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Vehicle-to-Grid (V2G) Communications

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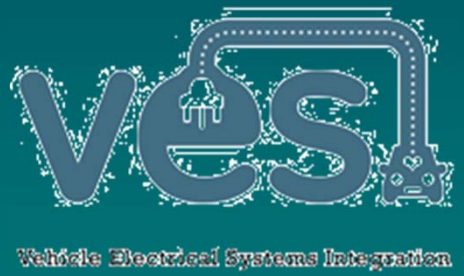

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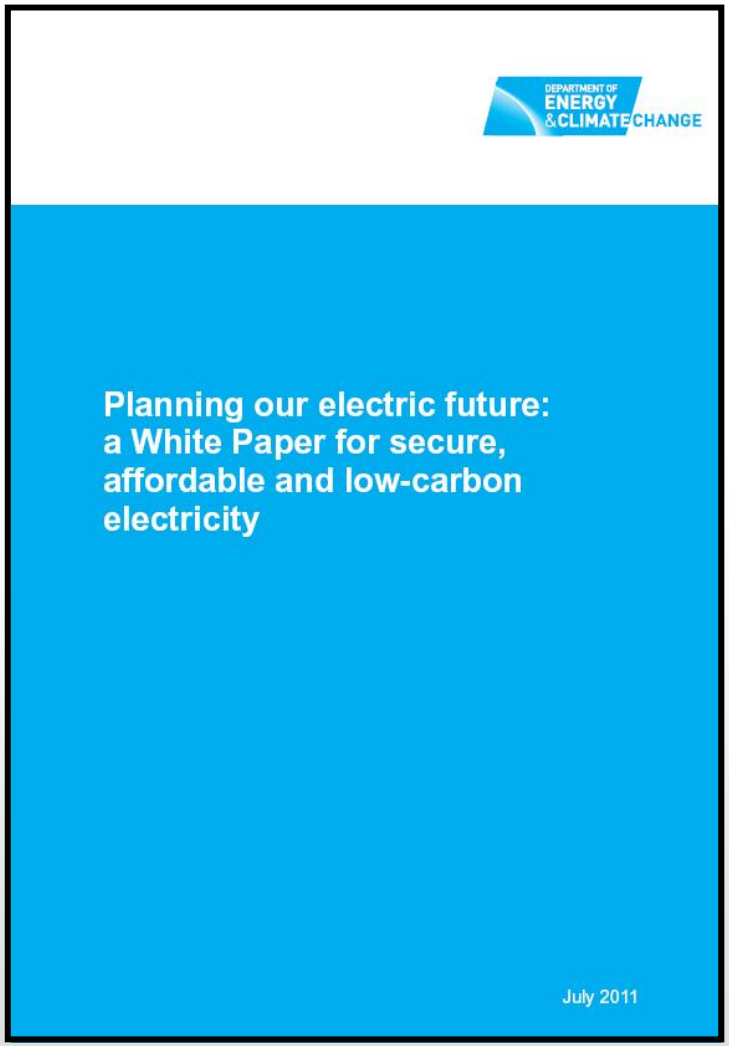
Overview

- **The need for grid-scale electrical energy storage**
- **Concept of Vehicle-to-Grid (V2G)**
- **EV batteries**
- **Overview of V2G communications**
- **Author's activity in V2G comms**
- **Summary**

Background & Context

- Over 25% of generation shutting down over next 10 years
- Over £110bn investment needed for new generation and grid infrastructure
- Electricity demand set to double by 2050



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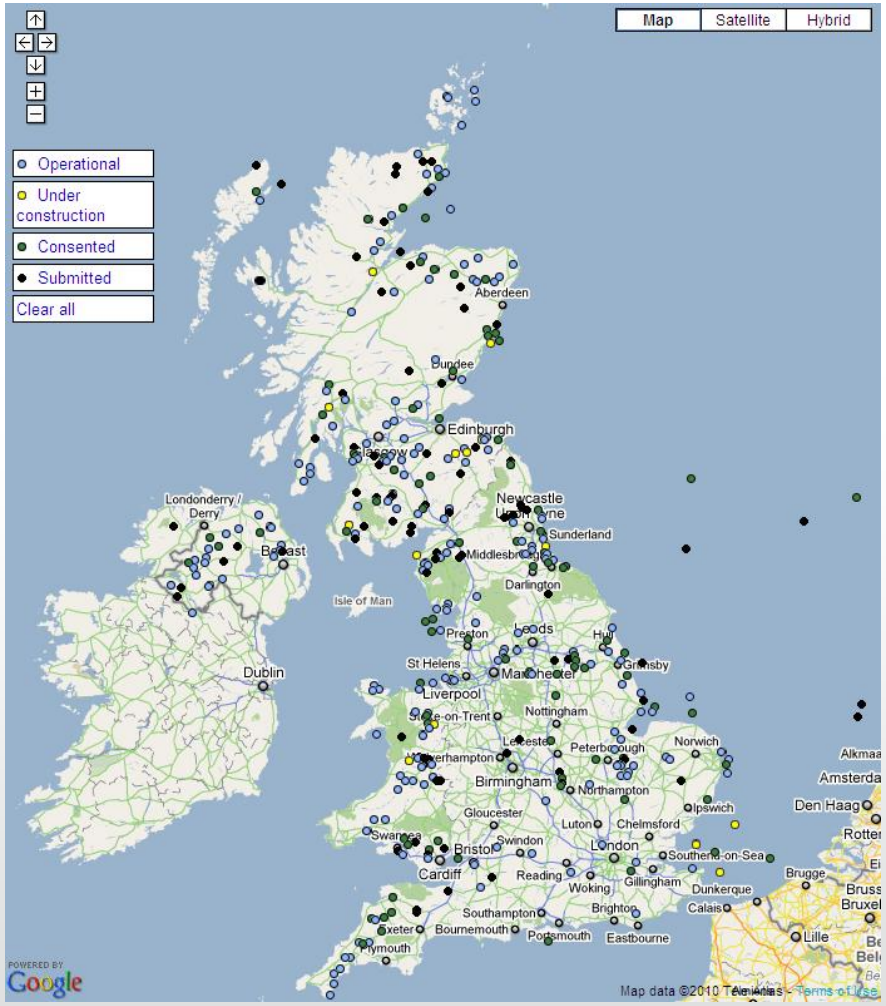
Grid Infrastructure - Background



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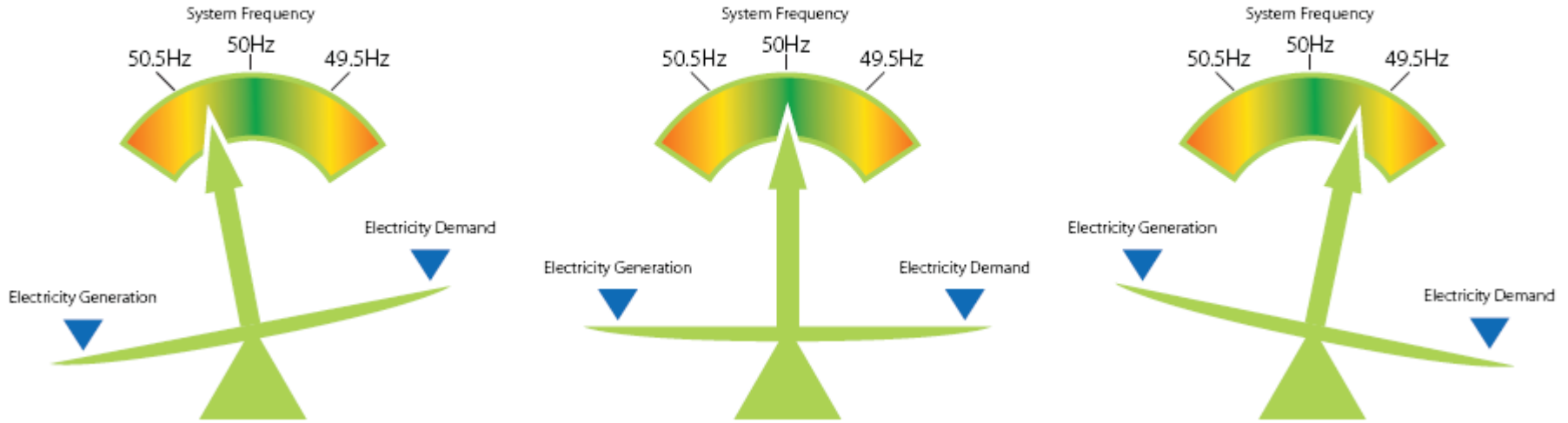
Grid System Frequency Control

