Context-aware Microgrid Storage using Electric Cars

Michael Donohoe
TSSG
Waterford Institute of Technology
Ireland
Email: mdonohoe@tssg.org

Brendan Jennings
TSSG
Waterford Institute of Technology
Ireland
Email: bjennings@ieee.org

Sasitharan Balasubramaniam
Dept. of Electronics and Communications Engineering
Tampere University of Technology
Finland
Email: sasi.bala@tut.fi

***Abstract*—Electric cars could provide a viable power storage option for suburban microgrids. Such stored power could be used by the microgrid or supplied to the main grid at key times as part of the operation and management of a microgrid cluster. Tracking driver behaviour then becomes important in order to estimate and forecast the level of stored power at any given time. Context-aware information gathered from external sources such as an electronic work calendar can provide one means of predicting driver and car movements. We are using simulation studies to quantify the benefit of such context-aware information for calculating and forecasting battery storage capacity in a microgrid cluster. This capacity is then used in a simulation of power trading between the cluster and a main grid.**

***Index Terms*—microgrid, context-awareness, electric car**

I. Introduction

Domestic and industrial microgrids, providing distributed generation (DG) and possibly energy storage will be a key part of the emerging smart grid. A cluster of microgrids can be organised as a Virtual Power Provider (VPP) with a centralised controller communicating with local or domestic controllers on the one hand and a grid supplier on the other. A cluster controller will supervise the import and export of power in line with price points and agreed forecasts. A typical microgrid will have a mix of sources to (a) provide a balanced amount of power and (b) minimise the import of power from the grid. In any given domestic location it may be difficult to realise these objectives throughout the day as there will inevitably be gaps between the production level and consumption requirements. If some method of energy storage (e.g. battery storage) is provided then this can help to fill the gaps. Electric cars are seen as a potential method of storing power and then delivering that power to the microgrid or main grid (vehicle-to-grid or V2G) at certain intervals if necessary. The number of cars associated with the cluster and their availability at any time becomes an important factor in computing available battery capacity. Tracking and predicting driver behaviour is one way that the location of cars can be determined. The charge-state of the car will also indicate if it can be used as a source of power. This paper describes the use of sources of such *context-aware* information in determining driver behaviour and battery charge-state. Microgrid operation and storage are described in §II while relevant context-aware systems are in §III. The simulation model for forecasting improved storage potential is described in §IV with conclusions and future work in §V.

II. Suburban Microgrid

The electrical demand in a microgrid arises from the cumulative use of electrical appliances throughout the day. Typically this peaks in the morning and evening with additional seasonal and weekend variations. The bulk annual electrical demand and usage profiles for a country or a region will be known by the main supplier. Determining the exact power consumption profile of individual houses or small clusters is more difficult and would normally require detailed household survey data. In the absence of such detailed data, models have to rely on inferring appliance usage and power consumption from samples of household activity. A model derived from time-use data is described by Widen et al [2] where diaries of household activities were translated into corresponding power demands (where applicable). The output of the model was compared with a sample of specific household-use profiles. There was generally good correlation, though the accuracy did depend on how well the time-use diaries were completed. Similar time-of-use data was used by Richardson et al [3] in their model for UK household usage and it too was correlated with samples of real usage data.

A microgrid control system can assist in providing a closer match between peaks in demand and production in response to price points (import and export tariffs) as well as producing short-term forecasts. A deficit in power needs to be imported but a surplus must be either exported or stored. Exporting and importing surplus electrical energy in line with agreed forecasts or as part of a power-auction process requires a continuous interconnection with the main grid, a normal situation for any house. However power storage is a more difficult matter as it may not be possible to accommodate a large bank of storage batteries in a house or apartment. The only partial alternative is to draw down power from the charged battery of an electric car.

A. Electric Cars as Storage

Electric car batteries at present can store typically16kWh (Peugeot Ion) to 24kWh (Nissan Leaf). The charging time will vary depending on the type of charger. Typical charging

