Demand management of electric vehicle charging using Victoria’s Smart Grid

Project report

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Acknowledgements

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Disclaimer

The views presented in this report represent those of the report authors alone and should not be considered those of the contributors or the organisations that they represent.

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1 Executive summary

This demonstration project has delivered the world’s first use of a Smart Grid for electric vehicle charging demand management.

In doing so, the project has demonstrated significant benefits for consumers and utilities from the Australian state of Victoria’s rollout of Smart Meters. It has also highlighted opportunities to ensure these benefits are fully realised as Victoria’s Smart Grid matures and electric vehicles become more widespread.

As part of the demonstration, electricity demand was managed for the first time using the Victorian Advanced Metering Infrastructure (AMI). In managing Electric Vehicle (EV) charging through the Smart Grid, the project has demonstrated how EVs can be integrated into our electricity networks – easily, conveniently and cheaply.

For drivers, the benefits are clear. Based on residential electricity tariffs and the project outcomes, Victorian electric vehicle drivers could save around $250 per year, or around 50 per cent on their charging costs, by adopting ‘Smart’ charging practices. Grid-integrated ‘Smart’ charging technology would deliver this saving without sacrifice or effort on their part.
For utilities, the potential challenge posed in adding electric vehicle charging to existing demand may actually be an opportunity. Managing electric vehicle charging at the network level will not only defer costly infrastructure upgrades through peak demand management, but may deliver better returns on existing investments through improved asset utilisation. Grid-integrated ‘Smart’ charging technology would deliver these benefits and avoid creation of a ‘second peak’ in electricity demand as drivers individually defer charging to the off-peak period. Importantly, the outcome from these improvements will be lower costs for all electricity consumers – not just those who drive EVs.

The project also demonstrated how the relationship between utilities and consumers is a key to delivering the best outcomes for all. Consumers have indicated a willingness to defer their vehicle charging, including having it managed remotely, if provided with easy, convenient and financially-beneficial options. For a utility to control a potentially significant load on their network, consumer cooperation may be increased through the provision of real-time information via the Advanced Metering Infrastructure.

The importance of a fully integrated solution was also highlighted by the project. The home charging solution deployed for the project integrated the vehicle, the grid and the driver seamlessly and effectively. Differences were observed in the control strategies for different vehicle types, and grid integration required an approach tailored to the arrangements adopted by the electricity utility. The drivers received and responded to information provided through the web, their smartphone and via email/text message. The project home charging solution was successful in bringing these elements together with little effort from drivers or the electricity utility.

While the demonstration was successful in showcasing the benefits of Victoria’s Smart Grid, it also highlighted opportunities for improved outcomes. Easy, open and reliable access to the AMI Consumer Home Area Network (HAN) would assist consumers and utilities alike. Clarity on the Consumer HAN roles and responsibilities should also be a priority for action – refer below for the full list of recommendations.

The report documents the demonstration project as follows:

- Section 2 provides a brief introduction to electric vehicle charging, the Smart Grid and demand management
- Section 3 is an overview of the demonstration project
- Section 4 describes the project inputs, including the participants and the demand management strategies
- Section 5 explains the technologies used and their operation
- Section 6 reports the project outputs, including the system performance, charging profiles and participant acceptance
- Section 7 summarises key findings and implications, including recommended actions to ensure the benefits of Smart Grid investment are fully realised
- Section 8 concludes the report and summarizes the recommendations
Recommendations

Based upon the findings from the demonstration project, a range of recommendations have been identified for consideration that will aid in fully realising the benefits from Victoria’s Smart Grid investment – for more detail refer to Section 7:

Smart Grid

- **Reduce the barriers to market access** for Smart device providers by facilitating AMI Consumer HAN device interoperability across Distribution Network Service Providers (Recommendation no.1)

- **Improve consumer access to and confidence in Victoria’s Smart Grid** by addressing issues relating to the AMI Consumer HAN connection, performance and governance (Recommendation no’s 2 – 5)

- **Promote Smart Grid innovation** by establishing performance levels for various applications based on system response time (Recommendation no.6)

Demand management

- **Promote electricity demand management** through consideration of consumer costs, benefits and information requirements (Recommendation no’s 7, 8 and 10)

- **Reduce uncertainties relating to demand management effectiveness** by clarifying utility expectations and device capabilities (Recommendation no’s 9 and 11)
2 Introduction

This report documents the outcomes from an in-field demonstration of electric vehicle charging management using the Australian state of Victoria’s ‘Smart Grid’.

The demonstration project forms part of the Victorian Government Electric Vehicle Trial. The Trial is $5-million initiative to be completed in mid-2014 that is aimed at helping Victoria better understand the process, timelines and barriers for transitioning to electric vehicle technologies. The Trial will make Victoria an EV-friendly place through improved understanding and acceptance of electric vehicles.

Through the Trial a better understanding is being gained into the issues and opportunities associated with electric vehicle charging. As part of these investigations, insights are being sought into the use of Victoria’s emerging ‘Smart Grid’ for the purpose of managing electric vehicle charging.

DiUS Computing, along with project partners the Victorian Department of Transport, United Energy and University of Melbourne, have undertaken a project to investigate use of Victoria’s smart grid for the purpose of managing charging of electric vehicles deployed to households participating in the Trial.

To assist with reader understanding, answers to some common questions relating to the project are provided below:

2.1 What is electric vehicle charging?

Electric vehicles use electricity for some or all of their propulsion energy. Charging of electric vehicles generally involves a cable/plug into a wall socket similar to charging of mobile phones and other battery-powered devices. In its simplest form, electric vehicle charging begins once the driver plugs in and ends either when the battery is fully charged or the plug is removed (whichever occurs first).

2.2 Why electric vehicle (EV) charge management?

Compared to most other uses of electricity in the home, electric vehicles use a lot of electricity. By way of comparison, electric vehicle charging by a typical driver may increase their household electricity use by around 30 per cent.

Equally important is when charging takes place, as electricity networks are designed and built for times when demand for electricity is greatest. As electric vehicle charging times may coincide with and add to this peak demand, management of this additional demand may be required to avoid costly increases in network capacity.
Electric vehicle drivers may also wish to take advantage of cheaper electricity prices that are available at various times in the day. In being able to manage their charging, electric vehicle drivers can minimise their household energy costs.

For a more detailed account of the case for electric vehicle charging demand management, refer to Appendix A.

