UNIVERSITY OF LEEDS

Mobility & Energy Futures Series

ELECTRIC VEHICLES AND RENEWABLE ENERGY

WHAT ARE THE KEY ISSUES?

Energy Leeds

Power grids need to accommodate an increasing renewable generation share, which adds the variability of the weather and climate systems to the electricity distribution network. Further uncertainty on the demand side will be introduced by widespread EVs' recharging. Transport has been traditionally separate from the electricity grid but the transition to e-mobility will realize a closer integration. New configurations must be found to successfully merge renewable generation, electricity demand, transport/charging habits, and energy storage.

Will EVs be used as grid storage? The case of commuting

Car commuting is comparable to residential electricity usage in terms of societal and environmental relevance. Electricity storage may become the future replacement of "peak-following power plants", currently turned on when electricity demand is high, and storage may be partly provided by batteries on board future EVs. Whether EVs will bring stability to the energy system or not, it is not straightforward to determine: the main point at stake is the effectiveness of plugged-in vehicles to supplement the electric grid in satisfying demand's peaks and troughs.

Another relevant aspect is the financial viability of using EVs' batteries for purposes other than traveling, which increases wear and tear. EVs' maker Tesla recently introduced a lithium-ion battery for residential usage, with technology and cost per unit capacity similar to EVs' batteries; the divide between the two kinds of applications (cheaper, lower-tech packs for building use with respect to electric cars) may therefore get progressively blurred, thanks to technological advance and scale economy.

When and where will commuters charge their EVs?

It is often assumed EVs' batteries will be recharged in the dead of night and early morning, when demand is lower than average, to then provide peak power when people wake up. Then, EVs are driven to workplaces by commuters and parked for the day. There, they can be topped up while the sun is shining, driven back home where they provide for the dinner-time peak demand, to start being recharged again late at night. Daytime recharging seems compatible with California power demand (Fig. 1, green curve): topping EVs up during office hours may flatten the "duck-shaped" curve and accommodate solar generation. On the other hand, daily UK demand (Fig. 1, blue and red curves) does not display California's afternoon trough: recharging millions of EVs parked in workplaces' lots might therefore require additional peak generation rather than providing an outlet to excess power.

Variability in renewable generation and commuting patterns

During daylight hours (Fig. 2) in California, homes with solar panels cover a significant fraction of their own power needs, causing the demand trough displayed by the green curve in Fig. 1. This scenario may be unrealistic for the UK for two reasons. First, overcast skies suppress direct solar radiation, thus cutting up to 85% of clear-sky generation: the "duck" will exist only or mainly in sunny days. Second, the strong generation imbalance from winter to summer [1] due to high latitude can prevent the duck's trough from occurring in autumn and winter, even with clear-sky conditions.

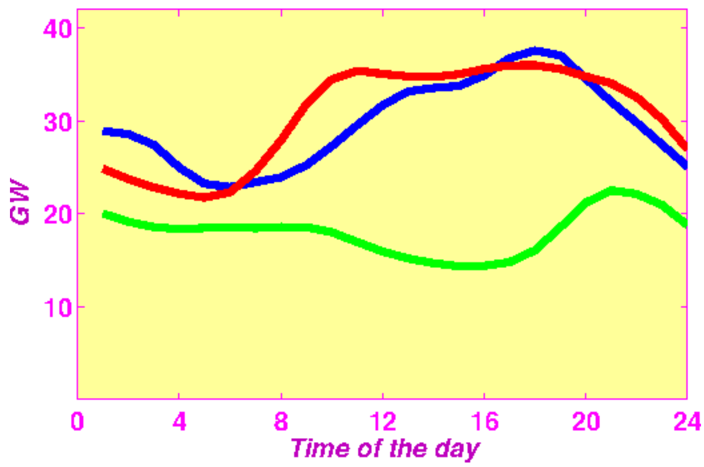

FIGURE 1. ***Green line:*** **"Duck-shaped" curve of daily California electricity demand (March 31, 2015; from bloomberg.com). The daytime trough is due to solar generation covering, partly or totally, the demand from homes with solar panels installed, hence reducing the electricity requested from the grid.** ***Red (blue) line*****: daily UK electricity demand on 1/1/2015 (1/7/2015); from nationalgrid.com.**

