Annexe B:Low Carbon Technologies for Smart Grid Evaluation Framework

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Document: Low Carbon Technologies for Smart Grid Evaluation Framework

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Contents

1 Introduction

This document incorporates a number of low carbon technologies (LCTs) and tyoes of Distributed Generation (DG) to be considered in the Smart Grid Evaluation Framework. The selection of LCTs and DG has been informed by the work carried out by DECC in Workstream 1 of the Smart Grid Forum.

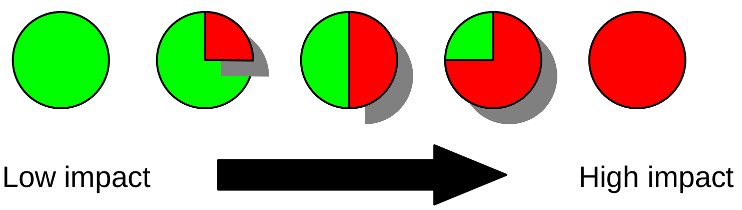
The LCTs considered in this document are:

- Photovoltaic Generation (Residential)
- Heat Pumps
- Electric Vehicles (Residential)
- Electric Vehicles (Car Parks)
- MicroCHP
- Small Scale Wind Generation

Foe each LCT, there are a number of sub-categories where comments and analysis is provided. These are:

- Description of the technology
- Typical profile
- Likelihood of clustering
- Network issues
- Impact table

The impact table is a graphical depiction of the likely levels of penetration and clustering of the various LCTs together with their impact on the thermal and voltage profile across the three network types (urban, rural and suburban). In each case, the impact has been assessed and is indicated as follows:



In several cases, there are also accompanying comments and notes on the impact table to explain the assessments that have been made.

2 Photovoltaic (PV) Generation

2.1 Description of the Technology

Energy incident from the Sun reaches a maximum of 1000W/m^2 on a cloudless day in mid-summer in the UK. Solar PV panels collect a proportion of this, typically around 14% of the incident energy, by utilisation of the photo-electric effect. The effect is realised in semiconductors when photons collide with atoms, creating an electron-hole pair. The presence of a semiconductor “p-n” junction allows electrons and holes to be collected separately and for current to flow in an external circuit, delivering power in the process. In the UK, panels are typically mounted on roofs in fixed planes and hence output varies according to the season as well as weather. Whilst techniques can be used to boost output such as by active tracking or concentrating lenses, the simplicity and low maintenance of fixed panels means that they are preferred. Power from solar panels is in the form of DC, an inverter is necessary to convert it into AC for grid connection.

The average size of installations under the Feed-in-Tariff was 2.8 kW for installations carried out in 2010. 53 MW was installed in just over 19,000 installations in the same year. The reasons for the relatively small average size are the constraint of rooftop space and increased rate of Feed-in-Tariff for installations of <4kW.

2.2 Typical Profile

The output of a PV panel principally varies according to the season and weather. Figure 2.1 presents profiles of power output for an average 2.8kW system in mid-summer for the conditions clear-sky, average cloudiness (for the time of year) and cloudy conditions. Real output for a typical mid-summer day varies between the maximum clear-sky-output and minimum cloudy-output. The rate of change of output of a single installation is in the order of seconds as clouds pass overhead.

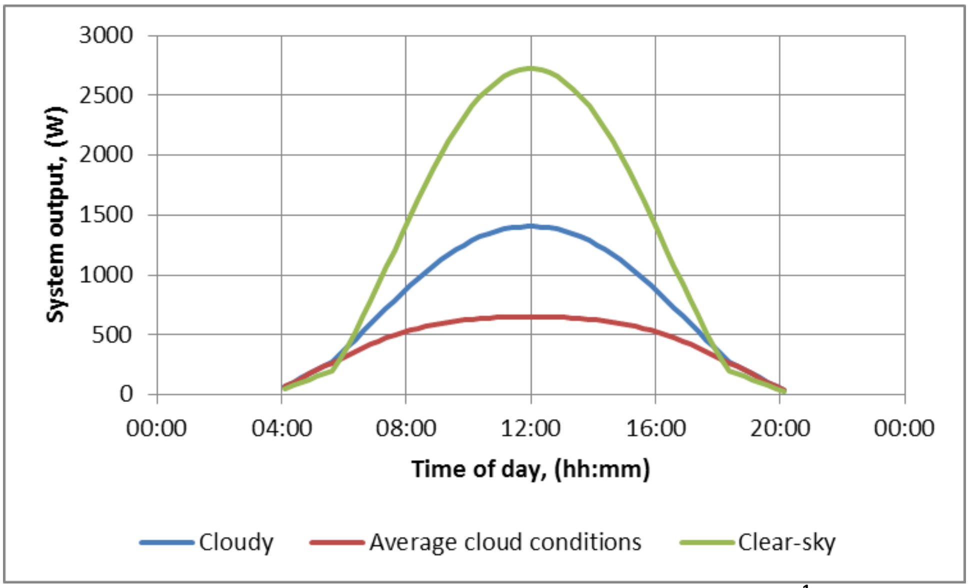


Figure 2.1. Daily Profiles of a 2.8kW PV Installation in June[1]

2.3 Likelihood of Clustering

Clustering is highly likely given the visibility of PV systems. The route to installation is likely to be in response to visibility of a friend or neighbour's installation. As an example, analysis of Ofgem's Feed-in-Tariff Installation Report[2] reveals that 5% of postcodes (defined in the

[1] Photovoltaic Geographical Information System daily output for a 2.8kW system located around Leeds, UK, available at http://re.jrc.ec.europa.eu/pvgis/ , accessed 03/10/11

[2] Ofgem, Feed-in-Tariff Installation Report 30 September 2011 (.xls), available at www.ofgem.gov.uk, accessed 13/10/11

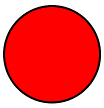
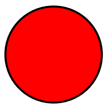
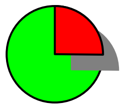
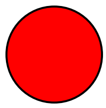
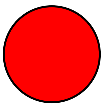
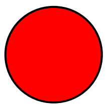
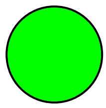
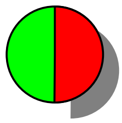
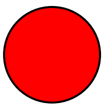
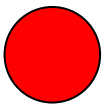
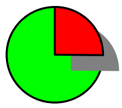
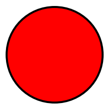
report as the first four digits, e.g. “AB11”) contained more than 58 installations. The maximum number of installations in one postcode was 295, in “S20”, with aggregate PV generation of 930 kW. It is worth considering that, rather like the proliferation of central heating, if the economics remain favourable then the eventual state of housing will be that all homes with suitable roofs will have PV or solar-thermal technology.

2.4 Network Issues

The major issues for PV are the upper voltage limit of 253V on UK distribution networks and the fact that maximum generation occurs (for South-facing panels) during the middle of the day, when network loads are relatively low. Typically, distribution substations are set to supply 250V (or above), leaving up to 3V of headroom available for generation, a small part of the 37V range between maximum and minimum voltage in the UK. When the upper limit is reached, PV inverters mandatorily switch-off and await ‘normal’ network voltage, which must be present for three minutes before reconnection is allowed. If the network operator is not able to provide extra headroom, owners will find that their PV systems are not providing the revenue expected.

Because PV is a generation technology, there is a requirement for an installer to notify the network operator. The network operator must effectively “connect and manage” and all installations must meet the requirements of Engineering Recommendation G83[3].
Issues arise for network operators when there are multiple installations. If these are installed by the same entity, then the network operator can assess the connection and determine consequential actions. If these are as a result of multiple different entities, then they must be connected regardless of whether there is voltage headroom available.

2.5 Impact Table

Domestic PV	**Penetration**	**Clustering**	**Thermal Profile**	**Voltage Profile**
Urban				
Rural				
Suburban				

[3] Available from the Energy Networks Association, details can be found at http://2010.energynetworks.org/distributed-generation/

3 Heat Pumps (Residential)

3.1 Description of the Technology

In general, heat pumps, dehumidifiers and refrigerators all use the same type of working system. A working gas (butane, CO_2, Chloro- or Hydrogen-Fluoro-Carbons) is compressed to high pressure and passed to a heat exchanger. The heat exchanger is cooled by a fluid (return water or air from a heating system), causing the gas to release heat and liquefy in the process. The liquefied gas is passed through an expander that separates the low-pressure evaporator from the high-pressure condenser. Low-temperature heat is supplied to the evaporator by atmospheric air (for air-source heat pumps) or ground loops (for ground or water-source heat pumps). The liquid boils, absorbing heat from the low temperature source.

Heat pump performance is measured in terms of their coefficient of performance. Whilst most heat pumps derive the energy required for compression from electricity, it is possible for this to be supplied from other sources such as internal combustion engines. These latter are not considered in this document since to the author's knowledge, there are no installations in the UK.