Supply and Demand Balancing



- National Grid has transmission licence obligation to maintain the system frequency to 50Hz ±1% i.e. 50Hz ±0.5Hz
- Grid balancing represented a £270m market in 2009/2010

Source: 'Bucks for balancing: Can plug-in vehicles of the future extract cash – and carbon – from the power grid', A report by National Grid & Ricardo

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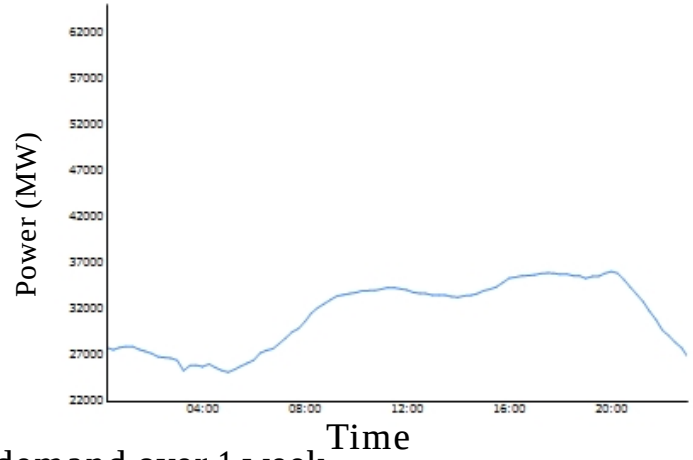
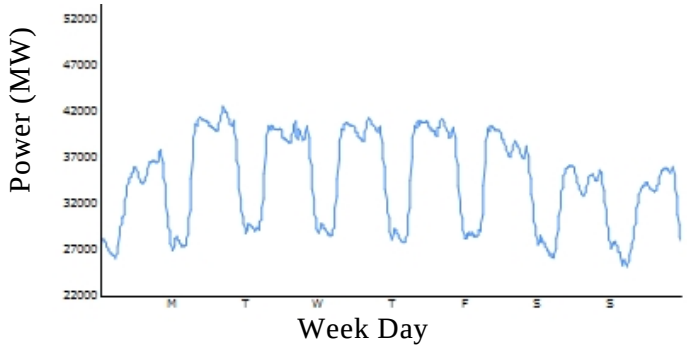
UK Electricity Demand Profiles

UK demand over 24hr



UK demand over 1 week



Data courtesy of National Grid & BM Reports

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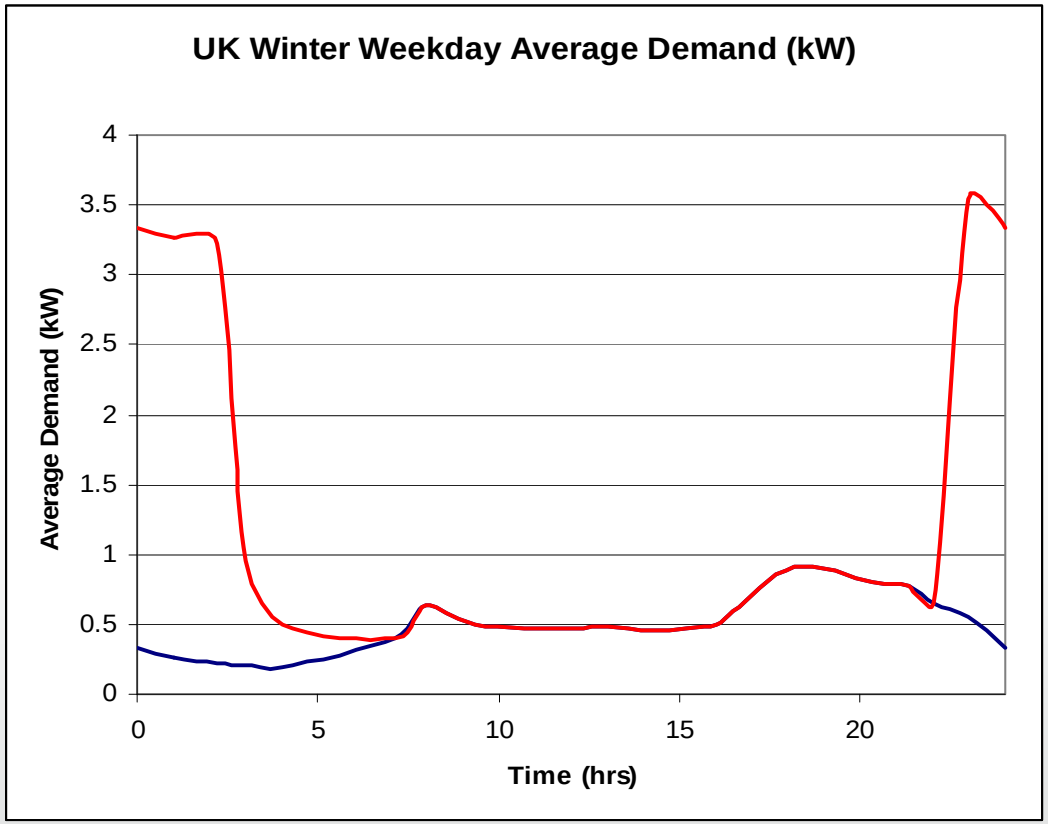
Typical Domestic Load Profiles