Each renewable generation mode shows its own peculiar variability and uncertainty pattern on different time scales (from hourly to yearly and beyond) and spatial scales [2], just as car commuting does (e.g., working days vs weekends). A fraction of variability is deterministic (entirely predictable, like the sun's day-night cycle), whilst another fraction displays various degrees of unpredictability, depending on desired time advance and precision on location (an example being the effect of clouds on photovoltaic generation). With power supply limited to fossil fuel and nuclear power, climate and weather mainly influence the demand side of the energy market. Inclusion of renewables in the mix introduces a "double dependency" on weather/climate which can sometimes damp fluctuations (e.g., summer highs of solar generation in Texas satisfy the increased air conditioning usage) but often amplify them (reduced winter solar generation is coupled with higher heating and lighting needs). Adding EVs to the balance makes the problem even more complicated. For example, bad weather can affect car-usage patterns; likewise, heating the cabin of an EV on a winter day increases consumption.

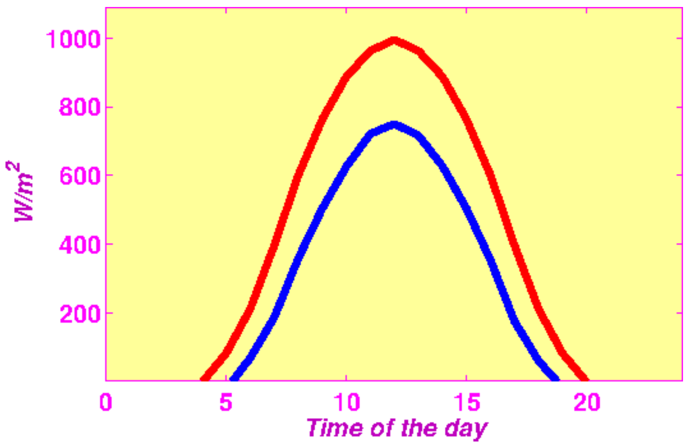

FIGURE 2. October (blue) and April (red) global horizontal irradiance per m² in Southern England, with clear sky conditions. Overcast skies, or just single clouds hiding the sun, may reduce irradiance by more than 80%, a common condition in the UK. Clear-sky causes the duck-shaped demand curve in California, as homes with photovoltaic panels are maximally fed by solar power during the day, reducing the demand on the grid by the same amount.

Coping with variability and unpredictability

EVs maximally help the grid if they are plugged-in, with the appropriate charge level, when generation or demand peaks occur. The seasonal imbalance may however cause the future British renewable mix to include a solar share smaller than sunnier countries; alternatively, long-term storage (like using electricity to produce hydrogen) will be the way to carry summer excess energy to the following winter. In either case, the grid may not need EVs' batteries plugged in at around midday time. On the other hand, wind generation is higher *on average* during daylight time (Fig. 3), like solar. This might cause a net result similar to the duck curve (by increasing grid power uploading, rather than reducing demand), although periodicities and probabilities of highs/lows differ from solar. It may be necessary to alter the timing of non-urgent freight and deliveries to respond to predicted grid needs (similarly to what already happens with industrial refrigeration), in line with weather forecasts.

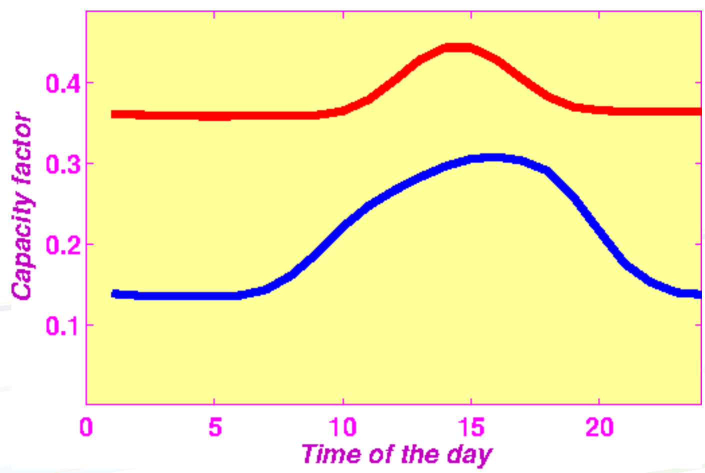

FIGURE 3. Seasonal average of UK hourly wind power availability averaged over 34 years (blue line indicates summer, red winter; adapted from [3]). No information is given on how values are distributed around the hourly means; therefore, the "day-after-day persistence" of the curves' shapes is not guaranteed.

