cars have come to dominate the vehicle market because of factors in the market favouring ICE vehicles and because the electric cars had a limited range.

This may now be changing. Electric vehicles are undergoing a revival.
Fig 1 shows the Smith Ampere light van

TNT has recently ordered a fleet of 100 of the heavier 7.5 tonne trucks manufactured by Smith

2.1 Batteries

The battery technology for electric traction, until very recently, had not developed very much in 100 years and the lead acid battery is still the battery most commonly installed in cars for motor starting purposes.

The lead acid battery is a very good way of storing electricity, but it has a number of disadvantages.

1) It has a low energy density – ie it is very heavy in relation to its storage capacity

2) It has a limited cycle life which varies but is around 1000 cycles (ie there is a limit to the number of times they can be charged and discharged

3) It can very easily be destroyed through negligent use, for instance if they are left in an empty state- ie if it is discharged and then not recharged fairly quickly, the internal chemistry will render the battery useless in a very short time.

2.2 New battery technology.

Recently, notably due to the development of portable computing devices, battery technology has been improved and research into better batteries by the likes of Toshiba and Sony continues.

As a spin off from the portable computer industry then, batteries have now been developed which make electric cars a much more viable proposition.

The type of battery currently being used by electric vehicle for their production vehicles is the Lithium ion battery.

Li ion batteries still have a limited number of cycles available, but they tend to have more cycles than a lead acid equivalent.

They have a much greater energy density (ie they are much lighter than lead acid batteries of the same capacity) and this particularily makes them very suitable for vehicles.

Li ion batteries have another characteristic which, while not being an advantage as such, lends itself to V2G technology. They have a limited shelf life (a problem that lead acid batteries suffer from to a lesser extent) meaning that if they are not used, their internal chemistry means they will still degrade. Therefore in order to get as much value out of them as possible, putting them to use as much as possible before they reach the end of their shelf life is recommended. Thus, although V2G will (if the battery undergoes deep cycle charge and discharge) degrade the battery and use up some of its cycles, using the battery for two purposes – one for driving and the other for selling V2G will, depending on the contract the owner has with the grid system operator, deliver more value can than be obtained by using the battery for transportation only.

At present Li ion batteries are still more expensive than the equivalent lead acid battery. The recently developed Smith vehicles (a very well established British company which is a world leader in industrial electric vehicles) Ampere van uses Lithium ion phosphate batteries. The cost of the replacement battery is £9000.00.

The Smith Ampere 25kWh batteries have a 3000 cycle life and 60 months warranted shelf life


Fig 14 The Tesla Sportscar with a 250 mile range and faster than a Ferrari

A very different vehicle, is the Tesla motors Tesla sportscar also uses Li ion batteries (50kWh) see Fig 14

The improvement in battery technology has come at a time when people are again looking to electric vehicles due to the high cost of fossil fuel.
This change will be accelerated if the auto manufacturing companies start to seriously invest time and capital into the development of battery technology.

2.3 V2G

V2G is an interdisciplinary technology linking two areas of study that have not been investigated as a unitary whole. The two areas are the auto industry and the electricity generating industry.

The idea of V2G is a new one and, it can be seen from the literature, that the authors need to describe the basics of the concept each time they write a paper on the subject. The concept *is* difficult to understand [see Kempton et al, 2001, p6].

V2G represents a paradigm shift in the way that electricity markets could work and it is difficult to see how, without considerable support from industry on both sides of the unitary whole that is V2G, and from Government that the project could take off with the speed that is required.

Parts industry of the industry, on both sides, may see V2G as a threat.

Parts of the electricity industry may see V2G from vehicles other than Battery Electric Vehicles with V2G (ie those vehicles *not* covered in this paper), ie vehicles with an on board supply of fuel, as competitors, in terms of electricity generation, and this may have outcomes for V2G as a whole

Other parts of the electricity industry may welcome V2G and see it as another way to manage intermittency and security of supply.

The car manufacturing industry with its many years in the business of manufacturing all the myriad items that go into a car and with its umbilical cord to the oil industry may also see V2G as a threat. The entire complex of the oil industry and associated refining industries with links back to the car industry and with loans from the big banks all together may make these industries reluctant to change.

Change is happening though and whether these old industries accept the new possibilities being developed with enthusiasm or whether they try to impose restrictions may dictate whether change happens at maximum possible speed or whether the disparate industries that do pick up the new technologies can develop them quickly enough.

