Smart Energy Interfaces for Electric Vehicles

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ABSTRACT

Electric vehicle charging strategies rely on knowledge of future vehicle usage, or implicitly make assumptions about a vehicle's usage. For example, a naïve charging strategy may assume that a full charge is required as soon as possible and simply charge at the maximum rate when plugged in, whereas a smart strategy might make use of the knowledge that the vehicle is not needed for a number of hours and optimise its charging behaviour to minimise its impact on the electricity grid. These charging strategies may also offer vehicle-to-grid services.

To achieve this functionality, a driver needs to specify the details of the next trip—or sequence of trips—in order for the charging strategy to perform optimally. This paper explores the value of next-trip information, and presents a potential user interface to assist a driver with providing these details.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*Graphical user interfaces (GUI)*

General Terms

Design, Human Factors

Keywords

Electric Vehicles, Smart Charging, Smart Grid, V2G

1. INTRODUCTION

There has been much research focussed on smart charging strategies for electric vehicles (EVs), for example [1, 4, 5]. The foremost goal of a charging strategy is to ensure that an EV has sufficient charge to meet its travel requirements; however, the energy needs of an EV rarely require the full capacity of its battery, and hence the excess capacity can be used to support the electricity grid—a concept known as vehicle-to-grid (V2G) [3]. Secondary goals of a charging strategy may include the ability to schedule charging during off-peak periods, actively minimise peak loads, provide ancillary services to the electricity grid, or utilise intermittent renewable energy when it is available.

All charging strategies either make assumptions about the future use of an EV, or require input from the driver. A *greedy* charging strategy could assume that the vehicle will be used again very shortly and require an urgent full charge, and hence charge at the maximum rate as soon as the EV is connected to the grid. While this approach will achieve the goal of providing the EV with sufficient energy for its journey (if possible), it imposes significant demands on the electricity infrastructure [6].

A smarter strategy could charge the battery at a variable rate according to available electricity generation from intermittent renewable sources. The full battery capacity may be used for grid storage, as long as the EV attains a sufficient charge by the time of next departure. This approach has been demonstrated to greatly assist with the integration of large-scale renewable electricity sources [5], however it does require knowledge of the future use of the vehicle; both the time of next departure, and the distance of that journey.

EV chargers are produced by a number of companies (e.g. General Electric, Leviton, Schneider Electric, Delta Group), and typically offer a simple user interface consisting of a display to show the current state-of-charge, provide the ability to delay charging to make use of off-peak energy, and have RFID interfaces for billing purposes. Currently available chargers do not offer the ability for the driver to specify the parameters required by an advanced charging strategy, which is the focus of this paper.

Modern EVs, including plug-in hybrids (PHEVs), offer visualisations within the vehicle. For example, the Toyota Prius incorporates a sophisticated dashboard visualisation to show energy flows between fuel, battery and the vehicle. These types of display will become more important when considering external energy flows between the vehicle and charging sources, which may include distributed generation owned by the driver.

With comparatively limited range and long charging times, EVs introduce a concept known as "range anxiety"—the fear that an EV might not have sufficient energy to complete a journey. It therefore becomes an additional challenge to plan longer journeys to include intermediate recharging stops. A number of websites contain databases of charging stations and provide the facility to plan routes to include charging stops, for example [7, 2].

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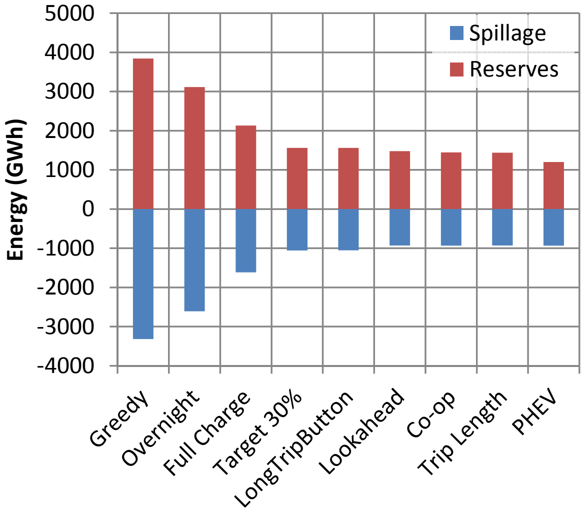