TABLE I
CHARGER CHARACTERISTICS

Time	*Power Supply*	*Max. Current*
6-8 hours	Single-phase 3.3kW	16A
2-3 hours	Three-phase 10kW	16A
3-4 hours	Single-phase 7kW	32A
1-2 hours	Three-phase 24kW	32A
20-30 mins	Three-phase 43kW	63A
20-30 mins	Direct Current 50kW	100-125A

times for different types (single-phase, three-phase, DC) are shown in Table I. The charging cycle of the car and its use during the day then becomes an important issue in determining the availability of stored power or the need for charging power. A stochastic model to simulate the driving behaviour of electric cars is described by Fluhr et al in [4]. The model used data from a major mobility survey in Germany to generate electric vehicle driving profiles. Three charging strategies were also modelled and the conclusion was that some form of controlled charging strategy was needed to avoid adding to power demand at peak times in the morning and evening. A market-based controlled charging strategy is proposed by Ghijsen and D'hulst in [5]. They note that the realisation of such a model requires a high degree of automation and improved information sources. Similarly Sundstrom and Binding [6] propose that a Charging Service Provider (CSP) would devise an optimised charging schedule for a vehicle using individual information and grid constraints. Again the objective is to reduce peak load while still meeting the charging requirements of each vehicle. The model assumes that key driver information is available but doesn't specify the sources. The authors also note the need for some method to minimise prediction errors in driver behaviour. Another approach is to derive aggregated charging patterns for the daily and seasonal demand and hence derive values for stored reserve power, as Keane and Flynn show in [7]. However the behaviour of individual drivers can still only be modelled based on some general usage patterns rather than very specific individual information. The challenge of modelling driver behaviour is similar to the challenge of modelling individual microgrid consumer behaviour. Some bulk statistical information will be available about daily driving profiles, usually through census information and transport surveys. The modelling objective then becomes one of generating individual profiles that reflect a wide variety of behaviours that, when aggregated would give a microgrid cluster profile. One area that can provide additional driver behaviour information is context awareness.

III. Context-awareness in Microgrid Management

Context-aware applications are designed to incorporate *presence* i.e. where a person/consumer is located at a particular time (home, work, leisure), what they are doing, what services might they require in that particular situation (context) and where those services are (proximity). A pervasive sensor network tracks the consumer movement. Sensor output is then evaluated and fused, sometimes with a user profile and other

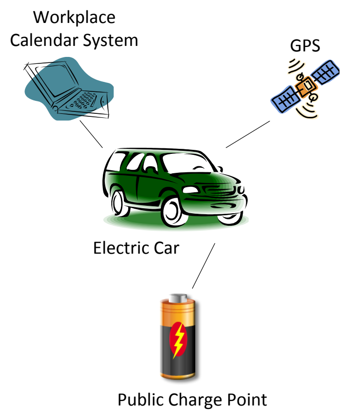

Fig. 1. Sources of Context Information

database information. This can generate a picture of consumer behaviour and likely requirements in certain locations (e.g. a workplace or shopping centre). Furthermore a prediction of likely behaviour can also be derived so that a forecast of requirements can be made. An overview of context modelling and reasoning is provided by Bettini et al [8]. Model requirements are listed and the three most prominent modelling approaches (object role, spatial, ontology) are described. A specific example of the use of context awareness for elderly homecare is in Pung et al [9] where context information is gathered by sensors in real physical spaces and mapped to abstract context spaces for further computation and behaviour prediction. In the case of microgrid storage, context-awareness can be used to track driver behaviour and hence the likely location and availability of their cars. In order to determine whether or not cars are available for storage the following inputs would be needed:

- a numerical distribution of electric cars for a typical microgrid cluster
- their availability (location) at any given time
- the state of charge of the battery
- the probability that they will remain at a given location for a certain period of time.

Information on general driver daily whereabouts could be inferred indirectly from a 'soft' work calendar. If the car uses a work-based or public charging system during the day then it too can provide relevant location and charge-state information, assuming the owner can be identified at the charger. The car could also periodically report its location based on GPS information. Potential sources of context information are shown in Figure 1. The information obtained from such sources would have to be integrated into a microgrid control system if it is to be used for power, storage and forecasting calculations.

A. *Context Sources for Electric Cars*

A workplace electronic calendar system (e.g. GoogleCalendar) can provide detail about the routine of a car owner during the working day. Most calendar systems can interwork with and update other similar systems (using standards like iCalendar) particularly for synchronising tasks and agreeing schedules through alerts and requests. A microgrid controller as part of its customer profile maintenance could contain an electronic calendar for every customer. A customer's work calendar could be set to synchronise with the controller's calendar for setting projected work start and finish times. The microgrid controller could then build a database of work start and finish times (and be aware of changes made by the customer) based on information received from the work calendar. The microgrid control system would also have a standard daily profile for each customer's car based on historical information such as detachment from the domestic charger in the morning and reattachment in the evening. Forecasts based on these profiles could be modified in line with updates from the work calendar system. There would still be some uncertainty around the accuracy of the information (a person may still leave work earlier or later than indicated) and this has to be incorporated in any modelling system. A workplace calendar or year-planner could also provide forecast information for work-related travel or vacation absence. This gives a longer term prediction of the general availability of cars in the microgrid and hence can assist annual forecasting.