Support from the Government may be the critical factor because public acceptance and cooperation will be a key issue and the Government is in a position to help ease the path of any start up projects.

2.7 Radio/ Frequency/ Intelligent Communications

One of the important factors that add value to V2G, is the amount of control the electricity grid operator has over the V2G vehicle.

It would be useful for the operator to know the state of charge of the battery and whether it will be possible to use the vehicle for V2G services, in other words whether the vehicle can be used for 'positive' or 'negative' reserve (also known as regulation up and regulation down) or not at all because the driver is driving it or has turned the facility off.

This could be accomplished through the systems similar to the type of technology found in intelligent communications equipment of which there are many examples in everyday use – e.g. mobile phones or GPS receivers.

However it may be possible to achieve most of the functionality without having a requirement to use communications equipment and this may be preferable to a more complex communications regime.

Currently, the system operator in the UK controls parts of the system by radio signals.

(Sent by a radio signal on longwave on the BBC Radio 4 channel)

The economy 7 start and end times are communicated by a signal sent out from the National Grid company picked up by a time switch installed on the customer premises. [Everett, 2007 ,p154]

A V2G car could receive the very same signal and switch to charge at the economy 7 start time and to stop charging when the signal is received for the end of economy 7 pricing. This can be done now with no further tariff or infrastructure changes.
In fact simply plugging in to the customer supply will achieve this.

An alternative possible way of controlling V2G remotely without the use of communications equipment would be to use the frequency of the electricity grid.

The frequency on the grid changes continuously from minute to minute (even second to second)

The system operator attempts keep the frequency within very narrow limits (50Hz(+/-0.2)).

The frequency could be used to trigger 'regulation up or down' If the frequency was below 50 Hz, the V2G system could detect that and (if this had been arranged in advance with the system operator) and start discharging (regulation up) into the grid. If the frequency was higher the V2G could detect it and start charging (regulation down).

Fig 1 illustrates how grid frequency continuously changes from hour to hour

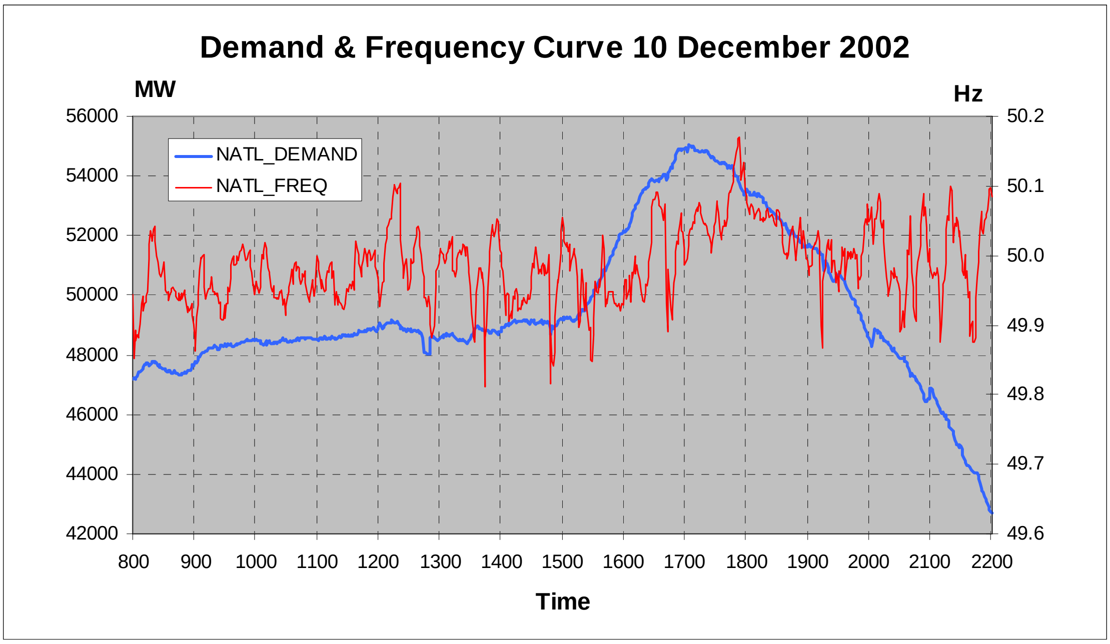

Fig 14 Frequency and demand on 10 12 2002

2.8 Jobs

If V2G is taken up a great many jobs would be created boosting the economy. This would be useful, of course, right now, with the world economy looking as if it is going to enter a recessionary period.