Installations have to date been led by social housing providers, able to access fuel poverty funds from energy suppliers and government. Heat pumps have been installed in off-gas-grid areas, the high price and variability of heating oil has been the main driver. Heat pumps pose a major problem for electricity networks because they are a form of direct-electric heating (as opposed to electric storage-heating) and electric heating requires a significant increase in supply capacity over fuelled heat-sources. The extra supply capacity is most significant around the time of the existing peak network load. One method of mitigation is to equip heat pumps with heat-storage elements, so that they can be switched-off for a period of time in response to high network loads. Storage elements are not commonly used with heat pumps today.

3.2 Typical Profile

The "Without Store" series presented in Figure 3.1 has been created from 5 days of load data taken during winter 2008 from an electricity substation supplying 19 properties[4], 18 of which had HPs installed by a social housing provider. Weather conditions were amongst the coldest experienced in recent years, the average daily temperature during the 5 days being +3°C, and the minimum being -5°C. According to the manufacturer datasheet, each heat pump possessed a maximum input power of 3.1 kW at 0°C, 90% relative humidity[5]. Some heat pumps are fitted with electric heating elements to supplement output. The heat pump should be sized to keep the additional cost and impact on carbon emissions to be a

[4] S.D. Wilson, Monitoring and Impact of Heat Pumps, Strategic Technology Programme, Project S5204_1, October 2010

[5] Calorex, Domestic Heatpumps, available at www.calorex.com, accessed January 2009.

minimum, but maximum demand would be increased for a) extremely cold days, b) cold-load pickup events.

The “Thermal Store” series presented in Figure 3.1 presents an interpretation of how a commercially available thermal store[6] could be charged and controlled to reduce the contribution of heat pumps to peak demand, which occurs here around 16:15. Key assumptions in creating this series are: 35°C useful temperature range in the thermal store, store comprised of 190 litres of water, recharging of the store starts from 01:00 and recharging occurs over 4 hours at night, and that the demand of non-heat pump loads is 0.8 kW around the time of peak demand. The heat pump is simply turned off in order to reduce peak demand. For this example, storage can be seen to reduce the peak demand of the 18 heat pumps by 5 kW. Great benefit could be realised if the thermal store is used to offset load from the heat pump rather than switch it off entirely, however this entails a control system which integrates operation of the thermal store with the heat pump control system.

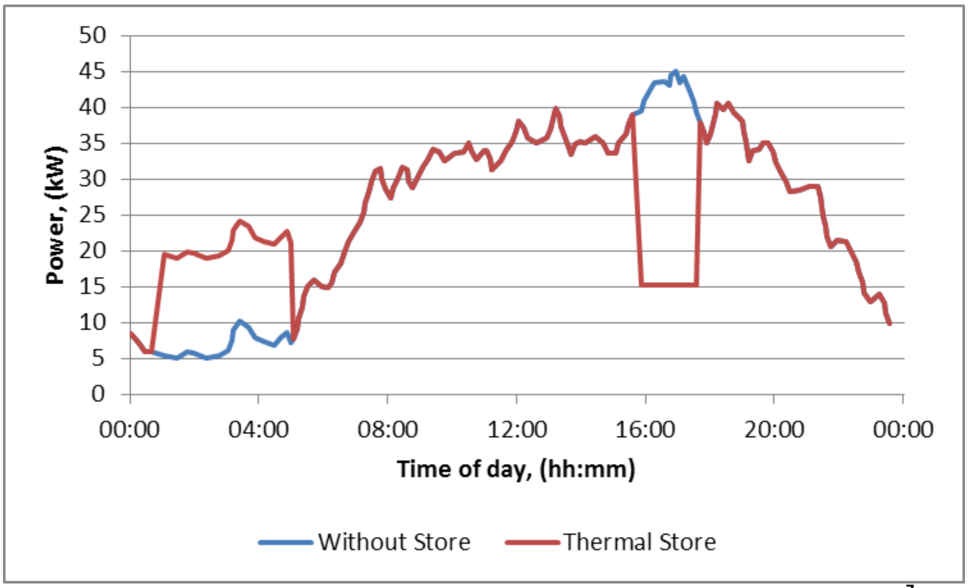


Figure 3.1. After-Diversity Load Profile for 19 Properties, 18 with Heat pumps[7]

3.3 Likelihood of Clustering

Heat pumps are most attractive in off-gas-grids, where the effects of oil price variability have driven customers to investigate alternatives. The relative certainty in electricity price offers somewhat of a haven, especially since the energy required is purchased piecemeal – rather than in bulk as for oil tanks. Social housing providers have driven the installation of heat pumps and as long as the need to provide assistance to those of little means continues, this is likely to continue. Clustering will also continue, because of the need to efficiently convert large numbers of properties. The levels of uptake and clustering of heat pumps will also be

[6] Gledhill, BoilerMate BP Technical Specification, available at www.gledhill.net, accessed October 2011.

[7] S.D. Wilson, Monitoring and Impact of Heat pumps, Strategic Technology Programme, Project S5204_1, October 2010

driven by any incentives that are put in place (such as the Renewable Heat Incentive[8], which is yet to be launched).

3.4 Network Issues

Network issues arise from the conversion of homes which have previously been heated using fuels, to electrically-driven heating via heat pumps. In the case of the properties that supplied data for Figure 3.1, peak load increased by a multiple of 3.75. Heat pump compressors cycle according to the heat requirements of the property. Each time the compressor starts up a surge in current equivalent to many times the normal load current is needed, which, unmitigated, has the potential to cause poor power quality in the area.
The conversion of homes which have been heated using storage heaters is not a problem, due to the decrease in electrical supply capacity required.
It is unclear whether householders/installers should make the DNO aware of their intention to install a heat pump in advance of doing so. The National Terms of Connection[9] Section 2 Part 3 (for LV customers metered directly, i.e. the normal arrangement for domestic customers) states:

> *Network constraints.* Our obligations under this agreement are subject to the maximum capacity and any other design feature of the connection. You must contact us in advance if you propose to make any significant change to the connection or to the electric lines or electrical equipment at the premises, or if you propose to do anything else that could affect our network or if you require alterations to the connection.

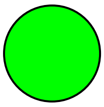
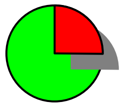
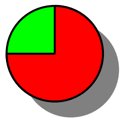
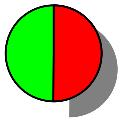
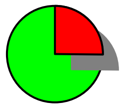
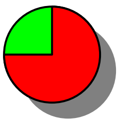
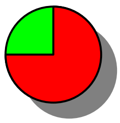
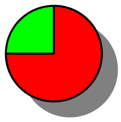
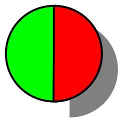
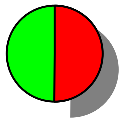
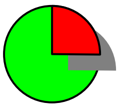
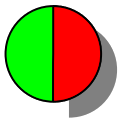
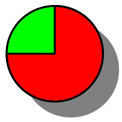
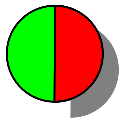
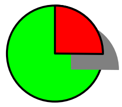
Whether a heat pump constitutes such a change has not been explicitly stated, but at present it has to be assumed for a worst-case scenario that DNOs will not be aware of the additional load caused by heat pumps until after the event of their installation. Along with causing thermal and voltage issues, a cluster of heat pumps can also give rise to flicker effects and can dramatically alter cold-load pickup requirements.

In the example, the addition of a thermal storage element and an inhibition of the heat pump at peak time reduced peak load by 11% (5kW/45kW = 11%).

[8] Renewable Heat Incentive
http://www.decc.gov.uk/en/content/cms/meeting_energy/renewable_ener/incentive/incentive.aspx
accessed 14th October 2011

[9] National Terms of Connection
http://www.energynetworks.info/storage/NTC%20for%20Connection%20Terms%20website.pdf accessed 14th October 2011

3.5 Impact Table

Heat Pumps (Residential)	**Penetration**	**Clustering**	**Thermal Profile**	**Voltage Profile**
Urban			Standard  Storage 	
Rural			Standard  Storage 	
Suburban			Standard  Storage 	

Penetration is biased towards rural, off-gas grid areas. Urban areas tend to have gas and so penetrations should be low.

Clustering – A general high level of heat pump clustering is likely given installations by registered social landlords.

Thermal Profile – the extra load is a concern in areas with previously fuelled-boilers. A small reduction is applied for heat pumps equipped with thermal storage elements and an on/off control around peak time.

Voltage Profile – this is of concern on weak networks for heat pumps which are not equipped with soft-starters and/or if load is already high. Some heat pumps are equipped with an additional heater to be used when temperatures are at their coldest as, without this heater, the heat pump cannot operate efficiently. At times of coldest temperature, demand is likely to be higher and hence this additional demand and associated voltage reduction comes at the worst time from a network perspective as it will exacerbate the worst case conditions.

3.6 Notes

In DECC's 2050 pathways analysis[10], 60-90% of all homes are expected to be driven by heat pumps, by 2050.

[10] See http://www.decc.gov.uk/en/content/cms/tackling/2050/2050.aspx, accessed 05/10/11

4 Heat Pumps (Commercial)

4.1 Description of the Technology

The technology is as described in section 3.1 Heat Pumps (Residential).