Figure 1: Energy balance by charging strategy

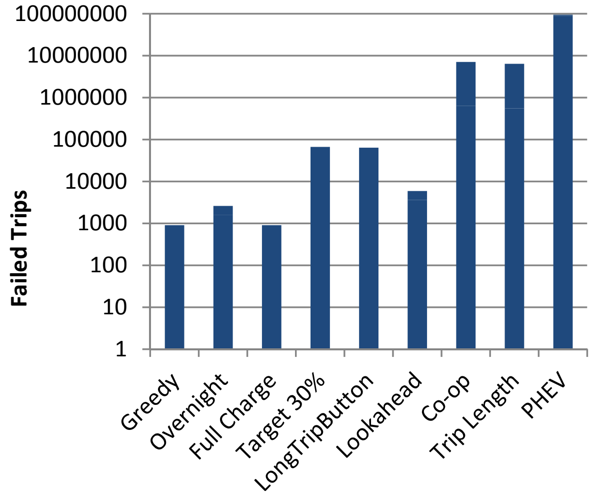

Figure 2: Failed Trips by charging strategy

2. THE POWER OF KNOWLEDGE

Previous work has explored the energy balance between electricity generation and load using an agent-based simulation, taking into account the variability of wind generation and the introduction of large numbers of EVs [5]. Smart charging strategies reduce the grid impacts of EVs, and help accommodate intermittent generation sources. However, achieving this relies on the assumption that future trips are known in advance, so that charging strategies have information to work with. In this paper we build on the existing simulation framework to explore the implications of having limited access to future trip information, in order to establish the importance of user interfaces to assist a driver with providing details for upcoming trips.

The parameters of interest include the time of next departure **(T)**, the length of the next trip **(L)**, notice of an upcoming long journey **(N)**, and the specification of multiple—or multi-stage–trips in the immediate or near future **(M)**. These parameters are tested for their effects on energy spillage (excess generation potential where no storage is available), energy required from reserves during generation shortages, and the number of trips that are unable to be completed due to insufficient charge at the time of departure. The simulation is run over one year, for one million EVs, and a generation profile of 30% wind and 70% base load.

A description of charging strategies follows, including the information required by each.

Greedy (-)
: When connected, charge until full

Overnight (-)
: Charge between the hours of 0100 and 0700

Full Charge (TN)
: Target a full charge at the time of next departure using the *Co-op* strategy

Target 30% (-)
: Target a 30% charge using *Greedy*, then use *Co-op*

Long Trip Button (N)
: Similar to *Target 30%*, but allows the user to invoke a full charge for an upcoming long trip

Lookahead (TLNM)
: Target a sufficient charge at the time of next departure to enable completion of a sequence of upcoming trips, using the *Co-op* strategy

Co-op (TLN)
: Target a sufficient charge to enable the next trip at the time of next departure, while adjusting charge/discharge (V2G) rates to match available supply

Trip Length (LN)
: Target a sufficient charge to enable the next trip using the *Greedy* strategy, then revert to *Co-op*

PHEV (-)
: The *Co-op* strategy with no charge target; fuel is used when electricity is not available for charging

From the results shown in figures 1 and 2, there is a clear trade-off between energy balance and the number of failed trips. Charging strategies that have access to more information about the future behaviour of a vehicle tend to perform better overall; in particular, the *Lookahead* strategy is very competitive in terms of energy balance, while maintaining an acceptable level of failed trips—but also requires the most detailed information about the upcoming use of the vehicle.

3. USER INTERFACES

Charging strategies tend to perform better with access to more information about the upcoming use of the vehicle. These parameters may be learnt to some extent, however there are always exceptions to regular usage patterns. This information must therefore be specified by a driver though a user interface. This could range from a simple "full charge" button that provides notice of an upcoming long trip **(N)**, to a multi-stage journey planner that can assist with route planning in addition to providing charging strategies with the information required. It is imagined that the proposed user interface will be implemented on a touch-enabled display within the vehicle itself, and utilise gestures such as