Source: UKERC Data

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Variability of Renewables

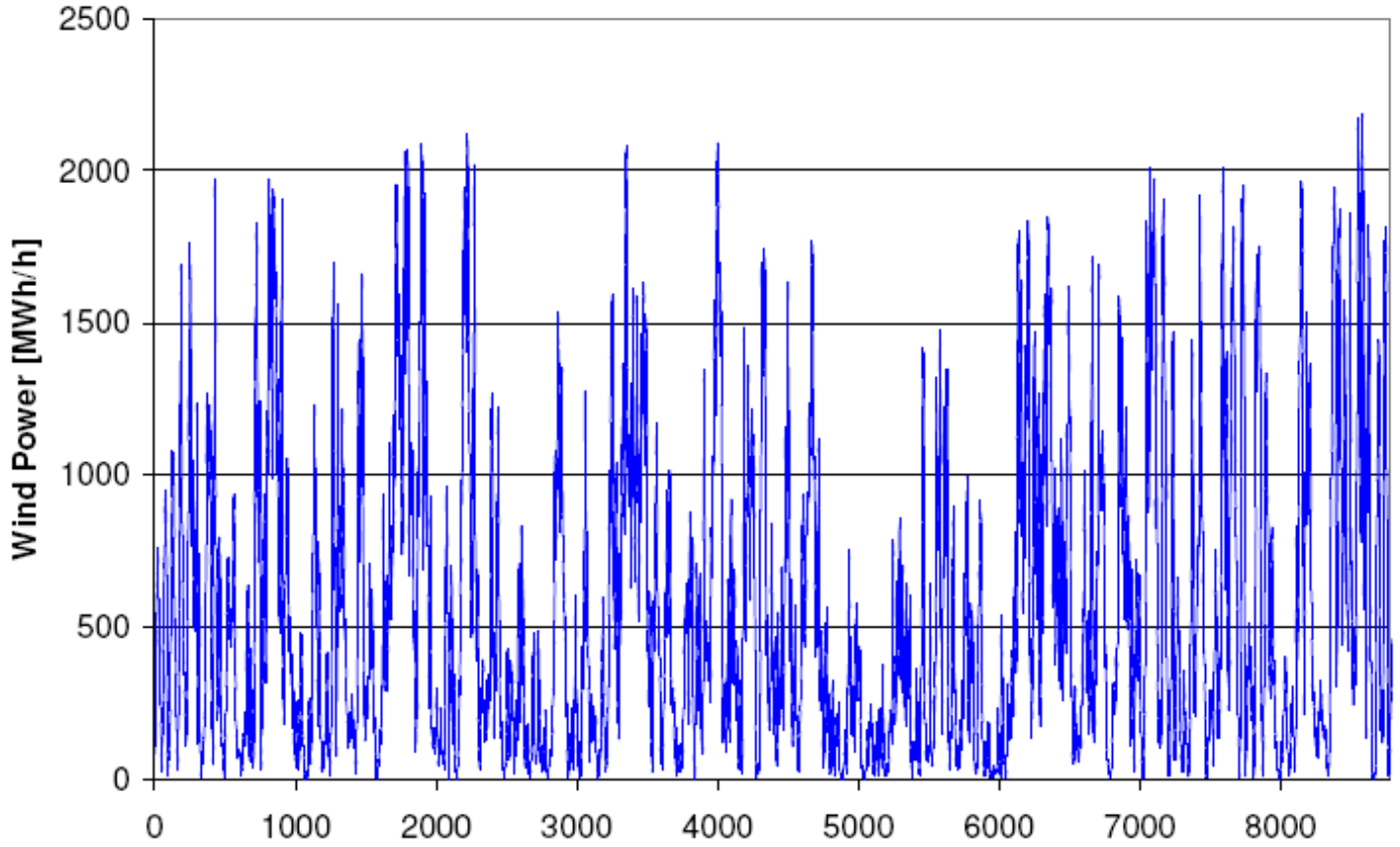


Figure 11: Wind power in DK-W 2004

Source: EcoGrid^{dk} – Steps toward a Danish Power system with 50% Wind Energy, 2007, www.ecogrid.dk

Price for variability of Renewables

The Telegraph

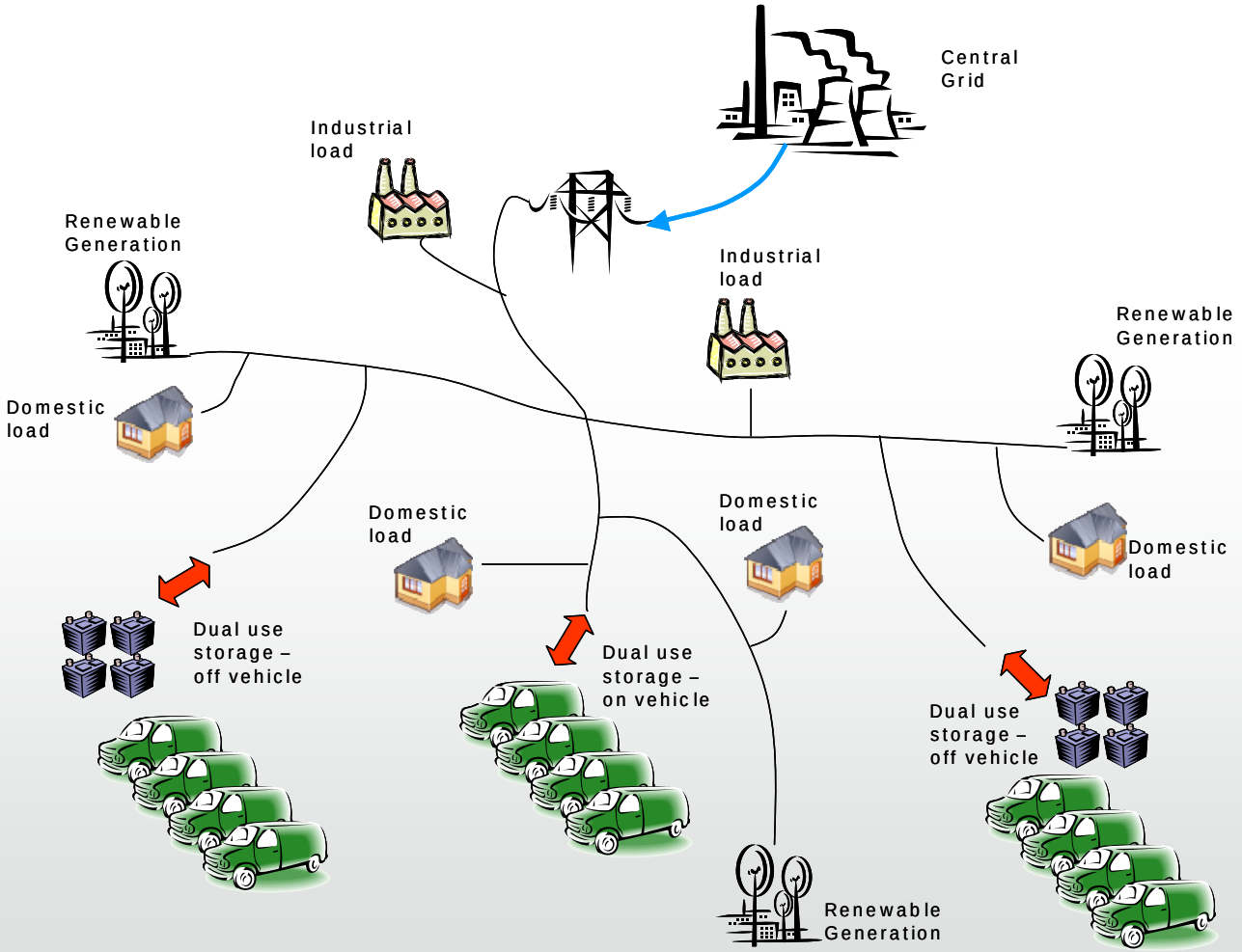
- 17th September 2011

  - The National Grid asked the company, Fred Olsen Renewables, to shut down its Crystal Rig II wind farm (60 turbines) last Saturday for a little over eight hours amid fears the electricity network would become overloaded.

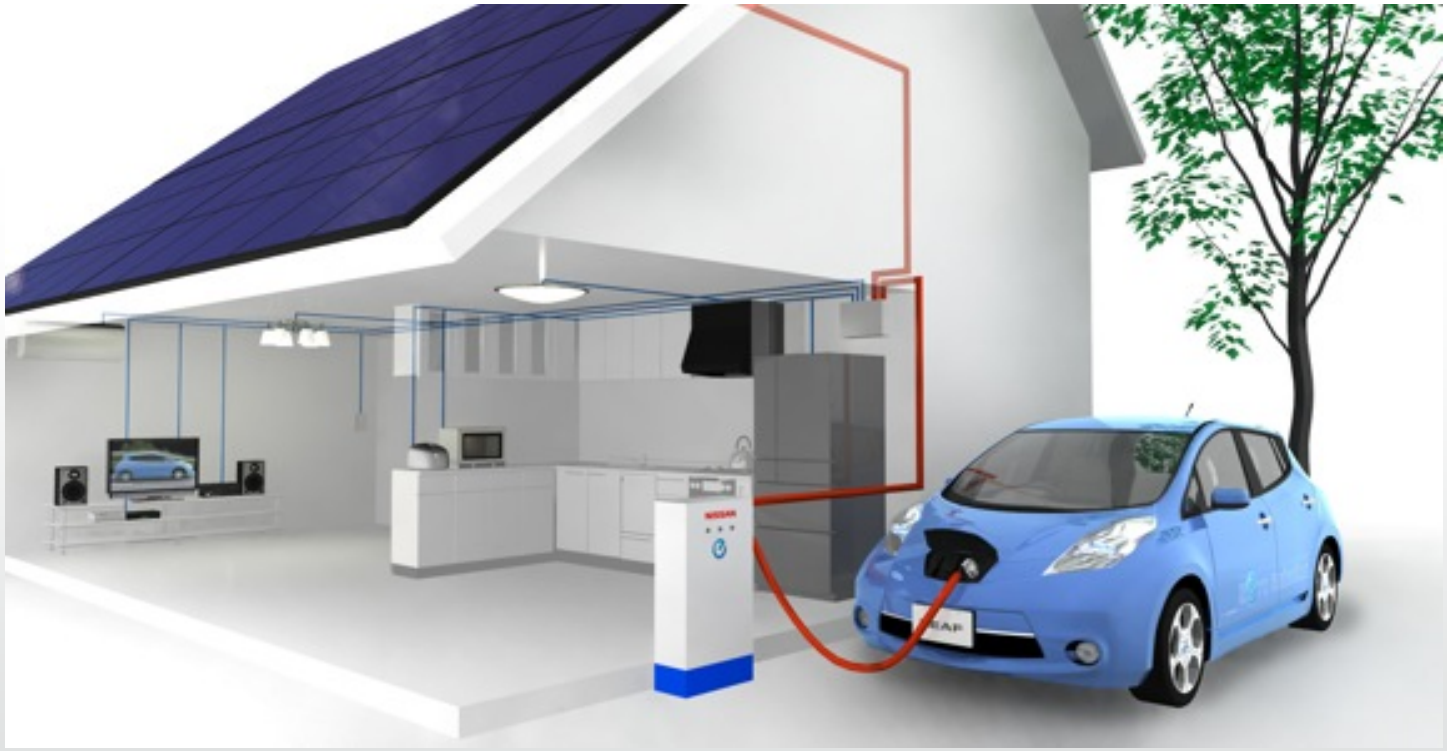
- Crystal Rig's owners asked for £999 per megawatt hour of energy they would have produced had they been switched on. Incredibly, the figure Crystal Rig had bid was accepted by the National Grid. Had the turbines remained on, Crystal Rig's owners would have received the going rate of about £100 per megawatt hour instead.