2.3 What are the EV charge management options?

At a practical level, Electric Vehicle charging can be managed a variety of ways:

- Drivers can simply plug in and out when it suits them, for example when it is cheaper to charge
- Some electric vehicles come equipped with charge management technology that may allow for charging to be scheduled and/or controlled remotely by the driver
- If installed, dedicated electric vehicle charging equipment will generally provide charge management capabilities that support scheduling and/or remote control – by the driver or a third-party such as the utility

Management of EV charging forms part of the larger challenge that is management of electricity demand. The network-level strategies for management of electricity demand are generally described in terms of demand or supply-side approaches:

- Demand Response (DR), is where consumers alter their electricity use in response to financial incentives, such as ‘peak’ versus ‘off-peak’ tariffs; the changes can include deferring energy-consuming activities, implementing on-site electricity generation or adopting more energy efficient usage options
- Direct Load Control (DLC), sometimes known as load management or simply load control (LC), is where electricity utilities balance the supply and demand on the network by reducing the load rather than increasing the supply capacity; this can be achieved by direct intervention by the utility to reduce load (such as temporary power outages to avoid more damaging overloads), or via ‘ripple control’ as is used on electric hot water heaters in some parts of Australia

These network-level strategies are applied via the means listed above:

- Price signals and/or information may induce a Demand Response by drivers
- Intervention in the vehicle charging by the utility is a form of Direct Load Control

2.4 What is a ‘Smart Grid’ and how does it relate to EV charging?

A ‘Smart Grid’ is an advanced electricity network that incorporates sensors, communications and computing to promote efficient management of the network. The most visible component

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1 ‘Ripple control’ is a form of direct load control where a higher-frequency signal above the standard power signal is sent through power lines to receiver devices that shut down electrical loads until another high frequency signal is received.
of a smart grid is the ‘Smart Meter’ that measures electricity use in people’s homes and communicates in real-time with the network.

Management of EV charging through the Smart Grid may include real-time/remote monitoring, messaging and control to help ensure that impacts on the network from the increased electricity demand are minimised. When the driver manages their vehicle charging in response to information supplied through the Smart Grid, this is a form of Demand Response (DR). When the utility intervenes in the vehicle charging using the Smart Grid, this is a form of Load Control (LC).

2.5 How can the Smart Grid be used to manage EV charging in Victoria?

The rollout of Smart Meters to Victorian households and small business commenced in late 2009 and is due to be completed by the end of 2013. As of December 2012, four Victorian electricity market participants had launched web portals that allow homeowners to access information about their electricity use obtained via their Smart Meter. For more information about Victoria’s Smart Grid refer to Appendix B.

As part of the rollout, the Smart Meters can also be used to communicate with appliances that are registered through the Smart Grid in a process known as ‘binding’. This feature of the Smart Grid enables real-time/remote management of electric vehicle charging through any dedicated charging device able to communicate with the network in this way.

The ChargeIQ EV home charge management system developed and operated by DiUS Computing is able to communicate with Victoria’s Smart Meters through a Home Area Network (HAN) interface that utilises the Zigbee\(^2\) communications protocol. When the ChargeIQ terminal is bound to the household’s Smart Meter, various network communications can be passed to the terminal via the Smart Meter. These messages can be understood and acted upon by the ChargeIQ for optimised management of EV charging. Such communications may include variable electricity pricing and notification of electricity demand management events. For more information about the ChargeIQ EV home charge management system refer to Appendix C.

2.6 What will demonstration of EV charge management using Victoria’s Smart Grid tell us?

Management of EV charging through the electricity network represents the first occasion electricity demand has been managed using Victoria’s Smart Grid, and one of the earliest Smart Grid demand management applications anywhere.

The learnings acquired from this milestone achievement will help deliver returns on our Smart Grid investment – more efficient use of our resources, saving us money and helping the environment.

\(^2\) Zigbee is a registered trademark owned by the Zigbee Alliance
3 Project outline

3.1 Objective

To demonstrate electric vehicle charge management capabilities using Victoria’s ‘Smart Grid’

3.2 Method

The project utilised three key inputs to demonstrate management of EV charging using Victoria’s Smart Grid:

(i) Households participating in the Victorian Government’s EV Trial (‘Household Participants’)

(ii) DiUS Computing’s ChargeIQ Zigbee-certified EV home charge management system (‘ChargeIQ’)

(iii) Victoria’s Smart Grid as deployed and operated by United Energy (‘UE’), a Victorian electricity Distribution Network Service Provider (DNSP)\(^3\)

Through coordination of the Household Participants, ChargeIQ and UE, the basic technology is in place for demonstrating various Smart Grid capabilities and EV charging attributes. Critically however, systems integration and operation of the EVs, ChargeIQ and UE represent the key activities for the demonstration to be of relevance. In particular, the DNSP’s ability at an operational level to utilise the Smart Meters for management of the EV charging load represents a significant milestone in the context of realising the benefits of Victoria’s Smart Grid investment.

Specific activities (outlined below) included:

- Inputs in preparation for the demonstration project (‘Inputs’/Section 4)
- Assembly and operation of the technology system to support the demonstration project (‘Technology’/Section 5)
- Capturing/documenting key outputs from the demonstration project (‘Outputs’/Section 6)
- Interpreting the outputs from the demonstration project in the context of Victoria’s Smart Grid (‘Implications’/Section 7)

\(^3\) A Distribution Network Service Provider own and operate the ‘poles and wires’ that link the electricity generators to the end-users – notably, they are not electricity retailers
3.2.1 Inputs

- System integration, for the various End-to-End system components ('System integration'/Section 4.1 and Appendices A and B)
- Household participant guidance, including for ‘Grid-friendly’ EV charging and the ChargeIQ system ('Household participant guidance'/Section 4.2 and Appendices D and E)
- Household participants, including the number of participants and analysis of participant charging behaviour as an input to generating the EV charge management schedule for the project ('Household participants'/Section 4.3 and Appendix F)
- Charge management scenarios, including Demand Response/Load Control interventions that simulate real-world network events ('Charge management scenarios'/Section 4.4)

3.2.2 Technology

- End-to-end system, including the UE Advanced Metering Infrastructure (AMI) network, ChargeIQ home EV charge management system, and the electric vehicles ('End-to-end system'/Section 5.1)
- System operation, including device binding through the AMI, end-to-end system operation and operation of the ChargeIQ charge management system ('System operation'/Section 5.2)