Public charge points may also be able to provide information on the charge-state of particular cars to a grid control system especially if some form of driver identification is required. If an identified driver is also registered with a particular microgrid cluster then the grid control system can inform the microgrid control system of charge status. Ideally the car itself would be able to report periodically to the microgrid controller on the charge state at set intervals. A GPS system can provide the exact location of the car. This in turn can be used to compute the relative position of the car in relation to workplace, home or the nearest public chargers. Hence some predictions can be made, based on the position of the car, on the likely time of arrival at home. In summary then these additional sources of information can provide more accurate information about the movement of cars in and out of the microgrid every day. This information can be used in two key ways: (a) scheduling the home charging of cars to avoid overloading the distribution grid and (b) computing the level of stored power that would be available for export to the grid, subject to the car being fully charged by the following morning.

IV. Modelling and Simulation of Car Movements

Details of travelling patterns in Ireland (start time, distance travelled, modes etc.) were collected in the National Travel Survey 2009 [10] and the Irish census of population in 2011 [11]. Both of these sources show the majority of commuting even in suburban areas is by car. A bulk spread of commuter departure from home times as well as the spread of work start times is shown in Figure 2 as normal plots. The difference in width between the two plots reflects the spread in commuting times. The first stage of our context-aware simulation uses the idea of workplace calendar information to provide more accurate information on the daily movement of cars in and out of a suburban microgrid cluster. Any given microgrid cluster will have its own particular household composition and daily profile. If we consider two different scenarios we can illustrate key potential differences in typical driver profile.

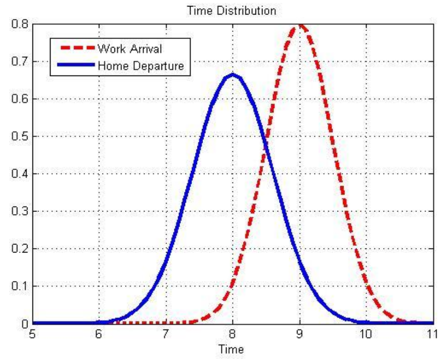

Fig. 2. Home departure times and work-start times

- A cluster with families where one or both partners work full-time or part-time and where there are children of school-going age.
- A cluster with predominantly older retired people who may have a car but use it mainly for leisure purposes.

The first type of cluster will exhibit a more typical commuting profile on weekdays with cars having a largely predictable pattern. At weekends however there could be more variability in driving behaviour. In the second case the cluster is likely to have a similar car-usage profile on both weekdays and weekends and there will be no noticeable departure of cars to workplaces on a weekday. Prediction of car usage is more difficult as workplace calendars may simply not be used by the majority of drivers. Consequently additional sources of information (other than work calendars) will be needed to cover (a) weekends in the first cluster and (b) all days in the second. These additional sources could include personal electronic calendars (subject to appropriate permissions), specific charge-state information and GPS traces. Our initial simulations however are directed at working weekdays in the first type of cluster. The modelling and simulation data is as follows:

- a distribution of 300 electric cars in a suburban microgrid cluster of 1000 houses
- the general daily usage pattern of the cars reflects current Irish behaviour
- initially only workdays are in scope, not weekends or public holidays
- cars are assumed to be fully charged when leaving home.

A sample daily profile for a specific car is shown in Figure 3 where the car changes from state 1 (at home) to state 0 (away)

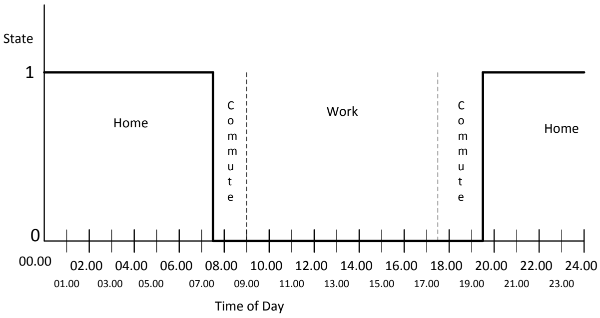

Fig. 3. Daily profile and state changes of one typical car

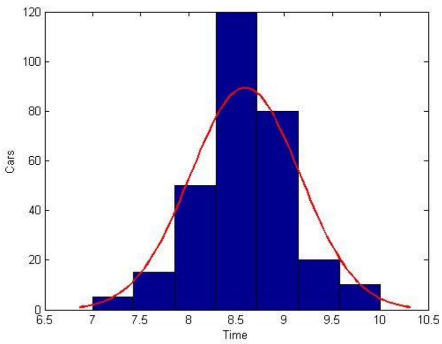

Fig. 4. Work arrival time for 300 cars

at the time of departure (detaching from the domestic charger). A certain commuting time elapses before the start of work. Similarly in the evening when work ends there is also a return commuting time before arrival back at home where the state changes back to 1.