2.9 Hydrogen from Surplus

For true security in energy, a surplus needs to be created, and that is technically possible. Once wind has been made secure by the use of V2G, any excess wind energy could be used to build up a large store of hydrogen which cold be used for further energy security and a myriad of things such as fuel cell vehicles and perhaps, planes. This is a long way in the future.

It would be necessary to keep the storage attached to wind to maintain the security of wind generation however.

2.10 Issues regarding infrastructure.

2.10.1 AC /DC

Electric cars can have DC or AC motors (the early GWiz is a DC vehicle)

It is a lucky accident that most electric vehicles now are AC since the cost of incorporating an inverter into DC vehicles would have had a negative impact on the viability of V2G (though not ruling it out)

2.10.2 Three Phase

Most UK residential areas are on single phase electricity. However some electric vehicles are manufactured for three phase charging.
This is an important area affecting electric vehicles in general and need not be an issue for V2G if manufacturers are aware of the needs of V2G. See 2.10.5

2.10.4 Frequency

The frequency in the US is 60 Hz while in the UK it is 50Hz.

Because a lot of vehicles are imported, standards would have to be set up so that UK vehicles produced 50 Hz and vehicles destined for other countries were set up accordingly

2.10.5 Charging

There are two types of charging for electric cars – inductive or conductive

Inductive charging is unsuitable for V2G since it would not be possible to have reverse flow from the vehicle with this charging method.

Again, standards would need to be set up to ensure future V2G compatability.

2.10.6 Charging Points

One issue for V2G (and firstly for plug in electric cars generally is where do you charge if you haven't got off road parking at home or work or if you are away from both.

There are a few charging points popping up in big cities. But nowhere near enough if we are to have the transport revolution that is needed. Again, Government assistance is needed for the electric project to succeed *quickly*

2.10.5 Infrastructure

What is extremely interesting about electric cars (and V2G) is that thebulk of the infrastructure is already there! The electricity network can be used as is. There may be some grid strengthening required at a future date, but this would be at nowhere near the expense (and hard work) of installing say a hydrogen pipe network or hydrogen tanker delivery for a future hydrogen economy

Summary

This chapter has identified some issues which need to be resolved before V2G can be viable

1 Electric Vehicles need to become more widely used

2 The recent improvement in battery technology is in the right direction, but more needs to be done to bring the price down and to improve the shelf and cycle life

3 V2G may need Government support in order for it to become useful technology

4 Infrastructure issues such as the type of charging for electric cars (needs to be conduction type for V2G); single phase motors need to be useed in the UK unless 3 phase electricity is channelled to residential areas and, since frequency of the grid varies across country borders, standards need to be adopted for V2G in relation to frequency.

Chapter 6 Conclusions

Overview

This chapter will attempt to provide a synthesis of the rest of the report, collecting all the relevant details and present the results in the context of issues of current relevance.

These issues are energy security and climate change

The results of the model 'experiment' suggest that the three criteria outlined in the Introduction have indeed been satisfied.

Main Conclusions

1 It was found that V2G should be able to provide for a 32% penetration of wind energy onto the electricity network, a method of generating electricity with wind energy that can indeed provide firm, secure electricity.
This may be a way in which electric cars can assist the UK Renewable Energy Strategy since secure electricity is one of the major ambitions of this strategy

2 It was found that net reductions in CO_2 from both the power generation source and from the vehicle fossil fuel use source will be the result of a turn to V2G assistance for intermittent renewables.
Again this demonstrates that V2G technology is capable of providing assistance to the UK Renewable Energy Strategy because climate change, which is happening as a result of anthropogenic CO_2 and other greenhouse gas emissions is central to this strategy.

3 The take up of V2G necessarily means electric cars, and so as V2G gets taken up, the number of ICE cars will reduce in proportion. To secure windpower enough to meet 32% penetration will require 16.5 million V2G vehicles which will in turn replace the existing ICE vehicles. The result will be a reduction in oil consumption. This reduction in oil consumption will assist the UK Renewable Energy Strategy both in terms of energy security, in that the reduction in consumption of oil should reduce the pressure on supplies of liquid fuels and hence increase energy security, and also in terms of CO_2 emissions in that less fuel will be converted to CO_2

2 Summary of points covered

2.1

It was established that it is important to carry out the sort of investigation undertaken here, because of the urgency and weight of the twin problems of climate change and energy security.