3.2.3 Outputs

- System performance, including the Consumer HAN connection and end-to-end system response times ('System performance'/Section 0)
- Charging demand management, including assessment of aggregate and individual charging behaviours in the context of the Demand Response/Load Control interventions ('Charging demand management'/Section 6.2)
- Charging demand profiles, including for the different Demand Response/Load Control scenarios ('Charging demand profiles'/Section 6.3)
- Participant acceptance, including outcomes from a survey of participant attitudes ('Participant acceptance'/Section 6.4 and Appendices H and I)
4 Inputs

As outlined in Section 3.2, a range of activities were undertaken as inputs into the demonstration project:

1. System integration – activities to integrate the various End-to-End system components ahead of the demonstration project
2. Household participant guidance – preparation of Household Participant guidance including for ‘Grid-friendly’ EV charging and the ChargeIQ system
3. Household participants – scoping the project participants and analysis of participant charging behaviour as an input to generating the EV charge management schedule for the project
4. Charge management scenarios – creation of Demand Response/Load Control interventions that simulate real-world network events

4.1 System integration

A range of activities were undertaken in the lead-up to the demonstration project that may be collectively thought of as system integration tasks:

1. ChargeIQ system integration – as a reflection of the agreed project scope, integration of the administration, web and notification servers with the ChargeIQ terminal, including specifically areas relating to Demand Management operation
2. Charge management system integration – integration of the UE Smart Meter, ChargeIQ terminal and the Electric Vehicles, including specifically the Zigbee Smart Energy Demand Response/Load Control (DRLC) messages and mapping to the SAE J1772 Electric Vehicle charging standard interface
3. Consumer HAN system integration – including registration and binding of the ChargeIQ terminal to the household Smart Meter, and detailed mapping of the Zigbee Smart Energy DRLC messages for charging load adjustment

4.2 Household participant guidance

Two documents were deemed to be necessary to support the Household Participants:

1. ‘Grid-friendly’ EV charging guide – to explain the background to the project, what was going to happen, and how this would affect them (refer to Appendix D – Electric Car Driver Guide to Grid-friendly Charging)
2. ChargeIQ system guide – to assist with use of the various system elements including the ChargeIQ terminal, website and smartphone application (refer to Appendix E – How to Manage Grid-friendly Charging)
4.3 Household participants

The demonstration project was delivered as a subset of the Victorian Electric Vehicle Trial, where Household Participants are provided with an electric vehicle and home charging solution for a three month period. For the demonstration project, ten Household Participants were selected to take part on the basis of them having received the ChargeIQ home charging system.

Household Participant charging behaviours were monitored for the first few weeks of their EV ‘ownership’ experience. Analysis of the charging behaviours was undertaken to inform design of the EV charge management schedule for the project. The objective of this ‘pre-analysis’ was to identify times of the day/week when a charge management event would be most likely to impact upon the Household Participant charging behaviours.

A decision was made to focus upon the Monday through Thursday charging behaviours, as this period was felt to most likely reflect ‘standard’ charging practices. Between 11 and 24 charging events were logged for each Household Participant over the pre-analysis period, with the distribution of charging behaviours varying markedly. The most significant influence on charging behaviour was the choice of charge mode – On-demand versus ‘Smart’ charging (known to the project participants as ‘ChargeNow’ and ‘ChargeIQ’ respectively). For those participants who predominantly used the default ‘Smart’ charging option, charging event times commenced between 10 and 11pm. Conversely for those who favoured On-demand charging, their session times commenced between 6:30 and 9pm. Once charging commenced, the average duration was between two and three hours.

As an outcome from this analysis it was decided to focus the charge management events Monday through Thursday evenings between 7 and 10pm. Section 4.4 and Appendix F provide further detail on the final charge management event schedule adopted for the project.

4.4 Charge management scenarios

Charge management scenarios were designed in consultation with United Energy (UE), the Distribution Network Service Provider (DNSP) participating in the project. A price signal was included in the project design to more closely replicate projected real-world conditions. The charge management scenarios incorporated both demand (consumer) and supply (utility) elements, providing a demonstration of Demand Response and Load Control strategies.

The foundation for the charge management scenarios were network management responses to likely real-world scenarios:

- Foreseeable peak electricity demand events that coincide with extreme (hot) weather conditions
- Scheduled maintenance of network infrastructure, such as a planned outage of a transformer or power line
- Avoidance of system overloads, for example due to a combination of unexpected network infrastructure failure and extreme weather/high demand scenarios
• Unplanned failures of network infrastructure, for instance due to lightning strikes

The likely network management responses to these scenarios were mapped out and overlaid on the Household Participant charging behaviours observed in Section 4.3 so as to generate a schedule of charge management events most likely to engage the Household Participants.

An additional consideration was made with regards the project delivery constraints. As the charge management events were scheduled to unfold at a rate of two per week timed to coincide with the most likely Household charging periods, an ‘opt-out’ option was maintained for Household Participants under all scenarios, including ‘Emergency charge management’. This was deemed appropriate so as to avoid the perception that future Smart Grid operation will consist of frequent and compulsory intervention in the Household electricity use.

A summary of the charge management scenarios deployed in the trial can be seen in Table 1 below.

<table>
<thead>
<tr>
<th>Charge management scenario</th>
<th>Attributes</th>
<th>Trial deployment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scheduling</td>
<td>Demand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>reduction</td>
</tr>
<tr>
<td>Peak charge management</td>
<td>Pre-planned / 24-hrs notice</td>
<td>50%</td>
</tr>
<tr>
<td>Emergency charge management</td>
<td>Unplanned / 10 to 15 mins notice</td>
<td>100%</td>
</tr>
<tr>
<td>Smart charging</td>
<td>Default ChargeIQ system operating mode (= ‘ChargeIQ’)</td>
<td>Charging deferred to off-peak periods</td>
</tr>
<tr>
<td>Demand charging</td>
<td>Household selection (= ‘Charge Now’)</td>
<td>None</td>
</tr>
</tbody>
</table>

Table 1 - Summary of charge management scenarios deployed as part of the project

The charge management demonstration was delivered over four weeks, translating to four ‘Peak’ and four ‘Emergency’ charge management events per Household Participant. Refer to Appendix F for the detailed charge management event schedule.