A. Calculating Storage Potential

The state changes for any given car will occur within specific timeslots, though these timeslots can vary from day to day. Our Matlab-based simulator uses transition-state matrices and cluster-state matrices to model the daily movement of cars. The simulations show the effect of a certain percentage of cars consistently reporting a more specific departure and arrival time. In particular the simulations study the effect of cars reporting start or finish times outside of peak hours. The simulated work arrival time for 300 cars is shown in Figure 4 where it's known from work calendars that the majority start at 8:30. The distribution does not fit a normal curve (superimposed).

A comparison between the volumes of traffic arriving at work in the morning under the bulk distribution and under the simulation model distribution is shown in Table II. In both cases all cars have arrived by 10:30. However the peak arrival slot for the bulk profile is 8:30 to 9:30 while the peak arrival slot for the simulation model is 7:30 to 8:30. The work arrival times can be projected back to corresponding home departure times by deducting the commuting times. The average commuting time in Ireland varies from 26 minutes to 50 minutes with the latter more common in the largest urban areas. A spread of departure times can be generated around such an average. Such a projection shows that the peak home-departure slot for the bulk profile (7:30 to 8:30) is approximately one hour later than the simulation model peak home-departure slot (6:30 to 7:30). For a cluster with 300 cars this translates to (a) the bulk profile showing approximately 50 cars having left by 7:30 and (b) the simulation profile showing approximately 190 cars having left by 7:30. This difference of 140 cars means far less battery capacity is available in the microgrid cluster (3360 kwh if the cars are 24kwh capacity) than a bulk profile would have indicated. Such differences even over one hour can be crucial when trying to estimate the level of power available for trading or the spare capacity available for storage.

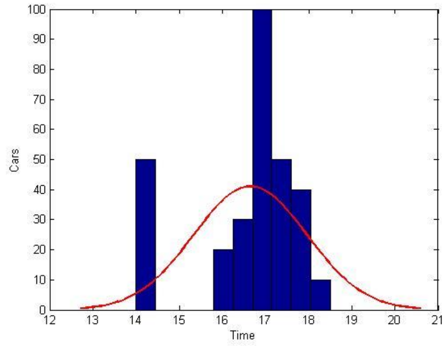

Fig. 5. Work departure time for 300 cars

In the afternoon and evening a work calendar should give some advance information on an earlier than normal departure from work. A simulated departure profile in Figure 5 shows 50 cars departing work at 14:00. This may be for personal purposes (school open day, vacation etc.) but in particular it may signal an earlier than normal arrival at home.

TABLE II
CAR WORKPLACE ARRIVAL VOLUMES (CUMULATIVE)

Profile	*7:30-8:30*	*8:30-9:30*	*9:30-10:30*
Bulk	16%	84%	100%
Model	63.3%	96.6%	100%

B. Power Auction

At present in Ireland there's no time-of-day variable consumption tariff and the standard 24 hr tariff is of the order of 17c per kwh. However in a recent smart metering trial (2010) the following tariffs were tested:

- 8.00 to 17.00, 13c per kwh
- 17.00 to 19.00, 32c per kwh
- 19.00 to 23.00, 13c per kwh
- 23.00 to 8.00, 10c per kwh

In wholesale auctions power markets use a System Marginal Price (SMP), set for half-hourly intervals. The more accurate knowledge of short term storage capacity feeds directly into the auctioning system that the cluster controller uses for bidding to supply power to the grid. These are likely to be day-ahead auctions so the cluster controller needs to have the best possible forecast of available export power (stored and generated) for every half-hour slot. The actual power offered will also depend on the tariff for offered power and this could vary across the day.

On a normal day the cluster supplies power in line with the agreed forecasts and tariffs and it may not supply any V2G power if it's not required. However if an exceptional situation occurs (unforecasted surge or drop in wind power) and the grid requests extra power during the day then the cluster may be in a position to supply extra from storage if (a) it has enough information to know that cars (sufficiently charged) will be available at the required time and (b) the tariff offered for the extra power makes it worthwhile. In our afternoon simulation scenario the control system predicts that 50 cars will be arriving home early (15.00) with different levels of charge. They will start charging at home either using microgrid power (no import cost) or grid power at 13c per kwh. The controller could offer this stored capacity (maximum 1200kwh for 24kwh batteries) in advance to the grid for peak evening use at relatively short notice. The tariff received for this power should reflect the fact that (a) it's supplied at peak time and (b) it's on foot of a special request. The cars can be recharged later on using lower-rate evening or night-time power (13c or 10c per kwh). The cluster can make a profit on the transaction if the export tariff offered is greater than the evening charge rate (i.e. anything greater than 13c per kwh).