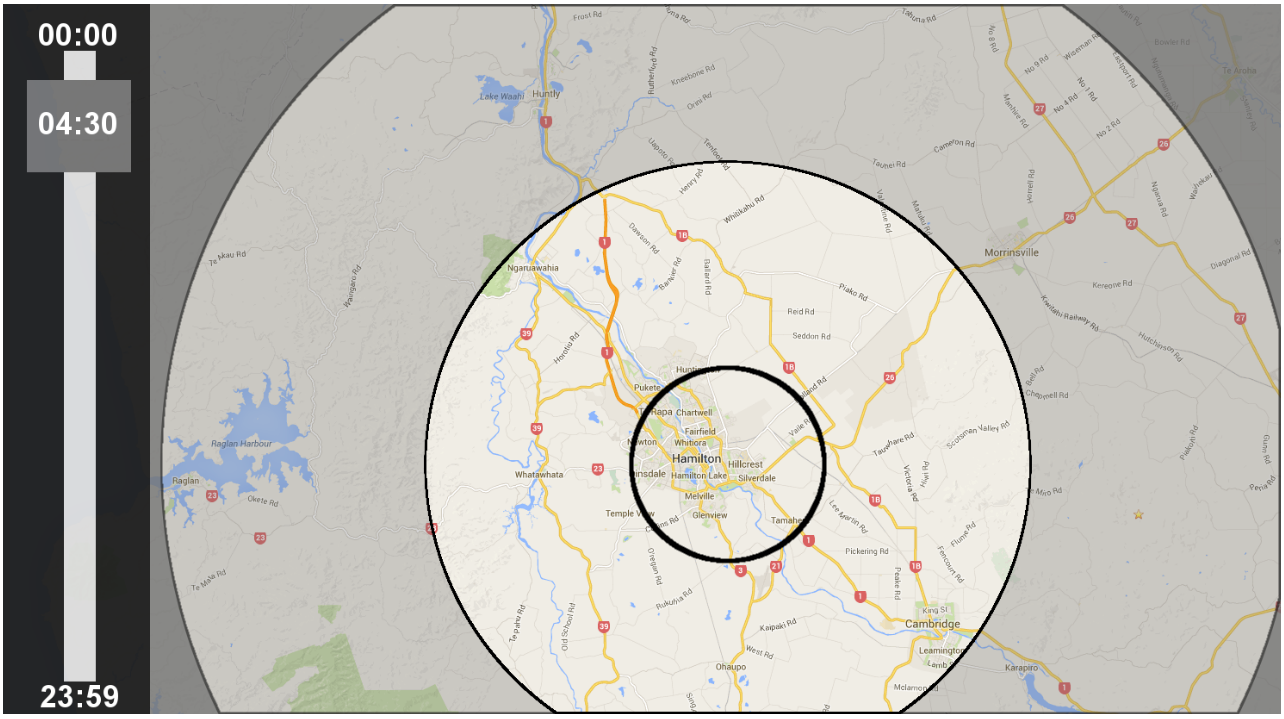

Figure 3: Visual interface to specify the next trip

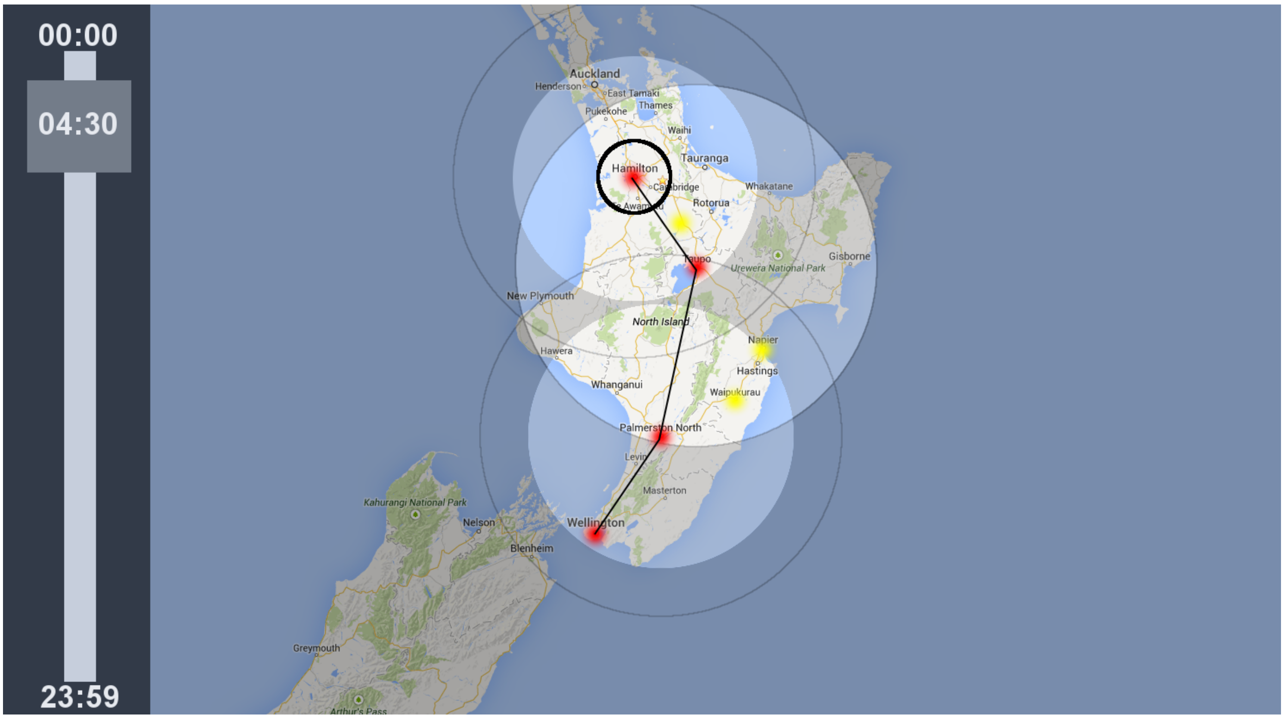

Figure 4: Visual interface to plan a sequence of trips

pinch zoom. It may also be useful to have the interface accessible via web or mobile, for situations where the requirements change while the driver is away from the vehicle.

Figure 3 illustrates an example user interface that allows a driver to specify details of the next trip to be completed by the vehicle. On the left is a slider that specifies the time of next departure **(T)**, while the main area illustrates the current location and estimated range of the vehicle. The outer circle represents the range of the vehicle at full charge, while the innermost circle represents the range at the vehicle's current state of charge. The intermediate circle represents the charge target required at the time of departure **(L)**, which may be adjusted by selecting a destination on the map. There is no reason why the current state of charge cannot be greater than the target; in this case, the surplus energy becomes available to support the grid. The example shown is of a driver planning to travel from Hamilton to Cambridge at 04:30, with a relatively low state of charge at present. As the time of departure approaches, the inner circle will change in radius according to the characteristics of the charging strategy in use.

Figure 4 shows an expansion of the idea to assist with the planning of a longer journey, involving several intermediate charging stopovers. In this example, the driver is planning a journey from Hamilton to Wellington, with stopovers in Taupo and Palmerston North. The outer circles again represent the fully-charged range from each selected charging station (shown in red), while the highlighted areas represent the charging targets to be achieved at those points. Alternative charging points (shown in yellow) may be selected, and will update the display accordingly. Once the driver has explored possible routes, the sequence of upcoming trips **(M)** becomes available for use by the selected charging strategy.

4. DISCUSSION

The development of advanced visual interfaces to support the adoption, integration and use of EVs is of particular interest. EVs provide significant opportunity towards the goal of reducing greenhouse gas emissions through having zero tailpipe emissions themselves, while also supporting the integration of intermittent renewable generation sources; however, they are not without their own challenges. Their successful adoption will require fundamental changes in both electricity grid operation and driver behaviour. A critical part of easing the transition is providing tools to help drivers to understand the performance limitations of EVs, and make the most of opportunities such as revenue from providing ancillary services to the grid.