These events were delivered against the backdrop of the Household Participant charging behaviours, which required the vehicle to be plugged in and Demand charging to have been selected for any actual demand (charge) management by the DNSP to take place. It should be noted however that the notifications supplied to the Household Participants through the

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4 Under a real-world Emergency charge management (Load Control) scenario this would be expected to be mandatory (rather than opt-out) – refer to body text for explanation
AMI/ChargeIQ systems also allow them to manage their charging (a demand response outcome).

In the future it is envisaged wider adoption of demand management would incorporate some form of financial incentive for households and businesses. Incentives today include Time-of-Use (ToU) tariffs to encourage consumers to adjust their demand to off-peak periods. It is foreseeable that financial incentives for direct utility control of electricity use would need to be put in place to reward/penalise EV owners for participating in the demand management program.

To more closely replicate these forecast real-world conditions, a financial incentive for the Household Participants was included as part of the project in the form of a gift certificate to the value of $40. Household Participant were informed that the final value of the gift certificate would be determined according to their response to the charge management events. Opting out of an event would decrease the value of the certificate by $5, translating to zero reward in the instance of a Participant opting-out of all eight charge management events.

A breakdown of the charge management scenarios according to the commonly accepted definitions of Demand Response and Load Control indicates that attributes of both are present in all cases – refer to Table 2 below.

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5 Although the trial participants were told that the penalty of opting out was $5, when the trial was complete all participants were still given the full $40 certificate in recognition of their help with the trial.
<table>
<thead>
<tr>
<th>Charge management scenario</th>
<th>Demand Response features</th>
<th>Load Control features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak charge management</td>
<td>• Opt-out option for Participants</td>
<td>• Utility control of charging</td>
</tr>
<tr>
<td></td>
<td>• Financial reward for not opting-out</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Information supplied to inform decision-making, including advance warning, cost</td>
<td></td>
</tr>
<tr>
<td></td>
<td>information, charging impacts estimation</td>
<td></td>
</tr>
<tr>
<td>Emergency charge management</td>
<td>• Opt-out option for Participants</td>
<td>• Utility control of charging</td>
</tr>
<tr>
<td></td>
<td>• Financial reward for not opting-out</td>
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<td></td>
<td>• Information supplied to inform decision-making, including advance warning, cost</td>
<td></td>
</tr>
<tr>
<td></td>
<td>information, charging impacts estimation</td>
<td></td>
</tr>
<tr>
<td>Smart charging</td>
<td>• Opt-out option for Participants</td>
<td>• Off-peak tariff information supplied by utility through AMI</td>
</tr>
<tr>
<td></td>
<td>• Financial reward for not opting-out</td>
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<tr>
<td></td>
<td>• Information supplied to inform decision-making, including cost information, charging</td>
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<td>impacts estimation</td>
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<td></td>
<td>impacts estimation</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 - Summary of charge management scenarios deployed as part of the project
5 Technology

The technology elements included in the trial were as follows:

1. End-to-end system – consisting of UE Advanced Metering Infrastructure (AMI) network, ChargeIQ EV home charging system, and the electric vehicles
2. System operation – including device binding through the AMI, end-to-end system operation and operation of the ChargeIQ charge management system

5.1 End-to-End system

The End-to-End system configuration used in the trial is shown in Figure 1 below. The system is based on the ChargeIQ system and the United Energy (UE) Advanced Metering Infrastructure (AMI) Network.

![Figure 1 - End-to-end charging demand management system deployed for the demonstration project](image)

With reference to Figure 1 above, the core elements of the system include:

5.1.1 UE AMI Network

Including:

1. UE Demand Response manager used to schedule and issue load control events
2. Customer portal that provides a user interface to access the UE AMI Network
3. AMI radio mesh network providing the wireless communications link between the UE backend office/Demand Response Manager and the Smart Meter
4. Household Participant Smart Meter

Further explanation of the Victoria’s Smart Grid can be found in Appendix B.
5.1.2 ChargeIQ Electric Vehicle home charge management system

Including:

5. ChargeIQ terminal – physical connects the electricity network to the car; provides a user interface for charge management; communicates with the Smart Meter and the ChargeIQ server

6. ChargeIQ terminal manager – provides the communications pathway between the Smart Meter and the ChargeIQ user applications; includes the web and notification servers; logs the user charging activity data

7. ChargeIQ user applications – provides information and/or control to the EV driver via the ChargeIQ web portal, smartphone application, SMS and email

Further explanation of the ChargeIQ EV home charge management system can be found in Appendix C.

5.1.3 Electric Vehicles

8. Cars being operated by the Victorian Electric Vehicle Trial Household Participants including the Mitsubishi i-MiEV and the Nissan LEAF.

5.2 System operation

5.2.1 Device binding

The first step in commissioning the end-to-end system into service is ‘binding’ of the ChargeIQ terminal to the Household Participant Smart Meter. Binding is the process of registering a device to a household Smart Meter so that it can be communicated with through the AMI network.

The ChargeIQ terminal is bound to a meter by entering the device MAC address and unique installation code along with the National Meter Identifier (NMI) for the household Smart Meter into the AMI web portal. Under real-world conditions this may be done by the homeowner, electricity utility or third-party product/service provider, however in the interests of ensuring all Household Participants were ready for the charge management events this task was done by the project team.

5.2.2 End-to-end system

Once the ChargeIQ terminal has been bound to the Smart Meter, the end-to-end system operation deployed for the trial is described below:
1. Schedule events – charge management events are scheduled in advance on the UE Demand Response Manager

2. Despatch events – charge management messages are issued to the Smart Meter NMI over the UE AMI radio mesh network by the UE Demand Response Manager at the specified time – one day ahead for Peak Charge Management events and 15 min ahead for Emergency Charge Management events

3. ChargeIQ terminal notification – charge management messages are delivered to the ChargeIQ terminal from the Smart Meter over the Consumer HAN interface

4. ChargeIQ terminal manager notification – charge management messages are sent from the ChargeIQ terminal to the terminal manager over a wireless connection on the 3G cellular network

5. ChargeIQ message despatch – the ChargeIQ terminal manager delivers charge management event details through the website and smartphone application, and initiates message despatch from the notification server to the Household Participant’s nominated email account and phone number

6. User notification – any charge management event impacting vehicle charging is displayed on the ChargeIQ website and smartphone application

5.2.3 ChargeIQ charge management system

The ChargeIQ electric vehicle home charge management system was the key enabler for the Demand Response/Load Control (DRLC) demonstration. ChargeIQ allowed Victoria’s Advanced Metering Infrastructure (AMI) to communicate with the vehicle and the householder, and permitted the householder to respond easily and appropriately. For more information about the ChargeIQ charge management system, refer to Appendix C.
For the demonstration project, the ChargeIQ system integrated the specific characteristics of the Victorian Smart Grid with the electric vehicles participating in the project.