Vehicle to Grid - Concept

- V2G concept is ultimate 'distributed' energy scenario!
- Could be used for:
  - *frequency support*
  - *Power flow control (including 'firming' of renewables)*
  - *Load levelling*

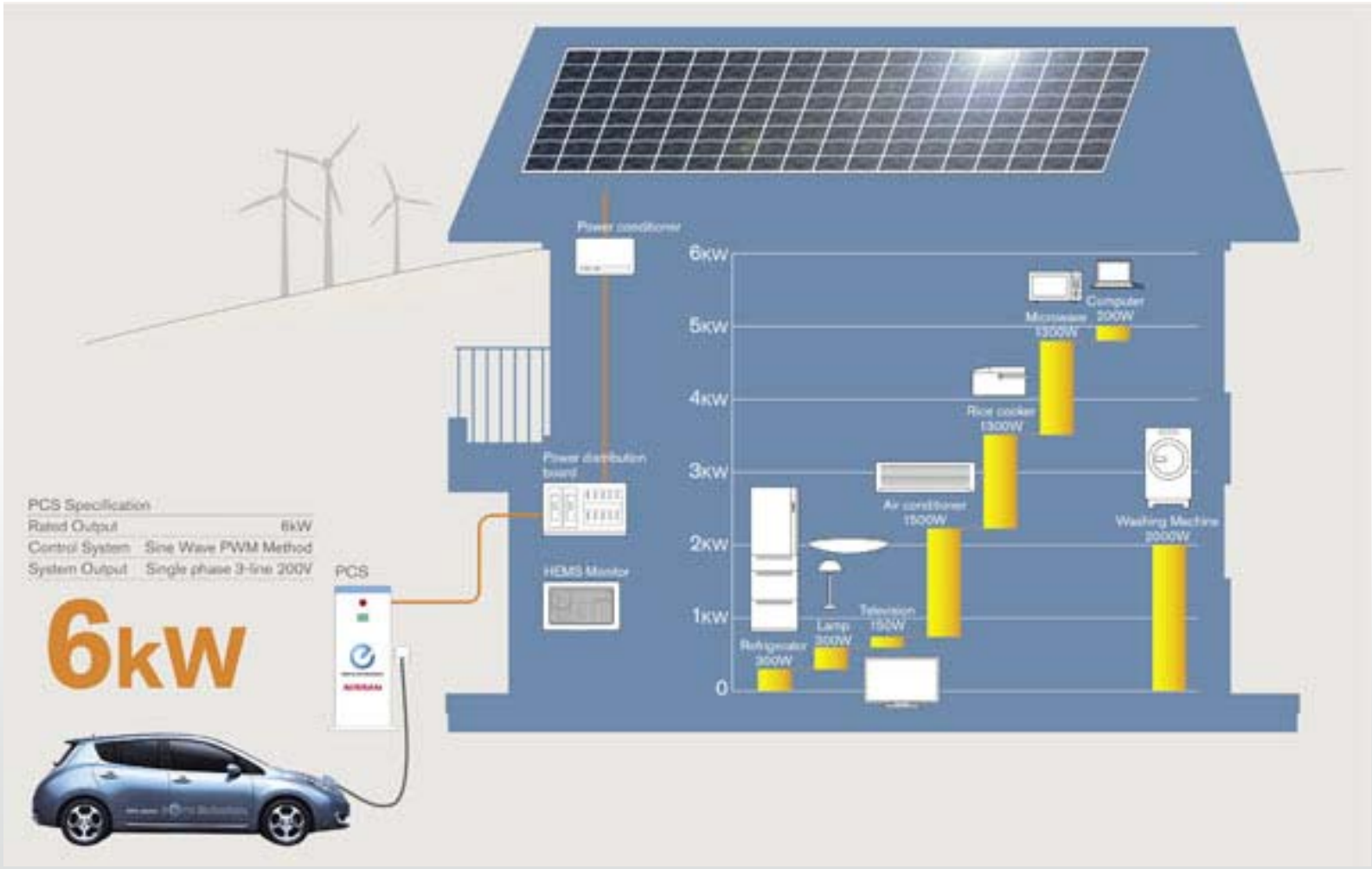


Nissan Vehicle-to-home (V2H) energy storage



Source of image: http://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/vehicle_to_home.html

Nissan Leaf-to-home energy storage



Source of image: http://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/leaf_to_home.html

Nissan Leaf-to-home energy storage

Run You Tube video at:
http://youtu.be/ylnWNaE4J1o

Grid Applications for Batteries

nationalgrid

Balancing Services by Technology

	Response	Reserve	Energy Balancing	Reactive Power	Black Start
Thermal generation	✓	✓	✓	✓	✓
Pumped storage	✓	✓	✓	✓	✓
Battery technologies	✓	✓	✓	✓	✓
Compressed air storage	✓	✓	✓	✓	✓
Flywheel	✓	X	X	✓	X
Supercapacitor	✓	X	X	X	X
Dynamic demand	✓	X	X	X	X
Smart metering	✓	✓	X	X	X
Large industrial sites	✓	✓	X	✓	X
Interconnectors	✓	X	✓	✓	✓

EV Usage Patterns

6MW/10MWh li-ion static battery energy storage – Leighton Buzzard

UK Power Networks have been awarded £13.2m (of £18.7m total) to develop this stationary battery energy storage system to study ‘Smarter Network Storage’

Source: http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-(SNS)/

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EV Battery – 43kWh, ~700kg

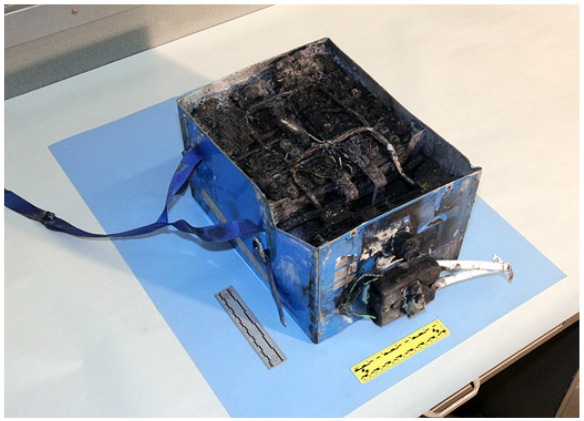
Tesla Motors model S car fire

Source: http://www.thenewstribe.com/2013/10/04/tesla-motors-explains-electric-model-s-car-fire/

Grounded Boeing 787 Dreamliners Use Batteries Prone to Overheating

A fire last week and a forced landing today have brought the possibility of such problems to the forefront.