The concept of a "smart grid" involves a great deal of automation and interaction with end users. This is especially true when considering EVs. It is imagined that an end user can specify goals, create a plan to achieve the goals with the assistance of advanced visual interfaces, and then leave the details to automation. In the example presented in this paper, a driver may specify a goal of "travel to Wellington tomorrow", and with the assistance of a journey planner might incorporate several stopovers along the way. Once this is finalised, a charging strategy can take over with a primary focus to enable the journey, and, where possible, make the vehicle's battery available to provide ancillary services.

This paper has described how the performance of electric vehicle charging strategies is affected by the level of information available, and provides an example visual user interface that allows a driver to specify this information, and also help plan longer journeys that involve intermediate charging stopovers. There are a number of factors that the proposed interface does not address, including provision for return journeys, destinations without charging facilities, and the exploration of how much time is spent at intermediate stopovers when planning routes.

5. FUTURE WORK

Future work should include the implementation and evaluation of the visual interfaces presented in this paper. Any user interface will require some effort from the driver; it is important to ensure that the effort is justified when compared with the benefits achieved.

Both versions of the interface use circles to denote the range of an EV. This seemingly ignores terrain and road layout; however, charge targets could be calculated as being able to reach any point within the circle by the most direct route, plus some safety margin, rather than relying on straight-line distances. In other words, the circles could represent minimums rather than absolute distances. This aspect must be considered in the implementation and evaluation. If circles prove insufficient, polygons may be the solution—at the expense of a more cluttered interface.

While this paper has presented preliminary results of how the performance of charging strategies is affected by limited access to information, there are many (often conflicting) factors to consider when comparing the overall "performance" of a charging strategy, and indirectly, user interfaces.

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