ChargeIQ maps the Zigbee Smart Energy Profile (SEP) Demand Response/Load Control (DRLC) messages issued by the utility to the vehicle standard SAE J1772 charging interface controls, adjusting the maximum vehicle current draw from the household electricity supply.

The ChargeIQ system operation varied according to the vehicle type due to differences between vehicles. The vehicles used in the trial included a Mitsubishi i-MiEV and Nissan LEAF. The method employed to adjust EV load varied with vehicle type and was based on two different SEP1.1 specified DRLC cluster techniques which are described below.

(i) **Duty Cycle Adjustment**: the 2010 Model Year i-MiEV does not implement the full SAE J1772 interface. Specifically the vehicle did not adhere to changes in duty cycle adjustments of the SAE J1772 Control Pilot interface. The method used in this scenario was to adjust charging by duty cycle control of the 240Vac supply.

For example, to effect a 50 per cent reduction in load over a three hour DRLC event the vehicle would charge for a period of 1.5 hours and on average charge at 50 per cent over the three hour period — refer to Figure 3 for an illustration of this.

(ii) **Average Load Adjustment**: the Nissan LEAF supported load adjustment directly via signalling on the SAE J1772 Control Pilot. Adjusting the control pilot to the appropriate duty cycle would result in the vehicle adjusting the level of charge current accordingly. As illustrated in Figure 4 below:

- Control Pilot with duty cycle of 25 per cent: results in a load of 15A
- Control Pilot with duty cycle of 12.5 per cent: results in a load of 7.5A (a 50 per cent load adjustment)

---

6 SAE J1772 Control Pilot: The J1772 Control Pilot is the primary control mechanism used to manage mains supply by the EVSE to the Electric Vehicle. The Control Pilot is nominally a 1 kHz square wave. Signalling between the EVSE and vehicle is achieved by adjusting the amplitude and duty cycle of the square wave.

7 This technique relies on enough terminals in the load control event to spread the load statistically over the period to yield a net effect of 50% reduction.
Central to the DRLC demonstration were the user (or Household Participant) facing elements – the charging terminal, website, email/SMS messaging and smartphone application. These system elements provide information to the user about charge management events that impact vehicle charging, and allow the user to respond accordingly:

(i) Following despatch of the charge management event from the UE Demand Response Manager to the ChargeIQ terminal, the Household Participant is informed of the approaching event via email, SMS and through the website/smartphone application

(ii) Using the website/smartphone application, the Household Participant is able to understand the implications of different charge management options available to them in response to the event – in terms of the estimated time their vehicle would commence/complete charging, and the costs associated with different charge management options

Based on this information, the Household Participant managed their vehicle charging according to their specific needs and priorities – to ensure their vehicle was charged when they needed it, at the least cost to them.
6 Outputs

The outputs from the demonstration project were as follows:

1. System performance – including the Consumer HAN connection and end-to-end system response times
2. Charging demand management – assessment of aggregate and individual charging behaviours in the context of the charge management (Demand Response/Load Control) activities
3. Charging demand profiles – for each of the charge management scenarios
4. Participant acceptance – based on a survey of participant opinions

Snapshot of results

System performance
- One residence out of nine participants had inadequate Consumer HAN connectivity
- Transmission time over AMI mesh network was between one and 25 seconds
- Time for messages to reach the ChargeIQ terminal was between two seconds and 42 minutes

Charging demand management
- 56% of charge events were undertaken as ‘Smart’ (off-peak) charging
- 11% of charging load control events resulted in a load shift
- Vehicle use was largely unaffected by charge management

Charging demand profiles
- Charging load management was successfully achieved using partial load reduction strategies tailored to the vehicle characteristics
- Charging loads are greatest at the outset of charging events

Participant acceptance
- Participants were accepting of charge management as direct load control, although this was influenced by financial benefit and voluntary/mandatory participation
- Information and control were key influences on participant acceptance of charge management
6.1 System performance

6.1.1 Consumer HAN connection

As part of the demonstration project an assessment was made of the Consumer HAN operation in terms of connection reliability.

A total of ten households were selected to take part in the demonstration project on account of them having received the ChargeIQ home charging system. Of these ten households, one household had not received their Smart Meter, and so were unable to take part in the demonstration.

Additionally, one of the installations exhibited poor radio connectivity between the ChargeIQ terminal and household Smart Meter. Connectivity was checked through verification of the number of Zigbee Smart Energy Demand Response/Load Control (DRLC) messages being received by the terminal. Connectivity was at best intermittent with only occasional data packets being received over a period of three to four days.

Although some messages were successfully transmitted, time synchronisation between the meter and terminal was unreliable. Maintaining time synchronisation is essential for correct operation of the charging terminal – in particular DRLC functionality. As a consequence, this household was excluded from the DRLC part of the trial.

To assist with assessment of the root cause for the poor connection, specific site details for the household are outlined below:

- Estate is relatively new with household smart meters located in a common area away from the premises – see Figure 5 for an overhead view of site and relative location of devices
- The ChargeIQ terminal was mounted inside the premises carport behind a brick wall and no direct line of sight with Smart Meter
- The Smart Meter is mounted inside a metal enclosure on the side of the street – Figure 6 shows the outdoor meter enclosure
- The distance between the ChargeIQ terminal and the Smart Meter was approximately 33 metres
- There was no evidence to suggest that the transmission performance of the devices involved was not within specifications – the ChargeIQ terminal performance was verified before installation, and although the Smart Meter performance was not verified, the configuration was confirmed as being 200mW transmission power standard
- In a direct line of site situation, the distance in this installation would not be expected to be a problem for communication between the devices

With the expectation of wider adoption of ZigBee-based devices connecting to Smart Meters and our experience with this specific household, further investigation of the Victorian AMI HAN operation appears warranted – this is discussed further in Section 7.
Figure 5 - Overhead view of the estate where poor Consumer HAN connectivity was experienced

Figure 6 - Common meter area for the household where the poor Consumer HAN connectivity was experienced
6.1.2 System response times

An objective of the trial was to assess end-to-end system response times for receipt of messaging across the AMI network and customer-facing systems. Figure 7 below shows the measurement points for system response times.