By Kevin Bullis on January 16, 2013



Burned battery: This lithium-ion battery from a 787 Dreamliner caught fire in a plane traveling from Tokyo to Boston last week.

Two major safety incidents involving Boeing 787 Dreamliners have caused two Japanese airlines to ground their fleets of the aircraft. The problems may be linked to a battery chemistry that's particularly prone to causing fires.

WHY IT MATT

High-energy batte
are being used in
applications, whic
makes safety a gr
concern.

Source: http://www.technologyreview.com/news/509981/grounded-boeing-787-dreamliners-use-batteries-prone-to-overheating/

Battery affordability and performance are critical advances that are needed in order to achieve the *EV Everywhere* Grand Challenge

Chevy Volt

- ~40 mile electric range
- HEV: 32 mpg /300 miles
- 16 kWh / 120 kW battery
- Battery Cost: ~$8,000

Nissan Leaf

- ~75 mile electric range
- ≥ 24 kWh / 80 kW battery
- Battery Cost: ~$12,000

Tesla

- ~ 250 mile electric range
- ≥ 85 kWh / 270 kW battery
- Battery Cost: ~$35,000

EV Everywhere Target Analysis		Current Status	PHEV40	AEV100	AEV300
Battery Cost	**$/kWh (usable)**	**< 600**	**190**	**300**	**110**
Pack Specific Energy	Wh/kg	80-100	150	180	225
Pack Energy Density	Wh/L	200	250	300	425
SOC Window	%	50	80	90	90

2

Source: http://www1.eere.energy.gov/vehiclesandfuels/pdfs/ev_everywhere/5_howell_b.pdf

Operation ranges of LiMO cells

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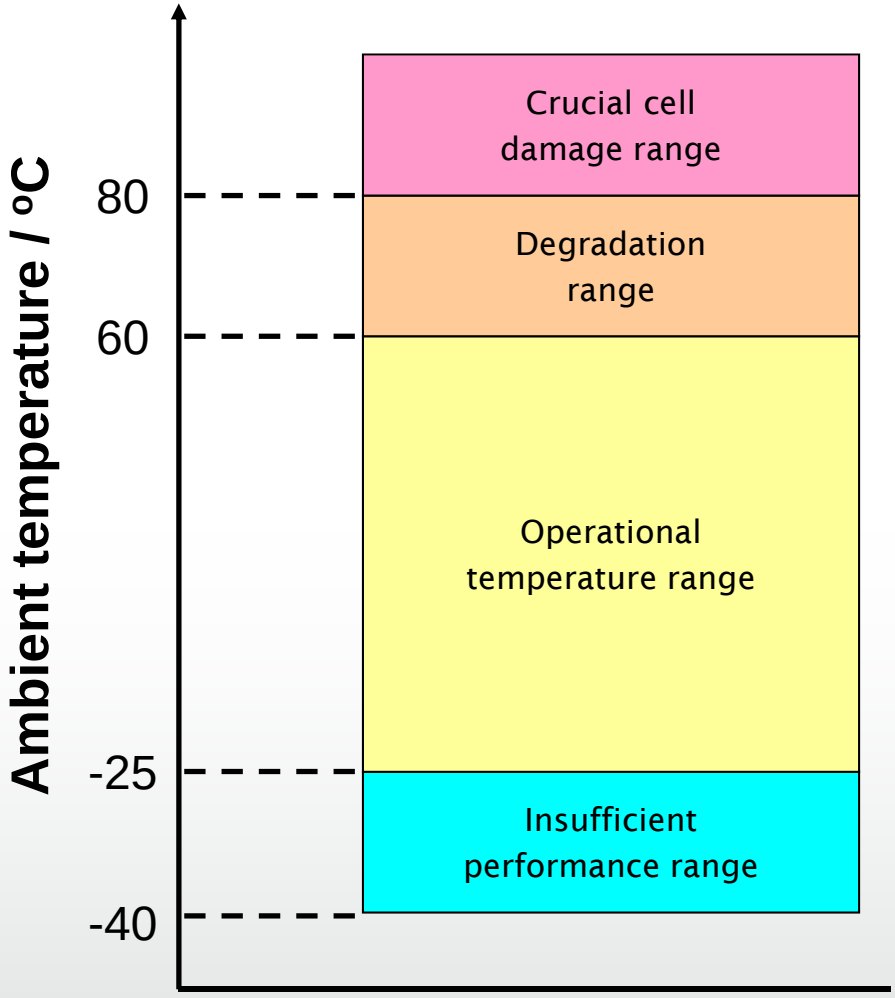
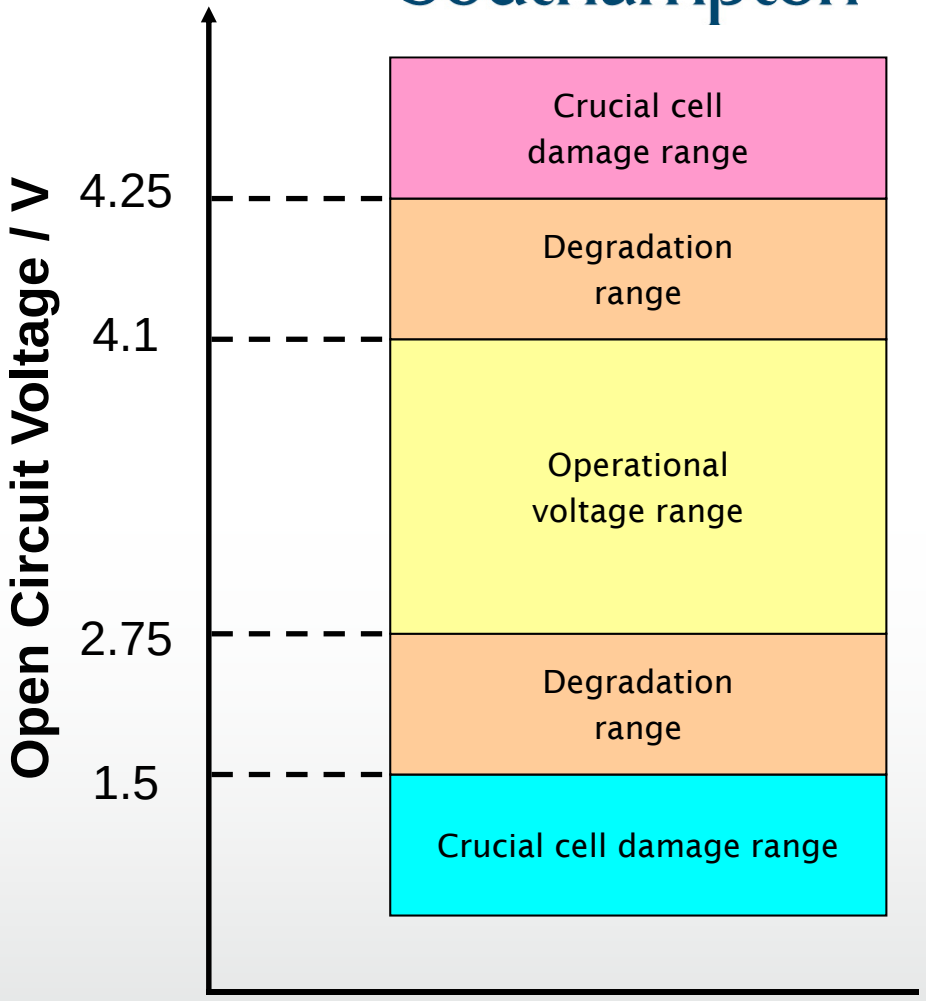


Operation Temperature



Operation Voltage

* These are standard values. They vary depend on the circumstances. For instance, short time deviation might be acceptable depending on the condition.