2.2

It has been noted that V2G is in an interdisciplinary area and that as such, extra efforts need to be made attempting to explain its relevance to current affairs.

2.3

It was noted also that if appropriate steps are taken now, then both major problems affecting the world today - energy security and climate change - can be resolved.
It has been argued that V2G can be a part of this solution.

2.4

Offshore wind was seen as of major importance and as such has been central in this study.

2.5

The UK has one of the best wind resources in Europe and it is to the good that progress seems to be being made in getting the infrastructure right for offshore wind albeit with security problems as large energy companies withdraw from important wind projects.

2.6

The problem of wind's intermittency was discussed at length and indeed was the focus of the excel model. The impact of the intermittency on winds' capability to provide secure power was examined. The model found that with the windspeed data obtained for 2002, wind turbines constructed on the four sites would have been unable to provide secure power in 2002 because on 19 days there was insufficient suitable wind speed to deliver power.

It is because of this lack of constancy that many in the energy industry regard it as impossible for wind to provide a service beyond 20% penetration without the need for equivalent reserves

It has been found in this study that that view may be incorrect in that with suitable storage, wind could indeed provide secure power beyond 20% and could, with the right amount of V2G storage and infrastructure even provide 100%. This is not being advised but simply to say that this is a theoretical possibility.

2.7

Large amounts of storage can support large amounts of intermittent wind and and the relationship between the two, between MW and MWh of storage to achieve a no 'Loss of Load' regime was illustrated in a chart.
Reproduced here in Fig 15
After a search, no other reference to this relationship was found in the literature.
This may be the first time this particular relationship has been investigated and illustrated.

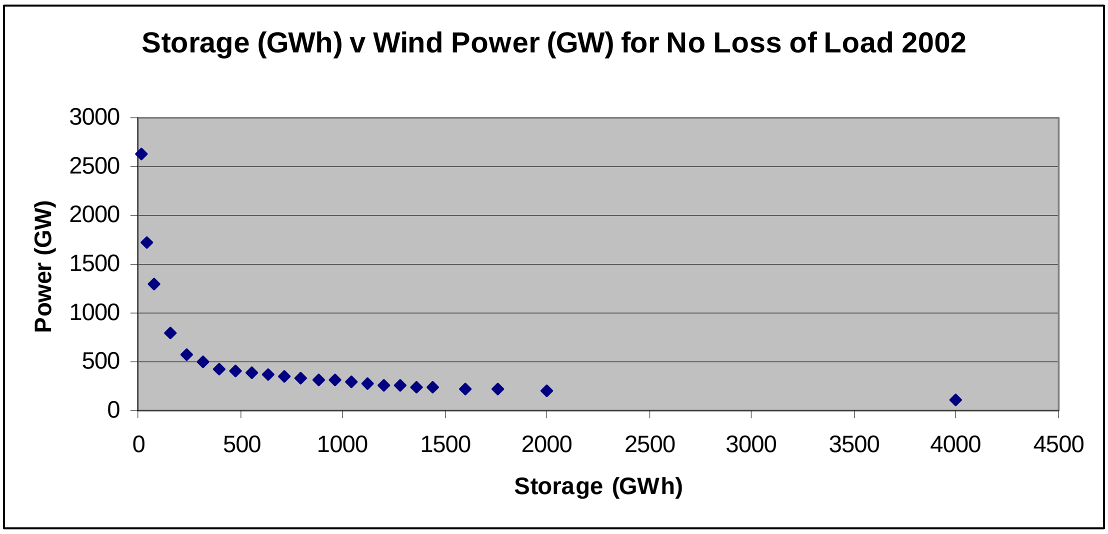

Fig 15
Wind generation of electricity, by its nature produces large excesses of power. When conditions are suitable for capture of large amounts of energy, but they coincide with a period of low demand, even with V2G, large amounts of energy must be discarded and cannot therefore be harvested.

It was noted that in a future (beyond 2020) with wind electricity secured by V2G, hydrogen could be manufactured using the excess helping to create a surplus in energy which would be the ultimate in energy security.

2.8 Savings in CO_2 from the conventional electricity generators

It was discovered that a fleet of electric cars would provide a considerable extra load on the electricity grid and that some grid strengthening might be required although as the use is widely dispersed this may not materialise as an issue.