![Diagram showing system response times](image)

**Figure 7 - Measurement points for the end-to-end system response times**

The times shown are all relative to when a message is despatched from the UE Demand Response Manager. With reference to Figure 7 above, each of the four points identified show the time taken:

1. From UE Demand Response Manager to household Smart Meters
2. From UE Demand Response Manager to ChargeIQ terminals
3. From UE Demand Response Manager to ChargeIQ terminal manager
4. From UE Demand Response Manager to ChargeIQ notification server message despatch

<table>
<thead>
<tr>
<th></th>
<th>Min</th>
<th>Max</th>
<th>Av</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Smart Meters</td>
<td>00:01</td>
<td>00:25</td>
<td>00:06</td>
<td>00:07</td>
</tr>
<tr>
<td>(2) ChargeIQ terminals</td>
<td>00:02</td>
<td>42:17</td>
<td>01:39</td>
<td>06:46</td>
</tr>
<tr>
<td>(3) ChargeIQ terminal manager</td>
<td>00:02</td>
<td>50:03</td>
<td>09:40</td>
<td>15:46</td>
</tr>
<tr>
<td>(4) ChargeIQ notification server message despatch</td>
<td>00:03</td>
<td>50:03</td>
<td>09:45</td>
<td>15:43</td>
</tr>
</tbody>
</table>

Table 3 - Summary of end-to-end system response times (n = 64, time format mm:ss)
The times for messages to propagate over the AMI network and be received by the household Smart Meters were centred on two intervals (refer also to Figure 8 below): 51 events at ~2 seconds and 13 events at ~20 seconds.

Figure 8 - Histogram of household Smart Meter charge management event message receipt times (n = 64)

For the most part the ChargeIQ terminals received the event messages within one to two seconds of receipt by the household Smart Meters. As can be seen from Figure 9 below, there are a number of outlying events – these were received at ~ 6, 37 and 42 minutes. One possible reason for these outlying events is the method used by the ChargeIQ terminal to synchronise time over the terminal 3G connection – an area for improvement that DiUS has identified for the product.

Figure 9 - Histogram of ChargeIQ terminal manager charge management event message receipt times (n = 61)
The response times of the ChargeIQ terminal manager showed 70 per cent of event messages being received within 30 seconds. However, average response times of approximately 10 minutes show that there is a great deal of scope for improvement.

The results also highlight there was little difference in response times between the ChargeIQ terminal manager and notification servers.

Although these response times are adequate for small-scale trials, improvements would be needed for larger deployments. Simple architectural improvements can be made that would result in ChargeIQ terminal manager response times in the order of one to two seconds or better.

### 6.2 Charging demand management

To understand how the charging demand management demonstration unfolded, the results are presented in aggregate and at the individual participant level.

#### 6.2.1 Aggregate charging behaviours

Charging events, loads, connection times and durations were recorded for all participants.

Table 4 below shows the aggregated number of vehicle charge events for all ten participants over the three month period of their EV ‘ownership’ experience, broken down according to on-demand versus ‘Smart’ (off-peak) charging.

In considering the split of ‘Smart’ versus on-demand charging, it should be noted that:

- ‘Smart’ charge is the default setting for the ChargeIQ system (in other words, users need to deliberately select ‘on-demand’ charging for charging to commence during ‘peak’ periods)
- Only one of the households was on a Time-of-Use (ToU) tariff (all others were on a flat rate)
- The ToU household contributed 49 ‘Smart’ charge versus 28 On-demand charge events

<table>
<thead>
<tr>
<th>Charging activities</th>
<th>No.</th>
<th>%</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Smart’ charge events</td>
<td>365</td>
<td>56</td>
<td>‘Smart’ charge is ChargeIQ system default setting</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>49 events (7%) by household with ToU tariff</td>
</tr>
<tr>
<td>On-demand charge events</td>
<td>291</td>
<td>44</td>
<td>28 events (4%) by household with ToU tariff</td>
</tr>
<tr>
<td>Total vehicle charge events</td>
<td>656</td>
<td>100</td>
<td>Average of ~50 charge events per week</td>
</tr>
</tbody>
</table>

*Table 4 - Aggregated charging events for ten households over their three month EV ‘ownership’ experience*
The charge management events were issued to eight of the ten participants only (refer to Section 0 above). The breakdown of charging activities over the demonstration project period inclusive of the charge management events can be seen in Table 5 below.

<table>
<thead>
<tr>
<th>Charging activities</th>
<th>No.</th>
<th>Comment</th>
</tr>
</thead>
</table>
| Total charge management events issued                    | 64    | Four ‘Peak’ charge management events and four ‘Emergency’ charge
|                                                          |       | managements events issued to each of eight households over four week period |
| Total charge events during demonstration project period   | 124   | For the eight Household Participants taking part in the four week
|                                                          |       | charge management event period, including all charge management events |
| Smart charge events during demonstration project period   | 29 of 64 | Vehicle charged in ‘Smart’ charging mode on day of charge
|                                                          |       | management event                                                      |
| Vehicle charging activities impacted by charge management events | 6 of 64 | Vehicle charge affected by charge management event                     |
| Incidence of vehicle not charging during charge management events | 28 of 64 | Vehicle was either connected and not charging (i.e. fully charged), or not connected at time of charge management event |
| Incidence of charge management event messages not received by ChargeIQ terminal | 3 of 64 | Charge management event message not received by charging terminal       |

**Table 5 - Aggregated charging events for ten households over demonstration project duration**

Of the 64 charge management events issued, six events affected vehicle charging through load control, on 28 (of 64) occasions the vehicle was either not connected or fully charged, and on 29 occasions the vehicle was set up to charge at off-peak times (i.e. ‘Smart’ charge).