Cell Gassing

- **Battery packs need to accommodate multiple cells gassing i.e. internal pressure rises and mechanical dimension changes**

Figure 1: Gassed and normal Li-ion pouch cell

http://www.leydenenergy.com/index.php?page=products&subpage=pouch

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Current V2G Communications

Current V2G communications architectures based on a 'fixed location' charge point system with hard wired or local wireless network connection (Wi-fi – Zigbee) [1]

- **Unoptimised**
  Often unnecessarily bulky with little thought given to traffic volumes
- **Incompatible**
  Usually rely on custom base protocols with little interoperability
- **Unreadable**
  rarely coded with 3rd party usability as a core priority
- **Geographically locked**
  Charge posts have never required to announce their current location as it does not tend to move after installation

[1] 'A conceptual framework for the vehicle-to-grid (V2G) implementation', Guille C, Energy Policy (2009)

Current V2G Communications

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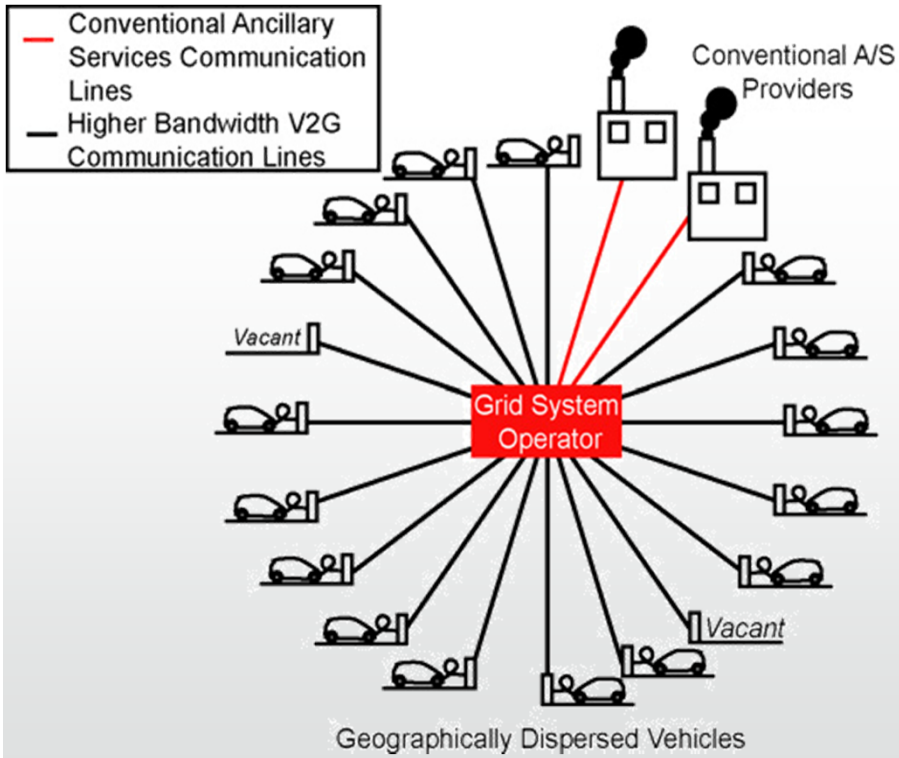
Example of a typical network framework relying on static charge units and fixed line communications.

Single Controller



Distributed Aggregators

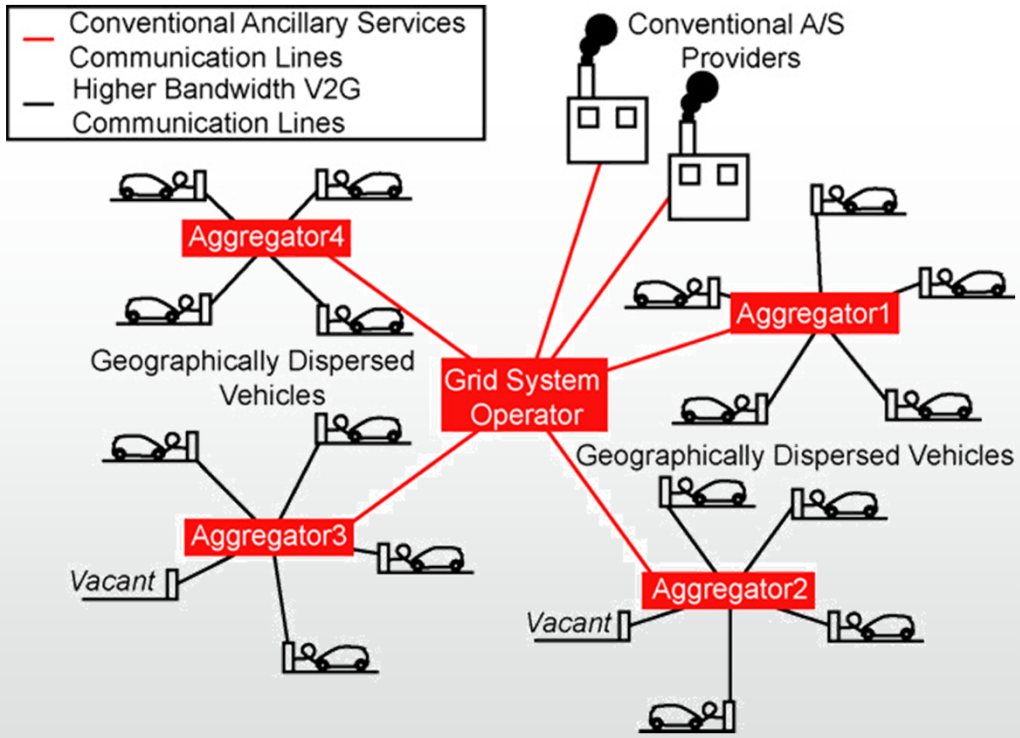
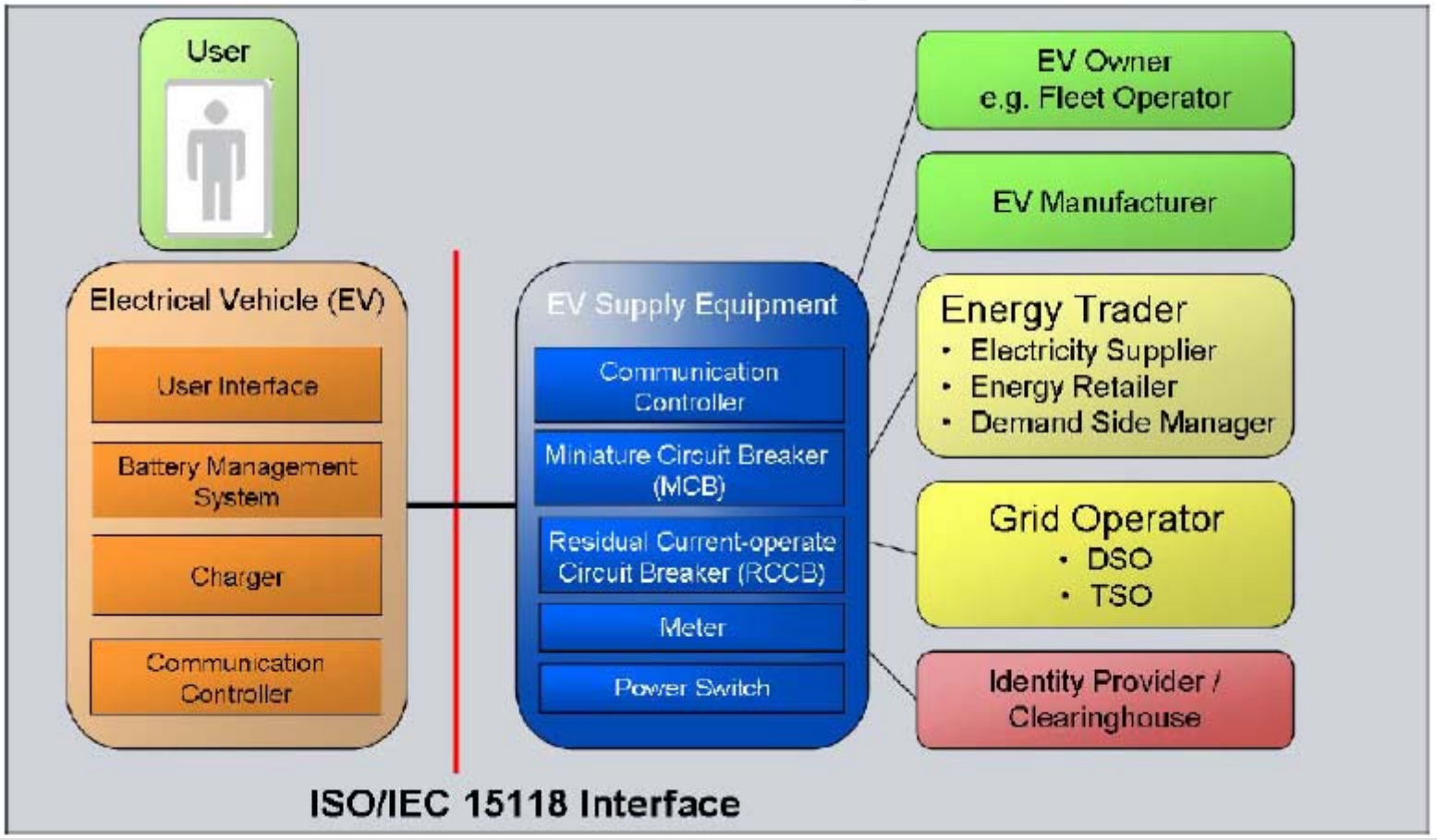


