IMPACT OF WEATHER CONDITIONS ON ELECTRIC VEHICLE PERFORMANCE

Paul G Leahy
University College Cork

Aoife M Foley
University College Cork

Abstract
Seasonal and day-to-day variations in travel behaviour and performance of private passenger vehicles can be partially explained by changes in weather conditions. Likewise, in the electricity sector, weather affects energy demand. The impact of weather conditions on private passenger vehicle performance, usership statistics and travel behaviour has been studied for conventional, internal combustion engine, vehicles. Similarly, weather-driven variability in electricity demand and generation has been investigated widely. The aim of these analyses in both sectors is to improve energy efficiency, reduce consumption in peak hours and reduce greenhouse gas emissions. However, the potential effects of seasonal weather variations on electric vehicle usage have not yet been investigated. In Ireland the government has set a target requiring 10% of all vehicles in the transport fleet to be powered by electricity by 2020 to meet part of its European Union obligations to reduce greenhouse gas emissions and increase energy efficiency. This paper fills this knowledge gap by compiling some of the published information available for internal combustion engine vehicles and applying the lessons learned and results to electric vehicles with an analysis of historical weather data in Ireland and electricity market data in a number of what-if scenarios. Areas particularly impacted by weather conditions are battery performance, energy consumption and choice of transportation mode by private individuals.

Introduction
In Ireland, the UK, and elsewhere, policy makers have moved to incentivise the uptake of electric vehicles (EVs) by private motorists. For example, in Ireland, a government target mandates 10% of vehicles sold in 2020 to be electric [1]. More significantly, the global automobile industry has responded to these initiatives by preparing for large-scale production of EVs. The policies are being driven by concern of national governments over CO₂ emissions from the transport sector, as well as a move towards greater energy self-sufficiency through renewable electricity generation in hydrocarbon-poor countries. It is clear from all these developments that the era of the EV is truly upon us. Looking beyond the 2020 targets, which will in reality only make a minor mitigation of CO₂ emissions from transportation, the prospect of national private motor vehicle fleets becoming dominated by EVs is very real indeed.

Work has been carried out to quantify the additional electricity requirement due to widespread uptake of EVs in Ireland [2]. This is important for power system engineers concerned with the issue of generation expansion planning, which seeks to ensure that the power system will be able to meet demand in future years. It is not sufficient to simply calculate a gross electrical energy requirement based on fleet size, average journey length, and vehicle power consumption. The temporal dynamics of electricity consumption by EVs are extremely important when it comes to quantifying the impacts of EV electricity demand on the power system.

The sensitivity of EV power demand to weather conditions adds a further level of complexity to such planning exercises. Electricity demand is known to be sensitive to weather conditions due to several factors, among these the demand for electric space and water heating during cold spells, and, in warm climates, air conditioning demand during hot spells. In Ireland, electricity demand peaks during the winter months, and the highest daily peaks in demand are also encountered during these months. The advent of large-scale power generation from variable renewable sources such as wind and solar photovoltaic (PV) adds further weather sensitivity to the combined supply and demand systems. In fact, the move towards such
renewable sources is one of the factors behind the move towards EVs, as the power generated is close to CO$_2$-neutral, unlike the fossil fuel sources they replace both in power generation and internal combustion engines.

Therefore, there is a need for a model to be developed to examine the effects of widespread EV adoption on power demand, power system capacity margins, and on loadings of the power distribution system. Such a model needs to take into account the temporal dynamics of EV charging patterns, as these are influenced by multiple external factors including weather conditions. A useful feature of any such model would be to allow the effects of climate change scenarios on the electrified transport sector to be simulated.

The aims of this paper are to identify potential influences of weather on electricity demand for EV charging, to propose a model to study these effects, and to discuss difficulties that are likely to arise in such an exercise.

Data sources

In 2008, the average distance travelled by private cars in Ireland was 16,376 km [3]. For vehicles with engine capacities below 1,000 cc, the corresponding distance was 11,664 km [3]. It seems reasonable that, at least in the initial years of EV uptake, EVs will largely replace cars at the lower end of the engine capacity scale. In the Dublin licencing region, the average distance travelled in the same year by all private cars was lower than the national average, at 12,886 km [3]. EVs are likely to be more attractive to purchasers in the Dublin area due to the lower distances travelled, as well as due to a higher concentration of charging points. However, it is also worth noting that in the Mid-East region, which roughly corresponds to the wider Dublin commuter belt, the average distance travelled was above the national average, at 17,241 km [3]. Therefore, if commuters in this region are to adopt EVs, greater ranges, battery capacities, and hence, greater loads on the power system are likely to result.

With a fleet of either fully electric vehicles (i.e. battery electric vehicles, BEVs), plug-in hybrid electric vehicles (PHEVs) or a mixture of both, there are a number of potential influences of weather conditions on the total EV energy demand. Some of these relate specifically to EVs but most are general to all forms of private transportation. These are summarised below.