On three occasions the charge management event messages reached the Smart Meter, but failed to reach the ChargeIQ terminal. One of the failed events coincided with an on-demand charge, consequently the vehicle charged normally. The three failed events were:

- Event #2 participant VIC009EVT05, Oct 18 Emergency charge management
- Event #3 participant VIC009EVT05, Oct 24 Peak charge management
- Event #6 participant VIC003EVT05, Oct 31 Emergency charge management

The exact reason for the failure to receive the charge management event messages was unclear – possible explanations include:

- The ChargeIQ terminal was powered down at the time of the charge management event
- There was radio interference at the time at the time of the charge management event
• Ambient noise levels at the site were such that a greater level of Signal-to-Noise margin was required for the Consumer HAN interface

The charging load breakdown for the project can be seen in Table 6 below:

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total overall vehicle charging load across ten participants/three months</td>
<td>4,444.4 kWh</td>
</tr>
<tr>
<td>Average charge event duration / std dev (hh:mm)</td>
<td>2:35 / 1:22</td>
</tr>
<tr>
<td>Average vehicle charging load per participant</td>
<td>37 kWh/wk</td>
</tr>
<tr>
<td>Total On-demand charging load</td>
<td>1,930.3 kWh</td>
</tr>
<tr>
<td>Total ‘Smart’ charging load (load shifted to off-peak times)</td>
<td>2,514.1 kWh</td>
</tr>
<tr>
<td>Percentage charging load shifted to off-peak times due to ‘Smart’ charging</td>
<td>57%</td>
</tr>
<tr>
<td>Total charging load affected by a charge management events</td>
<td>43.2 kWh</td>
</tr>
<tr>
<td>Total charging load shifted under direct load control charging management events</td>
<td>21.4 kWh</td>
</tr>
<tr>
<td>Ratio of “charging load shifted under direct load control charge management events” to “total load affected by charge management events”</td>
<td>49%</td>
</tr>
<tr>
<td>Ratio of “charging load shifted under direct load control charge management events” to “total overall charging load”</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

**Table 6 - Summary of charging events and load shift**
Figure 10 - Distribution of connection (plug-in) times for Household Participants over their three month EV ‘ownership’

Figure 11 - Distribution of disconnection (plug-out) times for Household Participants over their three month EV ‘ownership’
6.2.2 Individual charging behaviours

To assist with understanding the variability across the data-set, a breakdown of charging behaviours at the individual participant level is provided below.

The breakdown of the charging method employed by each participant is shown in Table 7 below. Although the most common mode used to charge a vehicle was ‘Smart’ charging, this can vary considerably between participants. The data shows a wide variation from almost exclusively on-demand charging to exclusively ‘Smart’ charging.

<table>
<thead>
<tr>
<th>Participant ID</th>
<th>ChargeIQ ID</th>
<th>No. of charge events</th>
<th>No. of on-demand charge events</th>
<th>No. of ‘Smart’ charge events</th>
<th>% Smart charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIC012EVT05</td>
<td>10011</td>
<td>78</td>
<td>6</td>
<td>72</td>
<td>92%</td>
</tr>
<tr>
<td>VIC006EVT04</td>
<td>10013</td>
<td>54</td>
<td>37</td>
<td>17</td>
<td>31%</td>
</tr>
<tr>
<td>VIC008EVT05</td>
<td>10018</td>
<td>82</td>
<td>68</td>
<td>14</td>
<td>17%</td>
</tr>
<tr>
<td>VIC022EVT003</td>
<td>10017</td>
<td>45</td>
<td>8</td>
<td>37</td>
<td>82%</td>
</tr>
<tr>
<td>VIC005EVT05</td>
<td>10023</td>
<td>40</td>
<td>37</td>
<td>3</td>
<td>8%</td>
</tr>
<tr>
<td>VIC028EVT003</td>
<td>10015</td>
<td>78</td>
<td>29</td>
<td>49</td>
<td>63%</td>
</tr>
<tr>
<td>VIC009EVT05</td>
<td>10021</td>
<td>101</td>
<td>46</td>
<td>55</td>
<td>54%</td>
</tr>
<tr>
<td>VIC020EVT003</td>
<td>10024</td>
<td>34</td>
<td>4</td>
<td>30</td>
<td>88%</td>
</tr>
<tr>
<td>VIC003EVT05</td>
<td>10020</td>
<td>81</td>
<td>6</td>
<td>75</td>
<td>93%</td>
</tr>
<tr>
<td>VIC031EVT05</td>
<td>10022</td>
<td>63</td>
<td>50</td>
<td>13</td>
<td>21%</td>
</tr>
</tbody>
</table>

Table 7 - Breakdown of charging activities for individual participants

Table 8 below the total EV charging load over the trial period for each participant. Details of the amount of charging demand shifted due to ‘Smart’ charging and direct Load Control by the utility (during ‘Peak’ or ‘Emergency’ charge management events) are also provided.
### Table 8 - Breakdown of charging load distribution for individual participants

The connection time, start of charge time and charge duration are provided in Table 9 below.

<table>
<thead>
<tr>
<th>Participant ID</th>
<th>ChargeIQ ID</th>
<th>Total charging load (kWh)</th>
<th>On-demand charging load (kWh)</th>
<th>'Smart' charging load (kWh)</th>
<th>% Charging demand shifted ('Smart' charge)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIC012EVT05</td>
<td>10011</td>
<td>344.9</td>
<td>30.0</td>
<td>314.9</td>
<td>91%</td>
</tr>
<tr>
<td>VIC006EVT04</td>
<td>10013</td>
<td>271.7</td>
<td>176.0</td>
<td>95.7</td>
<td>35%</td>
</tr>
<tr>
<td>VIC008EVT05</td>
<td>10018</td>
<td>543.2</td>
<td>504.2</td>
<td>39.0</td>
<td>7%</td>
</tr>
<tr>
<td>VIC022EVT003</td>
<td>10017</td>
<td>491.8</td>
<td>54.7</td>
<td>437.1</td>
<td>89%</td>
</tr>
<tr>
<td>VIC005EVT05</td>
<td>10023</td>
<td>235.1</td>
<td>217.9</td>
<td>17.2</td>
<td>7%</td>
</tr>
<tr>
<td>VIC028EVT003</td>
<td>10015</td>
<td>627.9</td>
<td>197.9</td>
<td>430.0</td>
<td>68%</td>
</tr>
<tr>
<td>VIC009EVT05</td>
<td>10021</td>
<td>707.1</td>
<td>400.5</td>
<td>306.6</td>
<td>43%</td>
</tr>
<tr>
<td>VIC020EVT003</td>
<td>10024</td>
<td>421.5</td>
<td>27.8</td>
<td>393.7</td>
<td>93%</td>
</tr>
<tr>
<td>VIC003EVT05</td>
<td>10020</td>
<td>373.5</td>
<td>27.3</td>
<td>346.2</td>
<td>93%</td>
</tr>
<tr>
<td>VIC031EVT05</td>
<td>10022</td>
<td>427.7</td>
<td>294.0</td>
<td>133.7</td>
<td>31%</td>
</tr>
</tbody>
</table>