Image Source: The effect of communication architecture on the availability, reliability, and economics of plug-in hybrid electric vehicle-to-grid ancillary services, Thomas H. Bradley et al, (2009)

IEC 15118-3 Road Vehicle – V2G Communication Interface

- V2G interface – the related components and stakeholders



Source: 'Interconnections and Communications of Electric Vehicles and Smart Grids', Kabisch S, IEEE (2010)

eMobility Project, Germany

- V2G message structure and content

V2G_Message

Header
generic information such as
- session id
- protocol version
- policy

Body
request / response in context of either
- service discovery
- authoriziation
- power discovery
- line lock
- power delivery
- metering status
- ...

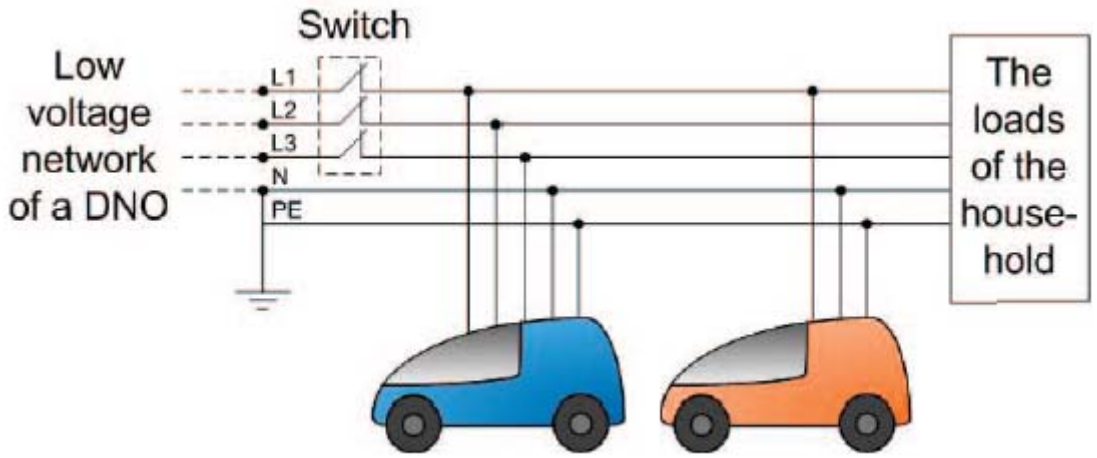
Source: 'Interconnections and Communications of Electric Vehicles and Smart Grids', Kabisch S, IEEE (2010)

Mobile (app) control and monitoring

- Mobile interface (app) for user interaction with the charging process
- Control and monitor EV charging & V2G operation

Source: 'Interconnections and Communications of Electric Vehicles and Smart Grids', Kabisch S, IEEE (2010)

Example of Finnish Project



V2H interface with 3ϕ and 1ϕ interfaces

- Work in Finland defined 4 levels of interface:
  - passive load (type 1), dynamic load (type 2), V2G (vehicle-to-grid – type 3), V2H (vehicle-to-home – type 4)

Source: 'Requirements for an interface between a plug-in vehicle and an energy system', Rautiainen A, IEEE Trondheim Power Tech, 2011

Vehicle Electrical Systems Integration (VESI)

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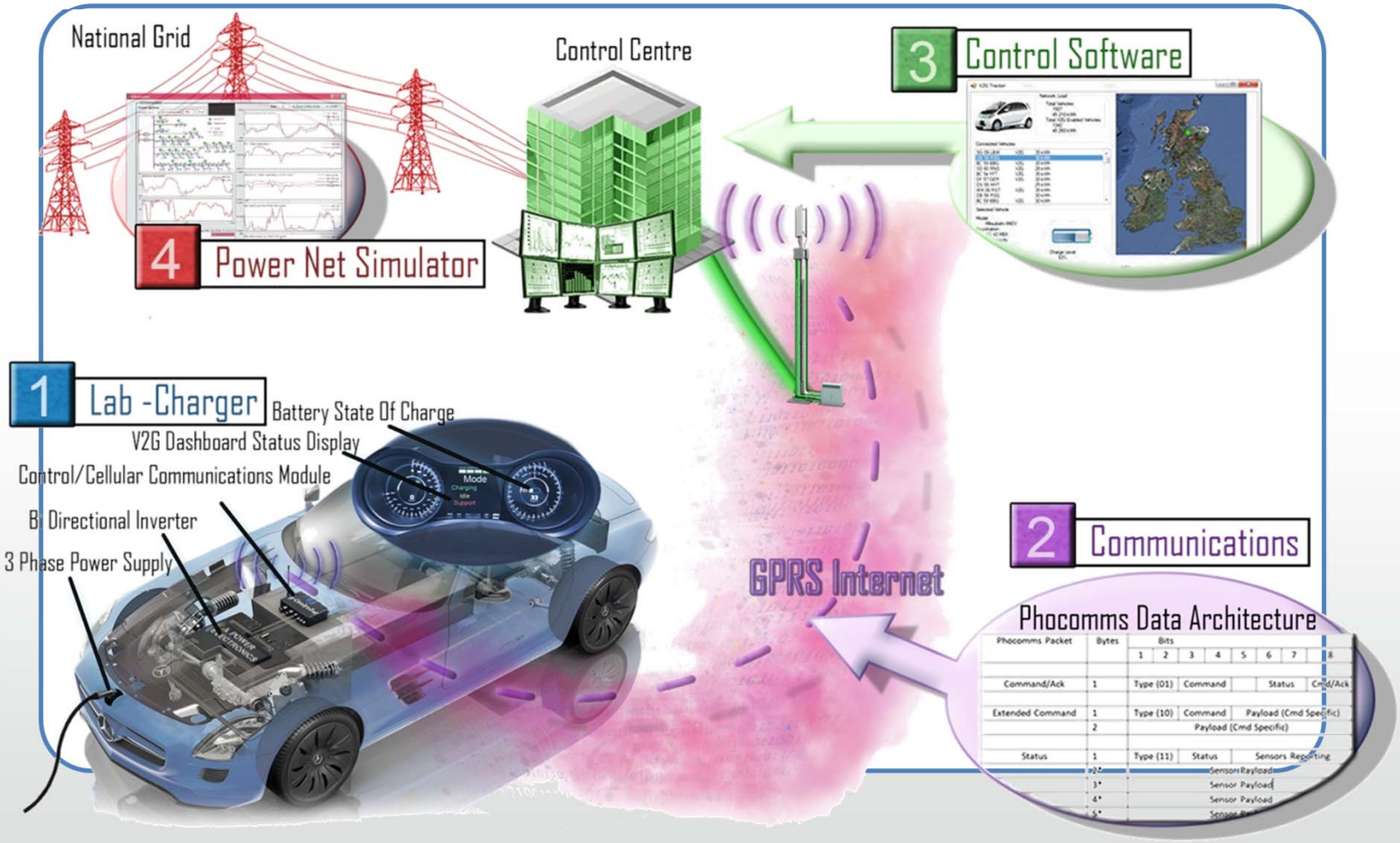
V2G System Overview