Commercial installations of heat pumps have been mostly to cater for air-conditioning load in Heating, Ventilation and Air-Conditioning (HVAC) systems. The HVAC requirements of commercial buildings are designed from the start and heat pumps have not traditionally supplied the heating requirement, because gas has been widely available in business parks, city and commercial centres. Some supplementary use of heat pumps is likely in shops and offices which have had air-conditioning retro-fitted, as some of these units are capable of providing heat as well as cooling.

Like residential application, the main growth area for commercial heat pumps is likely to be in off-gas areas (at least for the near-term), where the high cost and price volatility of heating oil makes electric heating more attractive. There are not likely to be many installations where gas is available. The caveat here is that this is the situation at the time of writing- the RHI has the potential to change the economics of fuelled versus electrically-driven heat pumps. This analysis assumes that new commercial buildings in off-gas-grid areas would use commercial heat pumps rather than oil or electric heating.

Thermal storage could be added to commercial heat pumps as for residential, however it is believed that the effect of such storage on network peak load would be less than for residential application, due to the profile for commercial heating load dropping off as network peak load rises.

4.2 Typical Load Profile

Commercial buildings vary considerably. Compared to the domestic scene, there is sparse information on the empirical performance and employment of heat pumps in the commercial arena. A load profile has been developed based on several assumptions, which have allowed the UK service-sector average energy consumption for heating[11], 30W/m^2, to be related to a Winter's month. Assumptions are: Co-efficient of performance = 3.0, base temperature = 15.5C, average daytime December air temperature = 2.8C and December degree-days = 311[12]. A "Small" office has been defined as 1,000m^2, with "Medium" 5,000m^2 and "Large" 10,000m^2. Heating is required for 12 hours, 06:00 to 18:00, the effects of thermal mass and cooling requirements are neglected. A real profile would change due to many factors. Cycling would also be evident. The profile is presented in Figure 4.2.

[11] MacKay, Sustainable Energy Without the Hot Air, Appendix E, pp298-300, 2009.

[12] CIBSE, Environmental Design, CIBSE Guide A, Table 2.14, October 1999.

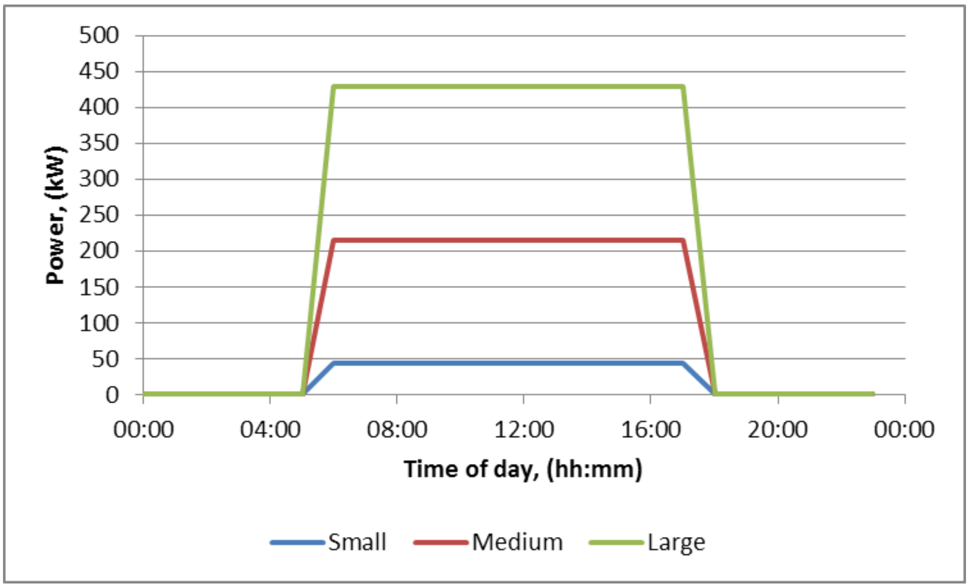


Figure 4.2. Estimated Commercial Heating Profiles

Thermal storage, for the profile presented would not have any effect on the peak load unless the stored energy could be released gradually during the day. Given the relatively large size of thermal stores, even to provide an hour of storage for a small property, it is assessed that few commercial sites would use thermal storage in this way. However, thermal storage does have benefits where air conditioning load is significant, such as in Australia and the USA amongst others. Here, chillers are used to freeze water overnight to reduce daytime peak air-conditioning load. The need for chilling in the UK is assessed as quite rare and hence the capital expense is not believed to be justified.

Even if thermal storage (for heating) was viable, given the profile of Figure 4.1, it would not be useful to mitigate against network peak loads occurring after 17:00.

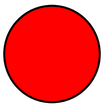
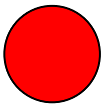
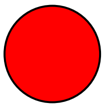
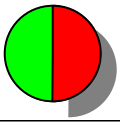
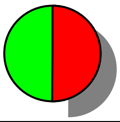
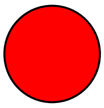
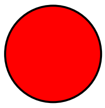
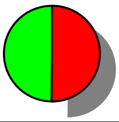
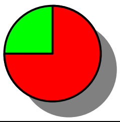
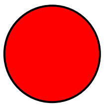
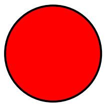
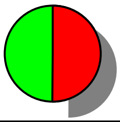
4.3 Likelihood of Clustering

There is a high likelihood of clustering for commercial use of heat pumps around existing commercial centres: village, town and city-centres, business and technology parks.

4.4 Network Issues

Heat pumps are typically powered by induction motors. In residential applications the frequency of starting is a concern for network operators, since these motors draw high currents at start-up. To some extent the high start-up current would be mitigated for commercial applications, since they justify the use of variable-speed drives. The magnitude of the load required is an issue however, especially due to the likelihood of clustering. Heat delivery creates high network load and it seems likely that any significant change from gas to heat pumps for commercial heating would require significant, expensive and time-consuming upgrades to networks

4.5 Impact Table

Heat Pumps (Commercial)	**Penetration**	**Clustering**	**Thermal Profile**	**Voltage Profile**
Urban				
Rural				
Suburban				

Penetration is assessed as being in proportion to the population density.

Clustering is assessed as being highly likely in all locations.

Load profiles will be significantly changed, because of the high magnitude of heating loads compared to all others.

The expected mitigation of starting currents by variable-speed drives should mitigate voltage impact, however the increase in electrical network load itself is likely to have a severe impact on voltage profiles unless a high level of reinforcement is undertaken.

5 Electric Vehicles (Residential)

5.1 Description of the Technology

Electrification-of-transport is an integral and fundamental part of the government's Low Carbon Transition Plan[13]. Electric vehicle (EV) technology comprises pure-electric, parallel- and series-hybrids. Pure-electric vehicles require reasonable range to be achievable; ranges around 100 miles are necessary to reduce range anxiety and relatively large quantities of overnight charging are to be expected. Parallel hybrids effectively use the electric motor to boost torque and enable regenerative braking, allowing for the downsizing of the internal combustion engine. Series hybrids are electrically-driven, requiring a full-size electric motor and battery combination capable of delivering and absorbing high peak powers under acceleration and braking, receiving top-up energy and creating range-extension using a small internal combustion engine. All major manufacturers are developing electric vehicles and those quoted below are for example purposes only.

[13] DECC, The UK Low Carbon Transition Plan, July 2009

Charging can be accomplished from standard 240V sockets at 10A[14] or via a dedicated circuit from a consumer unit at higher rates. A full charge of the Vauxhall Ampera series hybrid, 10.4 kWh is reputed to deliver an electric range of >25 miles, which would be delivered in a 4 hour charge window. A full charge of the pure-electric Mitsubishi MiEV is 16 kWh which is reputed to deliver a range of 90 mi. This amount of charge would be delivered over a 7 hour charge window.

Vehicle-to-Grid (V2G) technology, whilst not yet available, holds promise for the future. The need for this will be driven by the decrease in central generating stations (with large synchronous machines) which currently provide frequency response and reactive power services, as the amount of distributed generation increases. V2G requires EVs to be fitted with bidirectional converters, capable of discharging the batteries onto the grid at times of need. V2G requires control of fleets of electric vehicle chargers and will result in energy transfers across LV networks that are not present today.

5.2 Typical Load Profile

Daily mileage in the Technology Strategy Board's Ultra Low Carbon Vehicle Demonstrator (ULCVD) Programme[15] was an average of 24 miles for private drivers, requiring a charge window of just over 4 hours. A range of charge currents are possible from 10A (domestic 240V socket), 16A (dedicated charge socket) and 32A (high-rate charge) sockets. Figure 5.1 presents the charge power and duration required for these charge currents, from a single property choosing to charge on an Economy 7 tariff with charge-start-time at 23:00.

Figure 5.2 presents an estimated profile, using the distribution of charge start-times experienced in the ULCV, assuming an average journey length of 24 miles and an equal mix of 10A, 16A and 32A charging sockets. This profile presents the average power of a large number of EVs.