- Temperature influence on battery charging performance
- Temperature influence on battery self-discharge rate
- Temperature influence on choice of transportation mode for a particular journey (e.g. walking versus private car)
- Precipitation influence on choice of transportation mode
- Wind influence on choice of transportation mode (e.g. cycling versus private car, [4])
- Temperature influence on battery discharge rate through air conditioning usage.

Some of the above factors are likely to be weak or unquantifiable. Self-discharge rates, in particular, are likely to be negligible for EVs in regular use.

The supply of electricity to EVs from the power system and demand from the motor are not instantaneously coupled. In other words, EVs use their on-board batteries to store energy until it is required. Likewise, after a BEV's battery has been discharged through driving, the energy demand to recharge it is deferred until some time after the journey has ended. The magnitude and timing of this deferred energy demand is affected by a number of factors including battery technology; journey length and speed; EV factors such as driving and charging efficiency and the presence or lack of regenerative braking.

A distribution of journey lengths will have to be assumed in order to generate appropriate discharge magnitudes for the EV batteries. This may be assumed by comparison with similar
studies in other countries, or possibly from studies undertaken by local authorities or large employers.

Model description

The model is described in terms of a state variable, Q(t), which is the accumulated EV battery charge deficit in the fleet. This can be defined as the total amount of charge required at any time to fully recharge the batteries of all the EVs. Other variables in the model include the fleet-aggregated instantaneous discharge rate, D(t), and the corresponding aggregate charge rate, C(t). These values are the respective rates of charge accumulation from mains charging and charge depletion from all sources, aggregated over all EVs. The instantaneous power requirement from the grid, P(t), is related to C(t), with an allowance for charging inefficiencies. The discharge rate D(t) is determined by driving behaviour and self-discharge of the batteries, both of which are influenced by weather conditions. The two contributors to D(t) are indicated by V(t) (driving) and S(t) (self-discharge).

The value of Q(t) itself is not directly related to P(t), as charging is deferred until the EV user plugs in the vehicle to recharge. Therefore a decision module is required to determine when, and by how much, the vehicle is recharged. The decision module is also responsible for making driving decisions, i.e. whether to make an EV journey or not. Some of these decisions are also weather-dependent. Weather information is represented by instantaneous values of precipitation ppt(t) and temperature, temp(t). The model is run on an hourly timescale. In the model nomenclature, capitals (e.g. D(t)) will be used to denote aggregated quantities and lowercase (e.g. d(t)) will be used to denote values corresponding to individual EVs. The possibility of vehicle-to-grid power flows, whereby EV batteries may be used for energy storage by the power system, may be incorporated easily to an expanded version of the model.

The key elements of the model may be summarised by the following equations:

\[ d(t) = v(t) + s(t) \]  \[ \text{[eqn. 1]} \]

\[ p(t) = -kC(t) \]  \[ \text{[eqn. 2]} \]

\[ q(t) = q(t_0) + \sum_{t=t_0}^{t} (c(t) + d(t)) \]  \[ \text{[eqn. 3]} \]

\[ Q(t) = \sum_{i=1}^{N} q(t) \]

where:

k is an efficiency factor to allow for charging losses.

\( t_0 \) denotes the initial time point of the model;

i denotes an individual EV of the fleet;

n is the total number of EVs in the fleet.

A suitable time resolution, t, for the model would be either 30 minutes (the trading period of the single electricity market in Ireland) or one hour (the time resolution of most publicly-available meteorological data). These time resolutions should be sufficient to capture EV charging patterns in sufficient detail for the purposes of this study; it is only the charging patterns, not the actual driving patterns, that have to be represented with sufficient accuracy.

An EV fleet database is also required for the model. This should include battery technology types, charging requirements, and energy intensivity of usage (e.g. kWh/km). A car stock model for the entire future Irish car fleet has already been proposed by [5]. A simpler fleet database is likely to be sufficient for initial model development in this case.

Discussion

Different results have been found in studies of weather sensitivity of transportation mode choice by individuals. Several such results have been summarised by [6]. Studies in the medium-sized European cities of Brussels and Geneva found that a large proportion of car users change their behaviour in response to “bad” weather conditions. A key finding is that
the purpose of the trip is important in this regard, i.e. non-discretionary trips are less likely to be substituted. Sabir's own study of the Netherlands found that car and public transport usage increased (over walking and cycling) during periods of low temperatures, and that bicycle usage was substituted by cars and public transport during periods of precipitation [6]. The variability of precipitation regimes in Ireland ensures that even if morning commuting conditions are dry, many commuters may still opt to travel by car in case of rain during their return journeys.

Conclusions

The development and implementation of a model to study the influence of weather patterns on aggregated power demand dynamics from a fleet of EVs is reasonably straightforward. However, creating realistic user scenarios is a much more difficult task, and will require close collaboration with experts in the field of transportation mode choice. Before user scenarios can even be prepared, there is a need for data representing present-day private transport choices made in the face of varying weather conditions. Given the unique weather conditions of Ireland, with frequent rainfall, frequent high winds, but relatively low seasonal and diurnal ranges of temperature, this data will more than likely have to be gathered locally.

Acknowledgement

The authors would like to thank Science Foundation Ireland and the Environmental Protection Agency for financial support.

References