Commuters' EVs as energy deliverers

EVs will offer an additional opportunity. A future compact electric car with a 50kWh battery capacity can be envisioned as the "typical" vehicle (Tesla model S, a full-size car, has a 85kWh capacity with a 430km range). More than 15 million cars are driven in England and Wales every day for commuting, traveling an average distance of 16 km. Should all become electric, they would carry a capacity of 750GWh. In comparison, the output of the Three Gorges Dam in China, the world's largest power plant, is 22.5GW: more than 33 hours of the Dam's output would be needed to recharge these cars. On the other hand, such EVs could satisfy for 21 hours the entire England-Wales average power demand (about 35 GW), and the residential one (11.3GW) for almost 3 days.

Commuting patterns often involve cars flowing daily from suburbs to business districts and back: this scheme moves battery capacity and energy from an area to another. 100,000 EVs, with fully-charged 50kWh batteries, driven 20km from home to work every morning, bring 46GWh in business districts, assuming a 4kWh consumption per trip. EVs with batteries significantly larger than needed for just the commuting round trip may be recharged either at home only, or at the workplace only: they can therefore carry energy from one place to another and still be able to commute. The average UK home uses 13kWh/day; a fleet of 1,000 EVs with 50kWh batteries, consuming no more than 10kWh on a return trip, could therefore supply a substantial energy share to the nighttime energy demand of a residential suburb. Electricity generated near EVs' recharging locations will also reduce power grid's load: this effect could be maximal for workplaces adjacent to wind/solar farms or other power plants.

Key messages

- EVs are often foreseen as a means to stabilize the power grid by providing storage capacity. This vision requires that excess generation and demand peaks both occur when EVs are plugged in.
- Adding EVs to the energy balance increases complexity and dependency on atmospheric conditions: with the "wrong" combination of climate and energy mix, the need for grid storage may actually grow.
- Commuting, coupled to proper urban and socio-economic configuration, may create a net flow of stored energy from residential areas to business districts and back. EVs can be harnessed not only passively, as storage means, but also actively, as energy carriers, to supplement the power grid in transporting energy.

Giuseppe Colantuono
School of Chemical and Process Engineering

References
[1] Colantuono et al., Solar Energy 108, 2014
[2] Colantuono et al., Solar Energy 107, 2014
[3] G. Sinden, Energy Policy 35, 2007

Mobility & Energy Futures Series

Transport consumes a fifth of global energy and has a near-exclusive reliance on petroleum. As such it has an important role to play in the Energy Trilemma of reducing energy consumption and associated greenhouse gas emission, creating an energy system built on secure supplies and developing the system in ways which are affordable.

Addressing the Energy Trilemma in the transport and mobility sector is especially challenging due to the continued growth in demand for the movement of goods and people, the technical, regulatory and social challenges of moving away from an oil based system of mobility and a complex and fragmented set of stakeholders required to work together to deliver change.

Drawing on the expertise and opinions of the University of Leeds academics from different disciplines, this series will highlight the drivers, gaps and opportunities in reducing the energy consumption and carbon emissions from the transport sector in future. This is the fifth briefing in the series.

Other issues in the series are available online at www.its.leeds.ac.uk/research/mobility-energy-futures-series

Editors:

Zia Wadud
Centre for Integrated Energy Research
Email: **Z.Wadud@leeds.ac.uk**
Tel: **+44 (0)113 343 7733**

Greg Marsden
Institute for Transport Studies
Email: **G.R.Marsden@its.leeds.ac.uk**

Energy Leeds
University of Leeds
Leeds, LS2 9JT
Tel: +44(0) 113 343 4609
Email: energy@leeds.ac.uk
www.energy.leeds.ac.uk

UNIVERSITY OF LEEDS
University ofLeeds
Leeds, United Kingdom
LS2 9JT
Tel. 0113 243 1751
www.leeds.ac.uk