One of the results of the modelling (and a main finding detailed earlier in this chapter) was that if the amount of storage on the system (numbers of V2G vehicles) is increased beyond the level strictly necessary to provide energy security, the amount of energy that would otherwise have been wasted is available for use.

As this energy has been assimilated onto the electricity network, this means that conventional generation is being replaced and it was found for the scenario under investigation (32% wind penetration), that over 1 billion Kg of CO_2 annually may be saved from being emitted into the atmosphere.
This may be a conservative estimate since it does not include energy saved in the process of infilling the low points of wind energy output with energy saved from an earlier surplus, in the situation where, pre secure wind, the V2G fleet still contributes to the smoothing although, because there is a lack of V2G storage, full energy security for the wind energy output has not yet been reached.

2.9 The electric vehicle load and pickup

It was noted that with more electric vehicles drawing electricity from the grid, the load on the electricity network will rise. It was calculated that if an average daily trip is 10 miles, then the extra hourly load would be 1718 MW. Of course if the trip were 100 miles for every vehicle, the load would increase by 10 times.
In the same way that TV pickups in demand occur, pickups in the future may occur at holiday times when everyone drives extra miles and on return or arrival plugs in for a higher charge than normal. The load might go up by the equivalent of several large power stations briefly (a few hours) and then return to a standard pattern.

2.10 Wind Powered Cars

It was also noted that there is a symbiotic relationship between wind power and vehicles (if V2G is used)

The more electric cars there are on the road, the more demand there is on the grid; and the more storage there is on the grid, the more excess wind energy can be stored – thus delivering the extra supply for the demand arising from the greater number of electric vehicle owners needing electricity.

Main Conclusions

The main conclusions can be found at the start of this chapter.

All the conclusions are based on the premise that the wind patterns and results found for 2002 can be duplicated for other years.

Most of the technical issues concerning energy security and climate change have been resolved. Scientists and technicians know exactly what needs to be done [IPCC, 2007, Mitigation Report]. The problem for the planet is thus not a technical one, not one simply of how to achieve the goal, it is one of how to achieve the goal of energy security and a safe planet given the current existing economic and political structures.

Chapter 6 Conclusions

The issue of energy is constantly on the news. People may be beginning to realise that they cannot take for granted the instant supply of power when they flick a switch.

The Government is increasingly concerned about energy issues.

The fossil fuel companies continue to scour the surface of the earth looking for new sources of fossil fuels, at the same time as other voices are saying the peak has been reached for mining oil and that it should anyway be left in the ground because humanity cannot afford to endanger the planets' climate any longer.

There is a battle of ideas occurring about energy security and the environment.

The discussion about energy is one that goes to the heart of the societies we live in.

The motivation of the big oil and energy companies remains the same as it has been for decades. The example of shell withdrawing from the large London Array Windfarm indicates that it will always be the bottom line that dominates decisions when it comes to investment.

The problem is is that it seems to be these companies that could make the difference for renewable energy.

It may be the time for Governments to put pressure on the oil companies at least for a windfall tax which could go towards renewable energy.

However, in the absence of moves from the fossil fuel companies genuinely towards renewable energy, it must fall to others to attempt to carry through the change needed despite the intransigence of the forces that could implement the changes that are required.

Bibliography and References

Andrews, D., 2007, 'The potential Contribution of Diesel Standby Generators in Dealing with the Variability of Renewable Energy Sources', in Boyle, G.(ed) Renewable Energy and the Grid, Earthscan, Chapter 7

Black, M. and Strbac, G., 2005, Value of storage in providing balancing services for electricity generation systems with high wind penetration, Journal of Power Sources

Boyle, G (ed), 2007, Renewable Electricity and the Grid, Earthscan

Brooks, A., Vehicle to Grid Demonstration Project: Grid regulation ancillary service with a battery electric vehicle, 2002 California Air Resources Board]

Dale, L. Milborrow, D. , Slark, R., Strbac, G., 2004, Estimates for large scale wind scenarios in UK, Elsevier

Everett, B, 2007, 'Demand Flexibility, Micro-Combined Heat and Power and the 'Informated Grid', in Boyle, G.(ed) Renewable Energy and the Grid, Earthscan, Chapter 8

Ends Report 399, April 2008]

Gross, R., Heptonstall,P., Anderson,A., Green,T. Leach, J.and Skea,J.,2006, The costs and impacts of intermittency, UK Energy Research Centre, London

Helweg-Larsen, T. and Bull, J., 2007, zerocarbonbritain: An alternative energy strategy, CAT Publications