The results of multiple detailed simulation scenarios such as those described will quantify the benefits of the use of context-aware information derived from a work calendar in providing better details of departure and arrival times in the microgrid. The next stage is to combine the model with simulated charge-state information, some of it derived directly from charge points. The output will provide (a) storage capability at any time, (b) charging schedules for cars to avoid surges, (c) power available for use in the microgrid or for export to the main grid and (d) short term forecasts for power optimisation and market trading.

V. Conclusions

Modelling individual human behaviour is a complex task. If electric cars are to be used as microgrid storage then tracking and predicting driver behaviour is necessary in order to compute storage potential and battery charging scheduling. Valuable bulk traffic movement information can be obtained from traffic surveys and census information. Individual behaviour can also be tracked by time-usage surveys but there's a limit as to how extensive and accurate these can be. A better alternative is to harvest electronic information from a number of sources that are routinely accessed by the driver of an electric car in the course of a working day. We have focussed initially on simulating the use of context aware information from an electronic workplace calendar to provide better predictions of home departure and arrival times. Once we have completed simulations to quantify the benefits of such information over a range of scenarios we will then include external charging information sources. Ultimately our storage prediction model will be integrated with an optimisation model that will incorporate cluster power production and consumption, forecasting and power auctioning.

VI. Acknowledgement

This work was partially funded by the Irish Higher Education Authority under the Programme for Research in Third Level Institutions (PRTLI) cycle 5, which is co-funded by the European Regional Development Fund (ERDF), via the Telecommunications Graduate Initiative (http://www.tgi.ie).

References

[1] J. V. Paatero and P. D. Lund, "A model for generating household electricity load profiles," *International Journal of Energy Research*, vol. 30, no. 5, pp. 273–290, 2006. [Online]. Available: http://dx.doi.org/10.1002/er.1136

[2] J. Widen, M. Lundh, I. Vassileva, E. Dahlquist, K. Ellegard, and E. Wackelgard, "Constructing load profiles for household electricity and hot water from time-use datamodelling approach and validation," *Energy and Buildings*, vol. 41, no. 7, pp. 753 – 768, 2009. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0378778809000413

[3] I. Richardson, M. Thomson, D. Infield, and C. Clifford, "Domestic electricity use: A high-resolution energy demand model," *Energy and Buildings*, vol. 42, no. 10, pp. 1878 – 1887, 2010. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0378778810001854

[4] J. Fluhr, K.-H. Ahlert, and C. Weinhardt, "A stochastic model for simulating the availability of electric vehicles for services to the power grid," in *System Sciences (HICSS), 2010 43rd Hawaii International Conference on*, 2010, pp. 1–10.

[5] M. Ghijsen and R. D'hulst, "Market-based coordinated charging of electric vehicles on the low-voltage distribution grid," in *Smart Grid Modeling and Simulation (SGMS), 2011 IEEE First International Workshop on*, oct. 2011, pp. 1 –6.

[6] O. Sundstrom and C. Binding, "Flexible charging optimization for electric vehicles considering distribution grid constraints," *Smart Grid, IEEE Transactions on*, vol. 3, no. 1, pp. 26 –37, march 2012.

[7] E. Keane and D. Flynn, "Potential for electric vehicles to provide power system reserve," in *Innovative Smart Grid Technologies (ISGT), 2012 IEEE PES*, jan. 2012, pp. 1 –7.

[8] C. Bettini, O. Brdiczka, K. Henricksen, J. Indulska, D. Nicklas, A. Ranganathan, and D. Riboni, "A survey of context modelling and reasoning techniques," *Pervasive Mob. Comput.*, vol. 6, pp. 161–180, April 2010. [Online]. Available: http://dx.doi.org/10.1016/j.pmcj.2009.06.002

[9] H. K. Pung, T. Gu, W. Xue, P. P. Palmes, J. Zhu, W. L. Ng, C. W. Tang, and N. H. Chung, "Context-aware middleware for pervasive elderly homecare," vol. 27, no. 4, pp. 510–524, 2009.

[10] CSO, "National travel survey 2009," Central Statistics Office, Tech. Rep., 2011.

[11] Census2011, "Profile 10 door to door - commuting in ireland," Central Statistics Office, Tech. Rep., 2012.