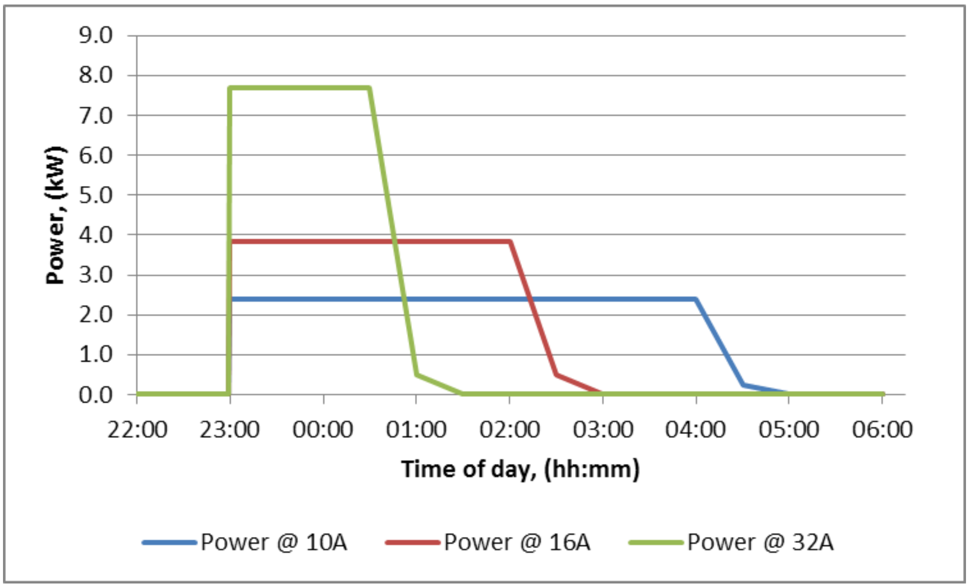


Figure 5.1. Estimated Charge Profile (Off peak, Single Property)

[14] www.chargemasterplc.com, accessed 03/10/11

[15] TSB, Ultra-Low Carbon Vehicles Demonstrator Programme, Initial Findings, 2011

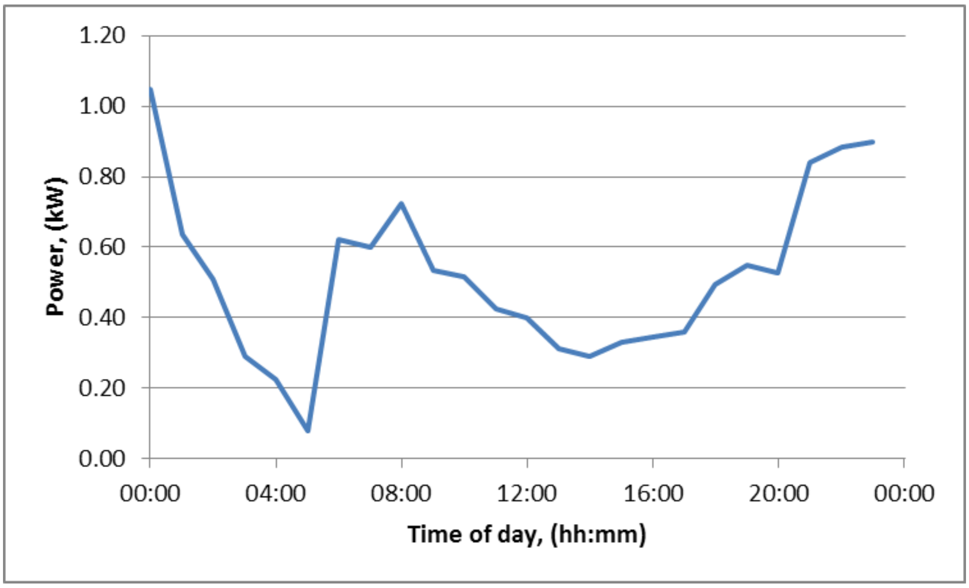


Figure 5.2. Estimated After-Diversity Charge Profile for a Residential EV (ULCVD Charge Start-Times)

5.3 Likelihood of Clustering

The purchase price of a Mitsubishi MiEV is around £23k (taking into account the Governments £5k allowance). Due to the high purchase price compared to internal-combustion-driven vehicles, they are likely to be purchased by the affluent and those with high disposable incomes. The characteristics of the second-hand market are hard to judge, since the batteries lose performance over time and battery renewal cost is a significant proportion of the as-new purchase price, 30% being generally accepted.

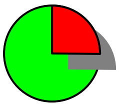
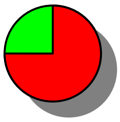
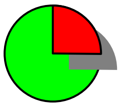
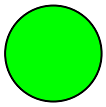
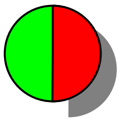
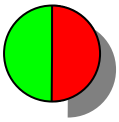
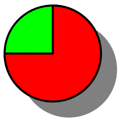
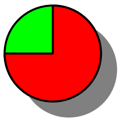
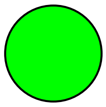
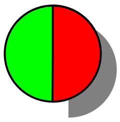
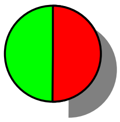
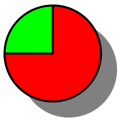
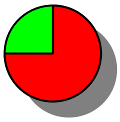
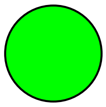
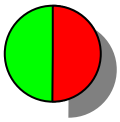
Clustering of EVs is likely in rural, affluent neighbourhoods and in expensive urban locations, though a fair proportion of the latter will likely be charged in car-parks. Exemption from congestion charges means that affluent suburbs around major cities could also experience EV clusters.

5.4 Network Issues

The main issue arises from the increase in power required to charge the vehicles around the time of network peak load, which occurs at approximately 18:00. From Figure 5., it can be seen that on average, an extra 0.5 kW per property is required. Network issues are compounded if EVs and other new loads such as heat pumps are used at the same time – both require power at peak times. The chargers comprise power electronics and hence should not create voltage problems.

Given the high purchase price of an EV and that one is likely to be bought in advance of any consideration of electric supply capacity; there is quite a high likelihood that a proportion of EVs will be connected without the prior knowledge of a network operator. It is therefore likely that EV-related loads would be higher than load estimates that have been derived from consideration of connection requests. It is also likely that a network operator, for fear of damage to their low-carbon reputation, would have to allow connection for retrospective applications.

5.5 Impact Table

EVs (Residential)	**Penetration**	**Clustering**	**Thermal Profile**	**Voltage Profile**	
				Standard	V2G
Urban					
				Standard	V2G
Rural					
				Standard	V2G
Suburban					

Penetration – EVs are unlikely to take off in mainstream application until the total cost of ownership of a combustion-engined car approaches parity. This does not seem to be likely any time soon, so penetration is generally low but with a bias towards Rural and Suburban affluent locations.

Clustering – Generally high as described.

Thermal Profile – Urban centres with strong networks and high load density should have spare capacity available, especially for overnight charging.

Voltage Profile – Since they are connected via power converters, voltage step-change should not be a problem. Overnight trickle-charging should be sufficient for most applications and the use of very fast-chargers should be quite rare. V2G technology could have quite a large impact on the voltage profile at times when balancing power is required and the upper voltage limit would be a concern at times of low network load around clusters.

5.6 Notes

Charge control is via power electronic converters located in the vehicle or in fast-charge points. These converters would be the largest (in terms of capacity) that exist in typical properties, drawing harmonic current and reactive power that is not the ordinary loading state of housing estate networks.

6 Electric Vehicles (Car Parks)

6.1 Description of the Technology

The technology is as described in section 5.1 Electric Vehicles (Residential).

Given the reduced range of EVs compared to internal-combustion engine vehicles, there is a perceived need to provide “opportunity-charging” by the provision of EV charging points in car parks and suchlike. Today, these are likely to be a small number of LV-connected points in supermarkets. When or if EVs become mainstream, these would proliferate and require an increase in connection capacity. The scenario and load profile then becomes quite similar to fleet-type operations, where opportunity-charging is accomplished by day, with longer charges overnight.

V2G technology is assessed as having a lesser impact on car-park charging networks than for residential or fleet use, because the amount of time that EVs are plugged-in and available will be less, on average. In the supermarket scenario, charge time of a half-hour would not cover a full settlement period. Car parks under residential flats will have this capability.

6.2 Typical Profile

It is assumed that a typical charge profile for car-parks would be similar to that of fleet operators since both would be return-to-base journeys, but there would be little charging before the start of the working day at a car park. The same ULCVD[16] charge start-times are therefore used for car-park charging as for fleet use, but with two differences. The first difference is that these are delayed by 3 hours so that very little charging takes place before 08:00 and the second is that the amount of charge required to be delivered is halved. The latter is to reflect the scenario whereby an EV driver travels to a city centre to work each day, car-park charging during the day, residential-charging during the night, with a 50% split between energy delivered at the car-park and home.