Infield, D., Watson, S., 2007, 'Planning for Variability in the longer term: The challenge of a truly sustainable energy system', in Boyle, G.(ed) Renewable Energy and the Grid, Earthscan, Chapter 11

Intergovernmental Panel on Climate Change, Climate Change 2007: The Physical Science basis, 2007, (Cambridge University Press, Cambridge

Kempton, W. and Letendre, S.,1997, Electric Vehicles as a New Power Source for Electric Utilities, University of Delaware, USA

Kempton, W., Tomic, J., Letendre, S., Brooks, A. Lipman,T, 'Vehicle-to-Grid-Power: Battery Hybrid and Fuel Cell Vehicles as resources for distributed electric power in California' 2001, California Air Resources Board

Bibliography and References

Kempton, W and Tomic, J, 2004[a], Vehicle to Grid Power Implementation: From stabilising the grid to supporting large scale renewable energy, Journal of Power Sources

Kempton, W and Tomic, J, 2004[b], Vehicle to Grid Power Fundamentals: Calculating capacity and net revenue, Journal of Power Sources, University of Delaware

Kempton, W. and Dhanju, A., 2006, Electric Vehicles with V2G: Storage for large scale windpower, University of Delaware

Laughton, M., ,2007, 'Variable Renewables and the Grid: An Overview', in Boyle, G.(ed) Renewable Energy and the Grid, Earthscan, Chapter 1
Mathew, S., 2006, Wind Energy: Fundamentals, Resource Analysis and Economics, Springer

Rowntree, D, 1981, Statistics Without Tears, Penguin

Sorensen, B, 2004, Renewable Energy, Elsevier

Strbac, G., Shakoor, A., Black, M., Pudjianto, D., and Bopp, T. 2006, impact of wind generation on the operation and development of the UK electricity systems

Tomic, J and Kempton, W., 2007, Using Fleets of electric–drive vehicles for grid support, Journal of Power Sources, University of Delaware

Turton, H. and Moura, F. 2008, Vehicle to Grid systems for sustainable development: An integrated analysis, Technological forecasting and social change

Twiddell, J. and Weir,T, 2006, Renewable Energy Resources, Taylor and Francis

UK Renewable Energy Strategy (Consultation) June 2008.

Websites

http://news.bbc.co.uk/1/hi/england/london/7421910.stm (accessed 21/07/08)

http://www.defra.gov.uk/environment/climatechange/internat/ipcc/ar4.htm (accessed 21/07/08)

http://www.statistics.gov.uk/CCI/nugget.asp?ID=24&Pos=2&ColRank=2&Rank=224 (accessed 21/07/08)

http://www.worldoil.com/INFOCENTER/SIMMONSPRICES.ASP?A=PRICES (accessed 21/07/08)

Bibliography and References

http://www.tnt.com/country/en_gb/about/tnt-press-office/news/news-2008/tnt_delivers_worlds_largest_zero_emissions_fleet.html (accessed 21/07/08)

http://www.carbontrust.co.uk/resource/measuring_co2/Measuring_CO2_Examples.htm (accessed 23/07/08)

http://www.bmreports.com/bsp/bsp.php (accessed 23/07/08)

http://www.smithelectricvehicles.com/ (accessed 23/07/08)

http://news.bbc.co.uk/1/hi/business/746569.stm (accessed 23/07/08)

Glossary

Loss of Load This refers to the situation when the system operator is forced to disconnect an electrical load on the system in an unplanned fashion due to a deficit in power supply.

Reserve (or reserve capacity) Refers to generation equipment kept running at low power but kept in synchronisation with the grid frequency so that at short notice it may be brought into operation

System operator (sometimes called simply operator) In the UK this is the National Grid Company, the company in charge of the UK electricity network.