Grid Modelling of EV Loads

- Network data for 2 feeders received from SSE
- One feeder input and tested in OpenDSS

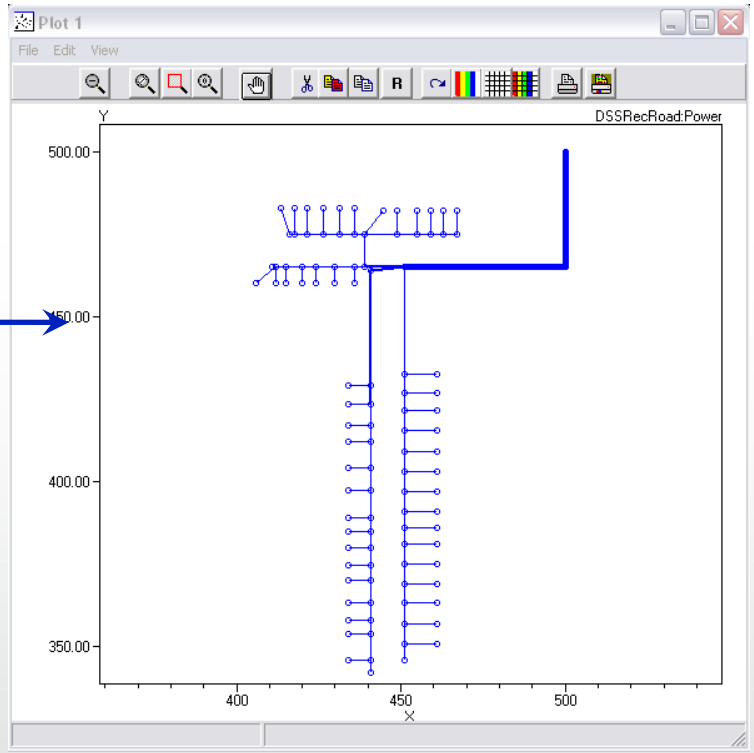


Image courtesy of SSE

Feeder rendered in OpenDSS

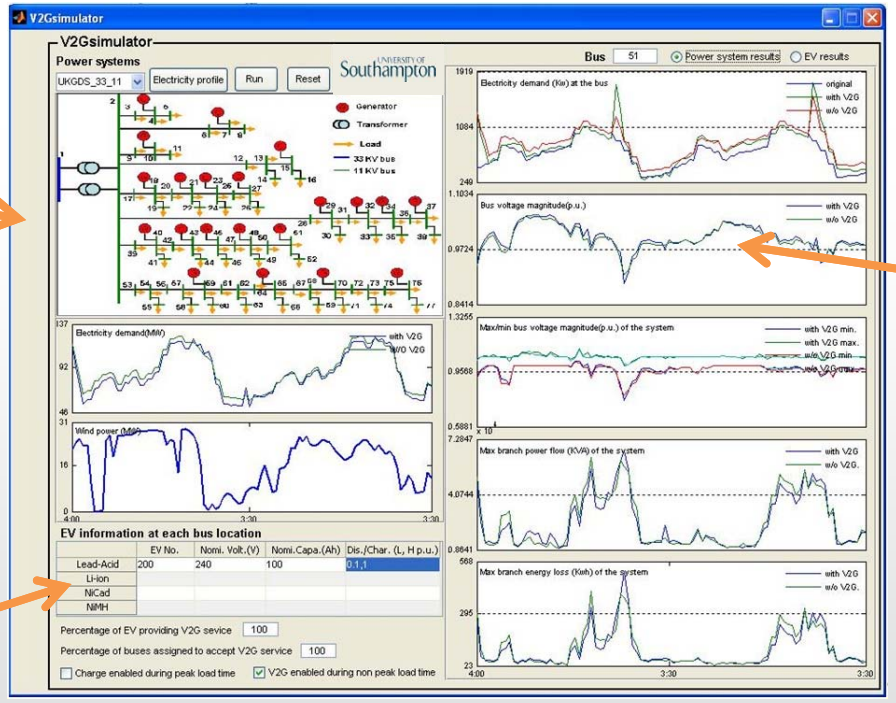
Thickness of lines is proportional to power flow

49 Houses on this feeder.

Network Simulation Integration

- Have developed a stand alone Matlab based V2G Power System Simulator (V2G PSS)
- Currently interfacing the V2G PSS to the GUI Control Software to allow 'full system' V2G modelling and testing of different V2G control algorithms

Simulated Network



Simulated Vehicle Details

Calculated network response showing results with and without V2G implemented

System GUI - Control Software

Current GUI Software has been developed to allow control and simulation of many vehicles connected to the network

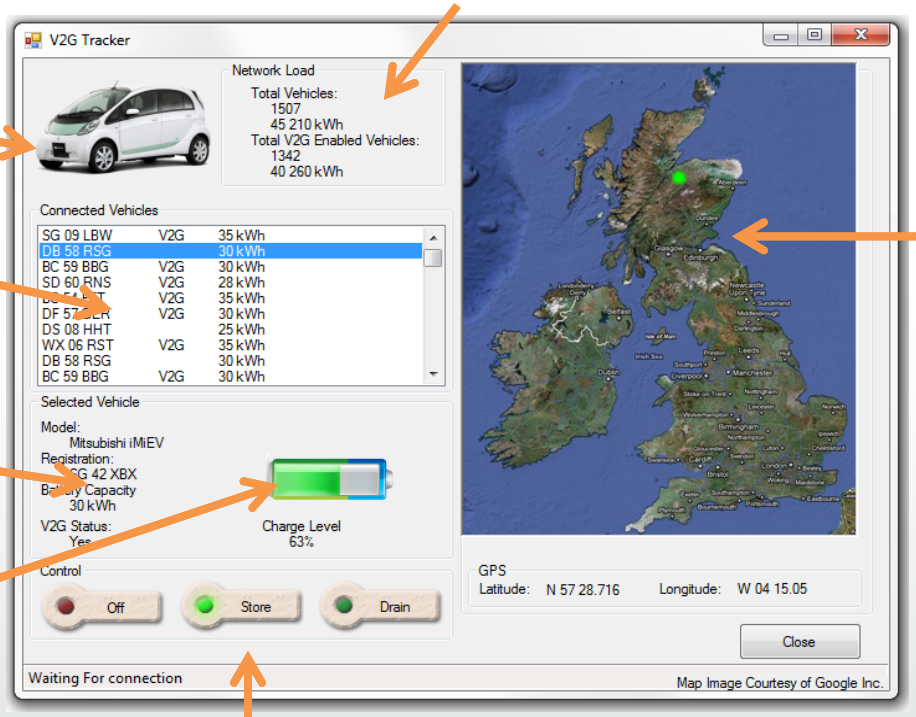
Network Status

Selected Vehicle

Connected Vehicles

Vehicle Details

Vehicle SoC



Location of Current Vehicle.

Send Control Signals to Vehicle

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VESI V2G Communications Concept

Designing a communication and control system for a fully dynamic system

- **Optimised**
  Aim to reduce traffic volume to allow for higher network efficiency over the 3G cellular network
- **Compatible**
  Using basic standards as a foundation, and designing a framework around XML maximises the systems interoperability with standard networking equipment
- **Developer friendly**
  Ensuring the high level data frames are structured in human readable format will encourage 3rd party developers to use the protocol as a foundation for their projects and build on it

Current EPSRC/NSFC Project on V2G

www.southampton.ac.uk/v2g

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Conclusions

- Illustrated the need for grid scale electrical energy storage
- Introduced the concept of V2G
- Considered EV usage and possible V2G patterns
- Discussed communication issues for V2G
  - Standards work
  - VESI alternative comms

Acknowledgements

- Thanks for assistance with this presentation go to:
  - James Donoghue, PhD, Southampton
  - Mahdi Kiaee, RF, Southampton
  - Peter Stevenson, Yuasa Battery Europe Ltd