[16] TSB, Ultra-Low Carbon Vehicles Demonstrator Programme, Initial Findings, 2011

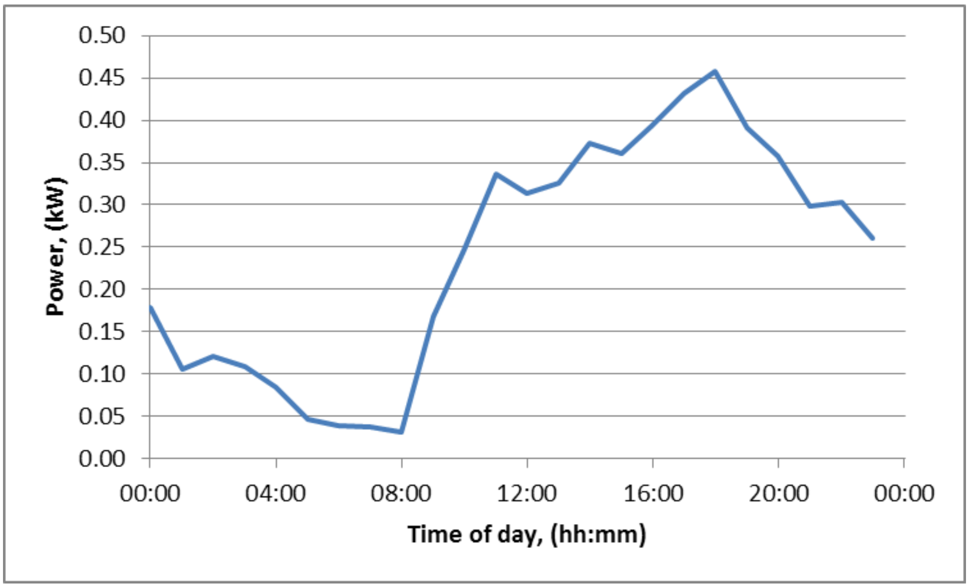


Figure 6.1. Estimated After-Diversity Charge Profile for a Car Park (ULCVD Charge Start-Times)

Where very fast charging is desired, a new connection is needed. The Mitsubishi MiEV is stated to be fast-chargeable to 80% of full capacity in 30 minutes[17], which requires 32 kW. The rate of energy delivery is about ten times that of a residential charge but the aggregated profile from many vehicles (e.g. 100) would not be different to that of Figure 6.1. The difference is that the vehicles would be charged in a shorter time – as little as 5 minutes for a 10 mile top-up charge, creating a 'peaky' energy delivery scenario.

6.3 Likelihood of Clustering

There is a high likelihood of clustering at supermarkets (keen to be seen as green to attract customers), city-centre car-parks (for opportunity-charging), on streets in central business districts (for opportunity-charging), around suburban offices and depots.

6.4 Network Issues

While car-park charging points are relatively few in number, the increased electrical load will be small compared to the supply capacity. Network operators will not necessarily learn of these installations in advance as they will utilise existing connections. If the number of points used significantly increases, then new connections will need to be negotiated and given multiple concurrent fast-charges at 32 kW then an HV connection is likely to be required. In this case the DNO would have prior knowledge of installation.

6.5 Impact Table

EVs (Car Park)	**Penetration**	**Clustering**	**Thermal Profile**	**Voltage Profile**

[17] http://www.mitsubishi-cars.co.uk/imiev/technology.aspx, accessed 04/10/11

Urban				Standard Fast Charge V2G
Rural				Standard Fast Charge V2G
Suburban				Standard Fast Charge V2G

Penetration – All classed with equal penetrations since business parks, distribution centres and shopping centres do not concentrate in any one category.

Clustering – By the nature of car-park charging, a high level of clustering is to be expected.

Thermal and voltage profile – due to the existing large loads at sites with car parks (offices, supermarkets, industry), the extra load due to EVs will be relatively small. As they are connected via power converters, they should soft-start and stop and not cause significant voltage step-changes.

6.6 Notes

Charge control is via power electronic converters located in the vehicle or in fast-charge points. In the case of fast-charge points, the size of these converters is equivalent to a relatively large variable-speed drive. The harmonics and reactive power requirements would therefore not be as different to the normal situation in industrial areas as they would be in residential areas.

7 MicroCHP (µCHP)

7.1 Description of the Technology

µCHP technologies are replacements for standard domestic boilers that generate electricity at the same time as providing heat. Whereas the heat in a typical fuelled electricity generator is dumped to the atmosphere, in µCHP this is reclaimed via a heat-exchanger to a return fluid from a central heating system or hot water store. Heating and hot water can thus be provided. µCHP is environmentally more advantageous than separate boilers and electrical generation plant because there is less energy wasted. Operators of µCHP systems can earn revenue for their electricity generation under the Feed-in-Tariff, offsetting to an extent the cost of purchasing fuel for heating and hot water.
µCHP technologies consist of: Stirling-cycle engines (heating and cooling a working fluid to provide a pressure differential for engine-power), Rankine-cycle engines (evaporating and

condensing a working fluid to provide a pressure differential for engine-power), fuel-cells (combining fuel and oxygen in a fuel cell to generate electricity directly) and internal combustion engines.

Electrical output power for a Stirling engine is typically 1 kW – all those registered under the Feed-in-Tariff during 2010 were 1 kW[18]. Output from a Rankine-cycle is also around 1 kW[19]. Internal combustion engines and fuel cells come in a range of sizes from 1 kW upwards. The Baxi Dachs is a typical small-commercial/residential internal-combustion engine unit of 5.5 kW[20]. Only Stirling engine types appear on the UK market at the time of writing.

A mix of generating technologies is employed: Stirling engines use induction generators or power electronic inverters, Rankine engines also; fuel cells are connected using power electronic inverters.

7.2 Typical Profile

Figure 7.1 presents an average profile collected from a selection of the 87 sites which formed part of the Carbon Trust's Micro-CHP Accelerator trial[21], conducted during 2007. The profile shows that electrical generation tends to mirror that of demand, effectively mitigating the problem that is evident for PV installations. As a consequence the profiled generation output from a domestic property is low – the maximum export is only a quarter of the electrical rating at 0.25 kW.

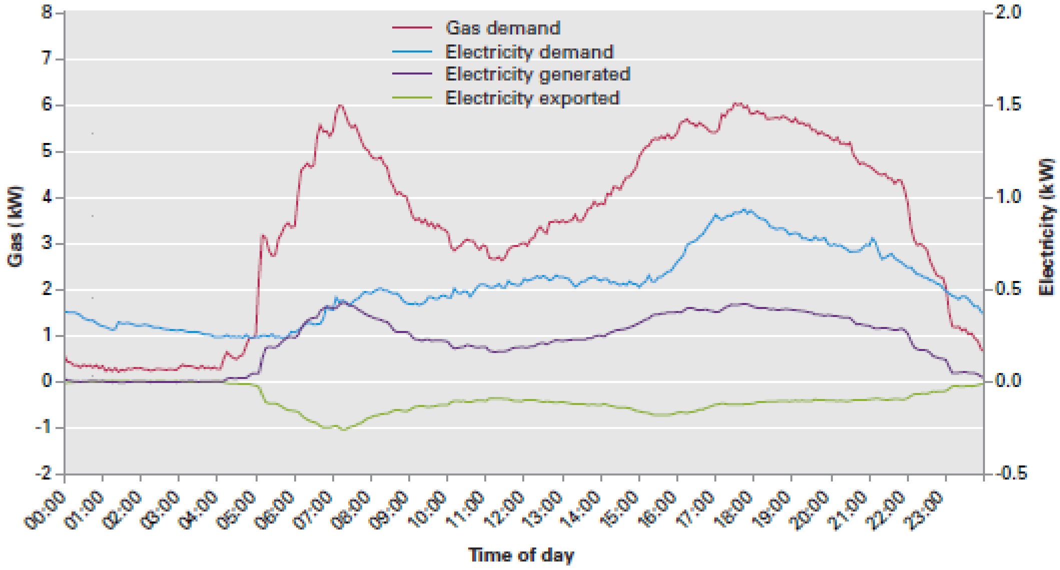


Figure 7.1. A Winter Month After-Diversity Profile for Thermally-Led µCHP

[18] Ofgem, Feed-in-Tariff Installation Report 30 September (.xls), available at www.ofgem.gov.uk, accessed 13/10/11

[19] See www.energetix.co.uk, accessed 03/10/11

[20] See www.baxi.co.uk/products/dachs.htm

[21] Carbon Trust, Micro-CHP Accelerator- Interim Report, November 2007, available at www.carbontrust.co.uk, accessed 02/10/11

7.3 Likelihood of Clustering

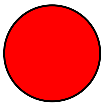
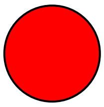
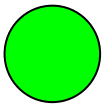
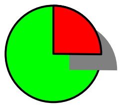
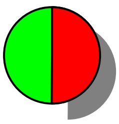
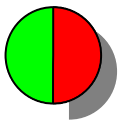
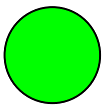
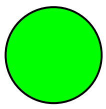
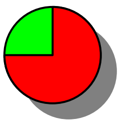
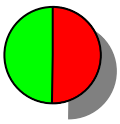
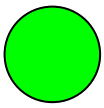
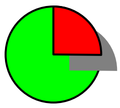
To date the technology has not reached mainstream application and so the geographical spread of installations is biased towards trials and early-stage applications of the technologies. There are examples of installations in clusters, the largest such being 54 Stirling-engines in a new housing estate in East Manchester[22]. Despite the large size of cluster, export from the network supplying the µCHP engines was extremely rare. Whilst it has been the case that µCHP has been exclusively installed in areas on the gas-grid, one modern type can run on LPG and thus installations and clusters could be present in rural and urban environments. When µCHP are closer to the market, the same sources of funding that are driving the installation of heat pumps by registered social landlords can be similarly used to install µCHP.