Appendix

Appendix 1

Data Descriptions

Vehicles and Batteries

Smith Ampere:

Variable	Value	Units	Description
Battery Size	25	kWh	Energy Capacity
Battery Cost	9000	£	Money Cost
Battery Cycles	3000		Manufacturer claim
Battery Type	Li – ion phosphate		
Battery min SOC	20	%	Min battery charge permissible
Battery Life Expectancy	5	years	

Below is a screen copy of the main data entry work sheet 'Variables'

This worksheet holds all System variables. Changes on this worksheet will result in changes to the Power and Energy Outcomes on sheet 'Performance and Storage'.
Cells Highlighted in yellow on this sheet can be altered to affect the results of the model
Text Highlighted in red on this sheet indicate calculated results

All windfarms in sea area 62303	1	(enter 1 for operational, otherwise 0)
All windfarms in sea area 62301	1	
All windfarms in sea area 6026	1	
All windfarms in sea area 62109	1	

412500	Total Storage in all cars (MWh)
19600	Total number of Wind Turbines
0	calculated hours without supply in 2002
0	Max Power Shortfall (MW)

Variable	Value	Units
Battery Size (kWh)		kWh
Battery Size (MWh)	0.0250	MWh
Battery Cost	9000.00	£ sterling
Battery Energy cost	0	kWh

Appendix

Battery Spec		
Battery Cycles	3000	
Battery Performance		
Battery Voltage	48	V
Battery Type	Li-ion	
Battery Min SOC Percentage	20.00%	
Battery Life Expectancy	5	years
Vehicle Type	car	
Vehicle Usage Patterns		
Electric Motor Type	ac	
Amperage of V2G wiring	16	A
Phase	single	
Number of e vehicles nationally	16,500,000	
Inverter Power	3	kW
Inverter Spec		
Inverter Efficiency	95%	%
Wind Turbine Capacity	5	MW
Cp	0.35	
Number of Turbines	100	
Number of Windfarms	49	
Windfarm/s		
Rotor Arm Radius	61.5	m
Rotor Height	100	m
Turbine Cut-In Speed	4	m/s
Turbine Max- Power Speed	13	m/s
Turbine Cut-Out (Shutdown) speed	25	m/s
Buoys		
Buoy Anemometer Height	3.3	m
Roughness Class/ Height	0.005	
Grid cable losses	80.00%	%
Cost of Domestic Night Electricity	4.3	ppkWh
Cost of Domestic Day Electricity	9.2	ppkWh
Density of Air	1.225	kg/m3
Total Storage Capacity in all cars	412500	MWh
Energy at Minimum State of Charge	82500	MWh

Number of miles driven per day	1.00	m
Number of miles on Full Charge	100.00	m
% cars driving at any one time	5.70%	%
Reduced size storage-reason driving	106012.5	
MWh Charge due to driving	-4125	

Appendix

Example input data and calculations

62109 Lat 570 Lon 0	32%INDO	15%INDO	20% INDO	INDO	Lat 516 Lon -51 buoy 62303 Wind Speed Knots	speed ms-1 62303 buoy	speed ms-1 at rotor height 62303	Wind Speed 62303 with cut in and cut out calcs	Power in Watts (one turbine) 62303
01/01/2002	11207.68	5253.6	7004.8	35024	13	6.69	10.20	10.20	2704935.20
01/01/2002	11613.12	5443.65	7258.2	36291	13	6.69	10.20	10.20	2704935.20
01/01/2002	11204.16	5251.95	7002.6	35013	14	7.20	10.99	10.99	3378398.81
01/01/2002	10825.28	5074.35	6765.8	33829	14	7.20	10.99	10.99	3378398.81
01/01/2002	10068.48	4719.6	6292.8	31464	15	7.72	11.77	11.77	4155282.79
01/01/2002	9656	4526.25	6035	30175	18	9.26	14.13	13.00	5597068.30
01/01/2002	9460.16	4434.45	5912.6	29563	16	8.23	12.56	12.56	5042974.31

speed ms-1 at rotor height 62301	Wind Speed 62301 with cut in and cut out calcs	Power in Watts (one turbine) 62301	Power in MW (one turbine) 62301	62109 Lat 570 Lon 0 Wind Speed knots	Date buoy	speed ms-1 62109 buoy	speed ms-1 at rotor height 62109
13.34	13.00	5597068.30	5.597068	17	01/01/2002	8.75	13.34
13.34	13.00	5597068.30	5.597068	19	01/01/2002	9.77	14.91
14.13	13.00	5597068.30	5.597068	19	01/01/2002	9.77	14.91
14.13	13.00	5597068.30	5.597068	20	01/01/2002	10.29	15.70
14.91	13.00	5597068.30	5.597068	19	01/01/2002	9.77	14.91

speed ms-1 at rotor height 62109	Wind Speed 62109 with cut in and cut out calcs	Power in Watts (one turbine) 62109	Power in MW (one turbine) 62109	speed knots 6026 lat 553 lon 11	speed knots errors removed 6026	speed ms-1 6026 buoy	speed ms-1 at rotor height 6026	Wind Speed 6026 with cut in and cut out calcs	Power in Watts (one turbine) 6026