7.4 Network Issues

As µCHP profiles tend to mirror those of domestic electrical load, their effect is to reduce that load rather than cause export through the distribution transformer, hence voltage headroom is not as much of a concern as for other generating technologies. The early-morning start-up period is when net generation would be highest. They are also equipped with auxiliary burners. This means that in the event of high network voltages (that would cause the generator to trip) the system can continue to supply heat to a property. Where the µCHP engine uses an induction generator, small voltage step-changes may be evident when the induction generator is used as a starter motor.

Because µCHP is a generation technology, there is a requirement for an installer to notify the network operator. The network operator must effectively "connect and manage" and all installations must meet the requirements of Engineering Recommendation G83[23]. Having said this, there are examples of small-scale generation being installed without notification being made.

7.5 Impact Table

MicroCHP	**Penetration**	**Clustering**	**Thermal Profile**	**Voltage Profile**
Urban				
Rural				
Suburban				

[22] S. Wilson, Project Report for LV Monitoring of Lovell's Microgenerator Cluster, Report No. 6225, June 2008.

[23] Available from the Energy Networks Association, details can be found at http://2010.energynetworks.org/distributed-generation/

Penetration – highest in urban networks with gas grids, lesser so in suburban and rural where there is a higher proportion of off-gas-grid homes.

Clustering – likely in urban housing estates where social landlords are investing, lesser so in other locations where homeowners make their purchases.

Thermal Profile – reduces load, does not cause an impact.

Voltage Profile – export is low as described, so there will be little voltage impact.

7.6 Notes

The above assumes that µCHP are thermally-led, that is, driven by a home heating system. The primary role of the µCHP boiler is to fulfil the heating requirement of a property. µCHP can also be electricity-led, that is, driven by the need to provide generation. In this mode large numbers are operated and aggregated together to create a Virtual Power Station (VPP). Electrically-led operation is a serious consideration for fuel cells which (dependent on type) are often most suited to continuous running (a need to keep the fuel cells hot).
If units are supplied with VPP software and communications then the extra cost is minimal compared to overall cost.

8 Small Scale Wind Generation

8.1 Description of the Technology

Wind turbines comprise a number of blades angled to the wind and shaped to transform the passage of air into mechanical energy. This is converted through an electrical generator into either AC or DC. Larger wind turbines comprise AC generators, usually based on a type of induction generator, but increasingly utilising the higher efficiencies of permanent-magnet machines. In large wind turbines a power converter provides control over the speed of the blades and generating characteristics. The small-scale wind turbines considered here range in size from 1 kW (Zephyr Airdolphin[24]) to 14 kW (Proven 35[25]). Very small wind turbines designed for mounting on buildings have been termed micro-wind, these were rated 0.4kW – 1.25 kW and were largely shown to have poor performance in the Warwick Wind Trials[26] with an average capacity factor of just 0.85%.

The small-scale wind turbines considered here are regarded to have been installed in sites with a reasonable average wind speed. Wind data for the following analyses has been obtained from a site located at Chevin End, where airflow was clear and from a height of

[24] www.zephyr.co.jp, accessed 04/10/11

[25] www.proven.com, accessed 04/10/11

[26] Encraft, Warwick Wind Trials, Final Report, 2009

approximately 8m, for the month of April. Typical power outputs have been estimated by the application of the manufacturer's power curve from a "Proven 11", 6 kW-rated wind turbine[27].

8.2 Typical Profile

In the UK, there is not a typical daily profile for wind generation, but wind variation does follow certain characteristics. For the purpose of determining the duty and requirements on networks, it is this variation in power that is important. Note that the data collected was 10-minutely and thus provides details of wind variations of time periods of 20-minutes and greater, see Figure 8.1. The theoretical form of wind variation is presented in Figure 8.2. By reference to Figure 8.1 it can be seen that the maximum 20-minute variation is about 0.2 kW and that in this region, variation increases as the time period is reduced.

To represent the addition of variations over the course of a day, seven days of estimated power output are presented in Figure 8..3 with each day's profile being represented by a different coloured line. Characteristics of aggregated wind generation across several sites are likely to depend to a large extent upon local geography.

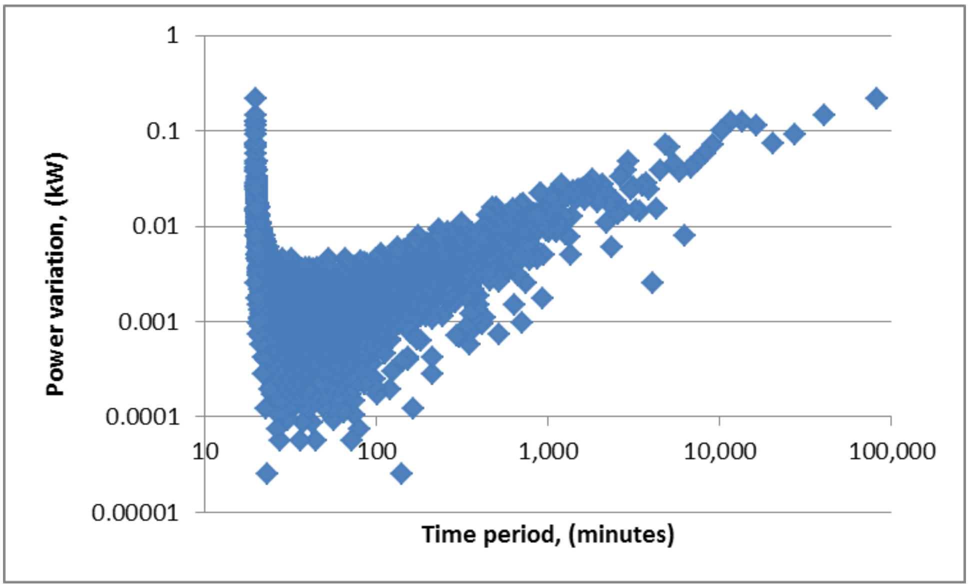


Figure 8.1. Time Periods and Magnitudes of Small-Scale Wind Power Deviation (Single-site)

[27] www.bettergeneration.com, accessed 05/10/11

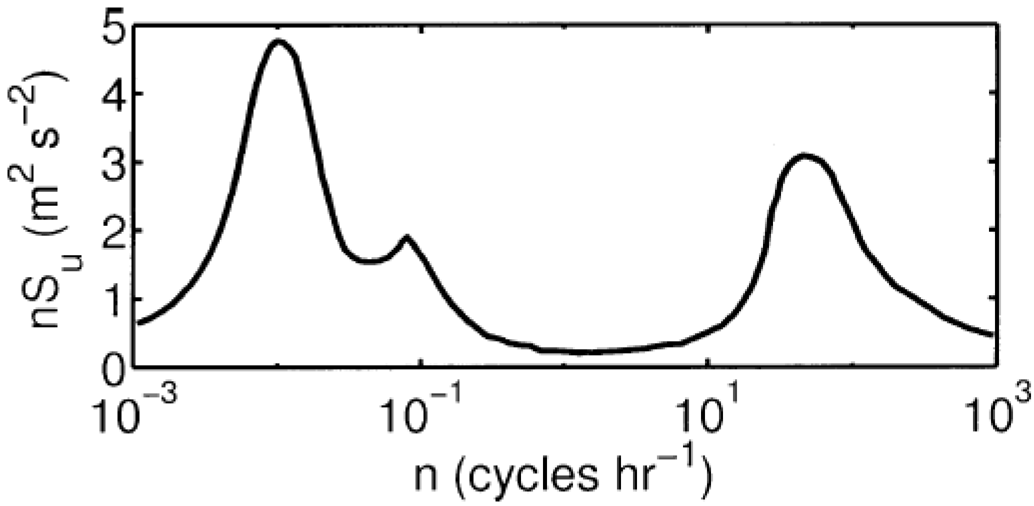


Figure 8.2. Time Periods and Magnitudes of Wind Deviation (Van Der Hoven)[28]