13.34	13.00	5597068.30	5.597068	16	16	8.23	12.56	12.56	5042974.31
14.91	13.00	5597068.30	5.597068	15	15	7.72	11.77	11.77	4155282.79
14.91	13.00	5597068.30	5.597068	15	15	7.72	11.77	11.77	4155282.79
15.70	13.00	5597068.30	5.597068	17	17	8.75	13.34	13.00	5597068.30
14.91	13.00	5597068.30	5.597068	17	17	8.75	13.34	13.00	5597068.30
14.91	13.00	5597068.30	5.597068	16	16	8.23	12.56	12.56	5042974.31
15.70	13.00	5597068.30	5.597068	17	17	8.75	13.34	13.00	5597068.30
17.26	13.00	5597068.30	5.597068	19	19	9.77	14.91	13.00	5597068.30

Power MW (windfarm) 62303 operational	Power MW (windfarm) 62301 operational	Power MW (windfarm) 6026 operational	Power MW (windfarm) 62109 operational	Power MW (All Operational Windfarms)	Nationl Power Shortfall (100%Wind)	National (Wind) Power Surplus (100% wind)	National (Wind) Power Surplus or Shortfall (32% wind) running
270.494	559.707	504.297	559.707	92816.03	0	57792.03	81608.35
270.494	559.707	415.528	559.707	88466.34	0	52175.34	76853.22
337.840	559.707	415.528	559.707	91766.31	0	56753.31	80562.15
337.840	559.707	559.707	559.707	98831.06	0	65002.06	88005.78
415.528	559.707	559.707	559.707	102637.79	0	71173.79	92569.31
559.707	559.707	504.297	559.707	106987.48	0	76812.48	97331.48
504.297	504.297	559.707	559.707	104272.42	0	74709.42	94812.26
559.707	559.707	559.707	559.707	109702.54	0	81760.54	100761.10

National (Wind) Power Surplus or Shortfall (15% wind)	National (Wind) Power Surplus or Shortfall (20% wind)	National (Wind) Power Surplus or Shortfall (100% wind)	Battery energy used by the cars (from lookup on patterns of use) C is charge	EV load	Stored + Surplusorshortfall (temp store)	Battery Fleet Net Stored Energy MWh	Excess power needing to be dumped through lack of storage	Battery Fleet SOC.
						82500.00		20
87562.43	85811.23	57792.03	C	-589.285714	164108.35	163519.06	0	39.641

83022.69	81208.14	52175.34	C	-589.285714	240372.28	239782.99	0	58.12
86514.36	84763.71	56753.31	C	-589.285714	320345.14	319755.86	0	77.51
93756.71	92065.26	65002.06	C	-589.285714	407761.63	407172.35	0	98.70
97918.19	96344.99	71173.79	C	-589.285714	499741.66	412500.00	86652.37	10
102461.23	100952.48	76812.48	C	-589.285714	509831.48	412500.00	96742.19	10

Appendix 2 Questionnaire

University of East London: MSc in Advanced Energy & Environmental Studies / Centre for Alternative Energy Technology

We are conducting some research into the important area of vehicle transport and energy use. We would be grateful if you would take a few minutes to complete this questionnaire, as accurately as you can. The results will be combined with results from elsewhere in London. Thank you very much indeed. NB All information is *anonymous and confidential:* no name requested.

If you drive to work:

1 How long is your journey to work? (in miles) ____

	Leave for Work	Arrive at Work	Leave Work for Home	Arrive back Home
2 Please indicate the start and end times: (eg 9am, 10:30 am, 5pm 6:30pm)	_____	____	___	___

3 Please indicate the days of the week the above times refer to:
(circle where appropriate)

M T W T F S S

Leisure / alternative use:

Please indicate, if possible, patterns of vehicle use on days other than work days:

4 Number of miles each day _____

	Leave	Return	Leave	Return
5 Start and End of Trip times (eg 11am, 1pm, 3pm, 3:30pm) (if more than two trips, indicate the longest two)	___	____	___	____

6 Please indicate the days of the week the above times refer to:
(circle where appropriate)

M T W T F S S

Vehicle Details

7 Type of Vehicle: Petrol Diesel Hybrid Electric Other
(circle where appropriate)

THANK YOU VERY MUCH INDEED!

Appendix