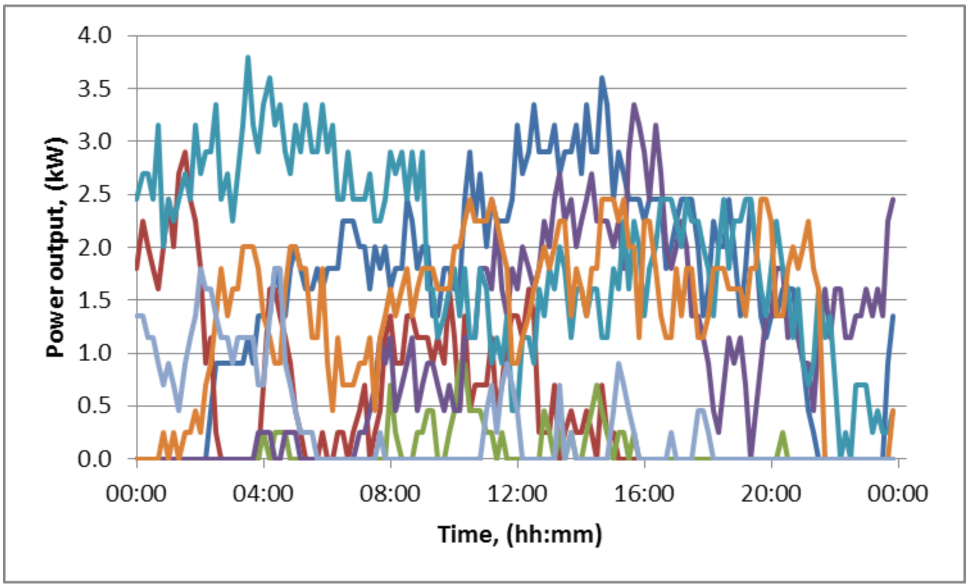


Figure 8.3. Power Output Variation for Seven April Days (Single-site)

8.3 Likelihood of Clustering

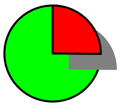
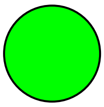
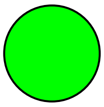
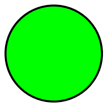
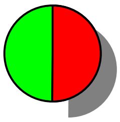
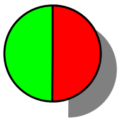
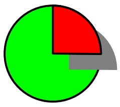
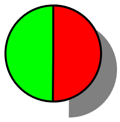
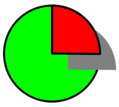
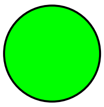
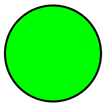
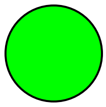
All wind turbines generate an amount of noise in operation and require free airflow surrounding them, for good/economical performance. This severely limits their application in built-up areas, as evidenced from the results of the Warwick Wind Trials. Hence, they are more likely to be deployed in rural areas, farms with good wind characteristics, near the crests of hills, etc. In these areas, the size of local geographical features and ownership boundaries define the size of clusters. In the near future, due to the capital cost of approx. £25k for installation, clustering within ownership boundaries will be quite limited. High densities of LV-connected small-scale wind generation, as possible for PV are not likely.

[28] Van der Hoven, I., 1957: Power spectrum of horizontal wind speed in the frequency range from 0.0007 to 900 cycles per hour. *J.Meteor.,* **14,** 160–164.

8.4 Network Issues

Issues around wind generation are related to the voltage rise and intermittency of wind generation. Small-scale wind, in the order of 1-10 kW as assessed here, will be LV-connected mainly in rural networks. In these areas, voltage rise from generation can be a concern due to higher system impedance, there is also the potential for flicker to be created. A householder wishing to connect a wind turbine should apply to the network operator in advance of the connection, there is a legal obligation to inform the network operator either before or at the time of commissioning for those of <16A per-phase. For greater than 16A per-phase, connection requirements must be agreed in advance.

8.5 Impact Table

Small scale wind	**Penetration**	**Clustering**	**Thermal Profile**	**Voltage Profile**
Urban				
Rural				
Suburban				

9 Distributed Generation (DG)

In this section we consider distributed generation between 100kW and 100MW, with a connection to either the 11kV, 33kV or 132kV network. The voltage level to which generation is connected will largely depend on the size of the generation, and the ratings of the associated assets at each voltage:

- Under 5MW is generally connected at 11kV.
- Between 5-20MW is connected at 33kV.

- Above 20MW is normally connected at 132kV.

The exceptions may be where the network is very weak and generators with capacities smaller than these thresholds have to be connected to a higher voltage.

Generation at 11kV or 33kV is generally connected according to Engineering Recommendation G59. At 50MW or above generators must comply with the more onerous criteria as laid out in the GB Grid Code. These vary according to technology and size but result in much more complex control than installed with smaller generators.

We will consider distributed generation from the following technologies:

- Large-scale onshore wind
- Small site wind
- Biomass

9.1 Large-scale onshore wind power

This section considers onshore wind farms with sufficient capacity to connect to 33kV or 132kV networks (e.g. from 5MW to 250MW) .

Most large-scale wind generators are variable speed doubly fed induction generators. Older units can be squirrel cage induction generators that cannot control reactive power however there are few farms connected to the 33kV network with this technology.

9.1.1 Penetration

Wind generation is likely to make a major contribution to decarbonisation, with over 28 GW expected to be on line by 2020, in order to meet Government's 2020 renewable target[29].

According to RenewablesUK (November 2011) there are 296 operational on shore wind farms with a capacity of circa 4 240 MW. Whilst these figures cover connections to all voltage levels, a significant number are connected to either the 33kV or 132kV networks.

Over 50% of the capacity is in Scotland. In addition over 5GW is consented or under construction.This is expected to continue into the foreseeable future with over 7GW in planning. These figures include small site wind but this is a small proportion of the total capacity

9.1.2 Load profiles

Wind is stochastic and therefore generation will vary from one day to the next. The frequency of fluctuations of different length has a defined pattern as indicated by the Van der Hoven spectrum. This demonstrates that there are significant fluctuations

[29] DECC (2010) National Renewable Energy Action Plan, http://www.decc.gov.uk/assets/decc/what%20we%20do/uk%20energy%20supply/energy%20mix/renewable%20energy/ored/25-nat-ren-energy-action-plan.pdf

due to seasonal variations (winter wind speeds are higher than summer wind speeds in general). There is then a second peak due to diurnal variation (differences between day and night) and a third due to turbulence of the order of 10 minutes or less.

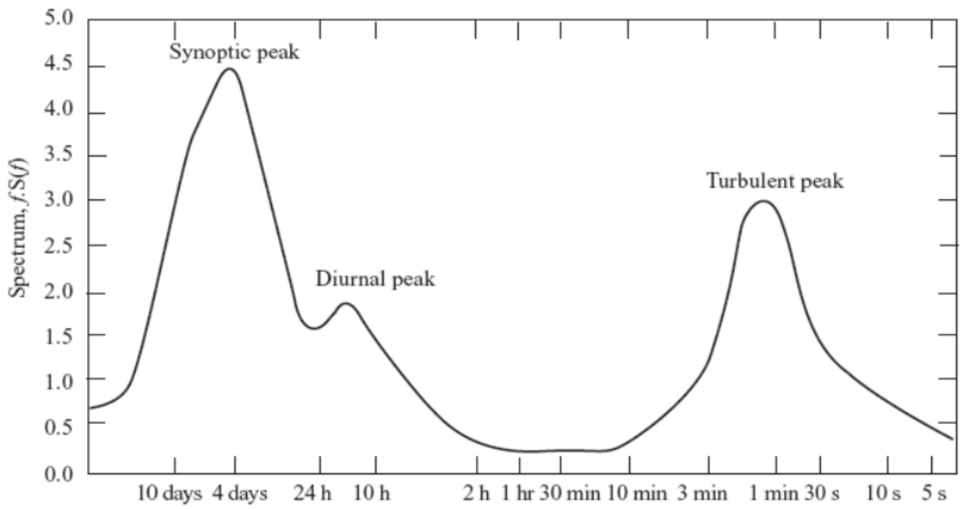


Figure 9.1 Van der Hoven Frequency Spectrum of Wind Speed Variation (source EA Technology)

9.1.3 Network issues and smart grid value

Issues around wind generation are related to the voltage rise and intermittent nature of wind generation.

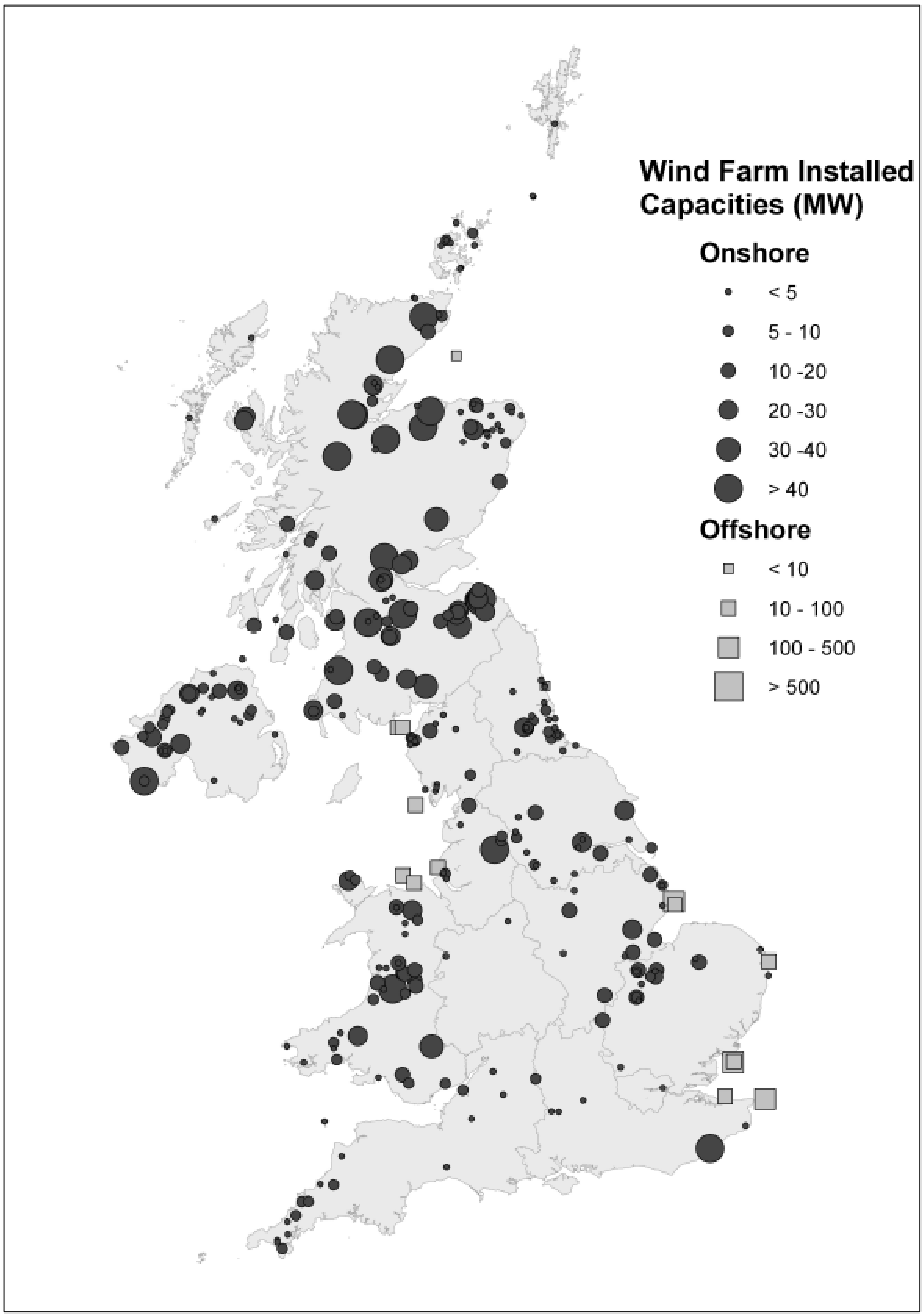
- Voltage rise is particularly a problem as generators are often sited in areas of weak networks with high impedance.
- The fluctuations in output can cause power quality problems and make matching demand and generation more difficult, although larger wind farms will generally have a smoother output.
- As the wind capacity grows in the UK, there will be a greater need for fault ride through capability so that it can provide firm power and more storage to smooth the power flow.

9.1.4 Clustering

Clustering of wind farms is likely as they locate in areas of high average wind speed, where energy yield is greatest. For GB there is a focus in the north of England, East Anglia, Scotland and Wales. Turbines are often in rural areas of electrically weak networks and low population.

We assume that this clustering effect will be the case for future deployments of large scale onshore wind.

The Location of Wind Farms in the United Kingdom, as at 31 December 2010.



From DUKES 2011 Chapter 7

9.2 Small site wind power

We are defining small site wind farms and turbines as those which are small enough capacity to connect to the 11kV network (e.g. between 500kW and 5MW). These may be community projects or situated by shopping centres, industrial parks etc.

Community projects are often sited on open ground in rural areas although the locations may be closer to areas of population than large windfarms. Installations near industrial or commercial centres are often closer to centres of population where the wind speeds are lower. Older units and smaller turbines tend to be fixed speed generators. Older units can be squirrel cage induction generators that cannot control reactive power.

9.2.1 Penetration

It is unclear what proportion of the present total wind capacity is from small-site wind (see large scale wind for the total capacity). While large-scale wind will tend to be more economic, the drive to meet the Government's 2020 renewable target is likely to involve the deployment of wind at some smaller sites.

9.2.2 Load profiles

As large scale wind.

9.2.3 Network issues and smart grid value

Issues around wind generation are related to the voltage rise and intermittent nature of wind generation.

- Voltage rise is particularly a problem as generators are often sited in areas of weak networks with high impedance. Whilst small-site wind may be located closer to centres of population where the network may be more robust, the fact that they are small in size means that additional assets to control voltage is harder to fund. Installation may therefore resort to cruder measure such as running at a lower power factor to prevent excessive voltage rise.
- The fluctuations in output can cause power quality problems and make matching demand and generation more difficult. Power quality can be more of a problem for small-site wind farms than large farms as load is situated closer to the generation. Fluctuations in output from small wind farms are greater that large wind farms due to less smoothing because:
    - The spatial separation of the turbines and number of turbines is smaller.
    - Each turbine is closer to the ground where turbulence is greater and has a smaller blade diameter.
- As the wind capacity grows in the UK, there will be a greater need for fault ride through capability so that it can provide firm power and more storage to smooth the power flow.

9.2.4 Clustering

The north of England, East Anglia, Scotland and Wales where the wind speed are highest and therefore obvious areas of focus however communities and companies across the country do and are likely to continue developing small-site wind.

9.3 Biomass generation

Biomass is any form of generation that uses an organic replenish-able material as fuel. This could be:

- Organic waste.
- Agricultural waste.
- Waste wood.
- Purpose grown wood or biocrops.
- Landfill gas.

Generation can be electricity only or combined heat and power (CHP). Technologies are:

- Direct combustion.
- Anaerobic digestion (AD) with a gas generator.
- Pyrolysis with a gas generator.

9.3.1 Penetration

The penetration of biomass generation capacity is likely to increase to reach more than 4GW by 2020 from less than 2GW today[30]

- There is a significant number of land fill gas generators in the UK, often using gas from landfill of old quarries or open cast mines. According to DUKES, in 2010 there was just over 1 GW of capacity . However, efforts to reduce waste going to landfill means that this capacity is likely to decline.
- There are 25 domestic waste incinerators located on the outskirts of cities (DUKES Chapter 7 2010). Smaller plants deal with waste from the food industry and sewage sludge. The sites range from a few megawatts to the largest which is 51MW.
- AD has yet to take off in the UK compared to the rest of Europe where it is often used to manage agricultural waste. Some direct incinerators take particular types of waste such as chicken litter.
- There are increasing numbers of biomass CHP plants using wood that is too poor quality for timber or purpose grown biocrops. The size is limited to a few megawatts as the supply chains for fuel often becomes non-viable above this threshold unless it is on site or domestic waste. Notable exceptions are a 32 MW and a 44MW wood burning schemes and a 40MW plant fuelled from straw (DUKES Chapter 7 2010).
- According to DUKES chapter 7, there was 189MW of capacity using sewage sludge, 435MW powered from waste combustion, 139MW using animal biomass and 309MW fuelled from plant biomass.

9.3.2 Load profiles

Most electricity led generation will be operating at full capacity and have a flat output.

[30] DECC (2010) National Renewable Energy Action Plan, http://www.decc.gov.uk/assets/decc/what%20we%20do/uk%20energy%20supply/energy%20mix/renewable%20energy/ored/25-nat-ren-energy-action-plan.pdf

Landfill gas will be dependant on the gas from the ground and can fluctuate. CHP may be heat led and dependant on heat demand, this may be seasonal or mainly during the day. Heat demand such as swimming pools and industrial uses will be more constant.

9.3.3 Network issues and smart grid value

Biomass generation will normally have a relatively flat output similar to conventional power plants and therefore not cause the power quality issues associated with wind.

As with all distributed generation it will cause voltage rise, and as a result, small plant may operate at a low power factor as more sophisticated voltage control mechanisms are economically unviable. As the fuel is controllable, most biomass plants can be scheduled if desired although this may be uneconomic for small plants. The exceptions are those plants that are heat led or landfill gas where the fuel source is not controlled (unless buffer storage is used).

9.3.4 Clustering

The location of plant will depend on the source of the fuel and heat demand. Given the range of the fuel sources and heat demand, locations can be in urban or rural environments and therefore there is no obvious clustering. If heat networks are developed there may be more plants in urban areas.

The vast majority of units will be connected at 11kV. The exceptions being large energy from waste plants and biomass plants with capacities above 5MW that connect at 33kV.

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