### Table 9 - Breakdown of charging activity times for individual participants

<table>
<thead>
<tr>
<th>Participant ID</th>
<th>ChargeIQ ID</th>
<th>Av connection/plug-in time (hh:mm)</th>
<th>Av charging activity start time (hh:mm)</th>
<th>Av charging activity end time (hh:mm)</th>
<th>Av charge duration (hh:mm)</th>
<th>std dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIC020EVT003</td>
<td>10024</td>
<td>17:05</td>
<td>20:55</td>
<td>3:34</td>
<td>1:57</td>
<td></td>
</tr>
<tr>
<td>VIC005EVT05</td>
<td>10023</td>
<td>17:27</td>
<td>17:30</td>
<td>4:46</td>
<td>2:23</td>
<td>1:30</td>
</tr>
<tr>
<td>VIC031EVT05</td>
<td>10022</td>
<td>16:50</td>
<td>17:28</td>
<td>4:37</td>
<td>2:28</td>
<td>1:19</td>
</tr>
<tr>
<td>VIC009EVT05</td>
<td>10021</td>
<td>18:58</td>
<td>20:40</td>
<td>3:51</td>
<td>2:59</td>
<td>1:12</td>
</tr>
<tr>
<td>VIC003EVT05</td>
<td>10020</td>
<td>15:50</td>
<td>22:11</td>
<td>6:00</td>
<td>2:34</td>
<td>0:50</td>
</tr>
<tr>
<td>VIC008EVT05</td>
<td>10018</td>
<td>18:29</td>
<td>19:18</td>
<td>4:06</td>
<td>2:50</td>
<td>1:34</td>
</tr>
<tr>
<td>VIC022EVT003</td>
<td>10017</td>
<td>18:47</td>
<td>17:19</td>
<td>7:40</td>
<td>2:18</td>
<td>1:31</td>
</tr>
<tr>
<td>VIC028EVT003</td>
<td>10015</td>
<td>19:09</td>
<td>15:31</td>
<td>7:35</td>
<td>1:59</td>
<td>1:31</td>
</tr>
<tr>
<td>VIC006EVT04</td>
<td>10013</td>
<td>16:07</td>
<td>17:37</td>
<td>5:03</td>
<td>2:24</td>
<td>1:11</td>
</tr>
<tr>
<td>VIC012EVT05</td>
<td>10011</td>
<td>19:01</td>
<td>20:32</td>
<td>6:00</td>
<td>2:19</td>
<td>0:59</td>
</tr>
</tbody>
</table>
6.3 Charging demand profiles

To help understand how charging loads vary with time, the demand profiles for each charging scenario were recorded.

6.3.1 On-demand charging profile

Figure 12 below shows a typical on-demand charging profile with the ChargeIQ terminal configured in ‘ChargeNow’ mode.

In this instance the user plugged in the vehicle at 2:55 pm and configured the terminal for ‘ChargeNow’ mode. The vehicle started to charge immediately with the first consumption event occurring at 2:56 pm.

The vehicle completed charging at 5:50 pm with all vehicle consumption occurring during the peak load period of the day. The total load for this charge event was 8.7 kWh.

![Figure 12 - On-demand charging profile – Participant ID VIC031EVT05](image)

Note the units on the vertical axis are in Watt–minute that is, the vehicle charging energy consumption measured over a one minute interval.

6.3.2 ’Smart’ charging demand profile

Figure 13 is representative of a charging demand profile where consumption is managed to take place between 11 pm and 7 am (a typical ‘off-peak’ period) – this is commonly described as ‘Smart’ charging, as would be adopted by a user on a Time-of-Use electricity tariff. On this occasion the charge session coincided with an ‘Emergency’ charge management event, however the ChargeIQ terminal was configured in ChargeIQ (i.e. ‘Smart’ charge) mode so the load control event had no impact to the vehicle charge. The connection and charge times were as follows:

- Vehicle connected: Thursday, 25 October 2012 at 7:05 pm
- Start of Charge: Thursday, 25 October 2012 at 11:00 pm
• Finished charging: Friday, 26 October 2012 at 2:11 am
• Total Vehicle load: 6.9 kWh

![Graph showing the time-of-use tariff ('Smart') charging profile for Participant ID VIC012EVT05.]

**Figure 13 - Time-of-Use tariff ('Smart') charging profile – Participant ID VIC012EVT05**

Note: the gap in the graph is the vehicle momentarily (for approximately three minutes) ceasing to charge – this is typical of many vehicle charge sessions, regardless of vehicle type.

### 6.3.3 Load Control charging demand profiles

a) ‘Peak’ charge management event #1 (50% reduction between 8 and 11pm) – Participant ID VIC031EVT05

Figure 14 shows the vehicle charging under load control. At 6:45 pm the vehicle started to charge at full load (around 53 Wmin or 3.2 kW). This continued until 8 pm when the load control event took effect reducing the vehicle load by 50 per cent (to around 26 W min or 1.6 kW) until it stopped charging at 10:44 pm. In this instance the vehicle completed charging prior to the end of the LC event at 11 pm.
Figure 14 - ‘Peak’ charge management event #1 – Participant ID VIC031EVT05

Charge Event Details

<table>
<thead>
<tr>
<th>Event</th>
<th>Time</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC Start</td>
<td>8 pm</td>
<td></td>
</tr>
<tr>
<td>LC Finish</td>
<td>11 pm</td>
<td>8116.2 Wh</td>
</tr>
<tr>
<td>Connect Time</td>
<td>6:25 pm*</td>
<td>4318.7 Wh</td>
</tr>
<tr>
<td>Start of Charge</td>
<td>6:45 pm</td>
<td></td>
</tr>
<tr>
<td>Finish Charge</td>
<td>10:44 pm</td>
<td>2159.4 Wh</td>
</tr>
<tr>
<td>Disconnect Time</td>
<td>7:00 am, Oct 17</td>
<td></td>
</tr>
</tbody>
</table>

NOTE*: Terminal configured to on-demand charge 6:45 pm.

b) ‘Peak’ charge management event #1 (50% reduction between 8 and 11pm) – DiUS Computing lease vehicle

Figure 15 depicts the DiUS Computing lease vehicle undergoing a 50 per cent load adjustment between 8 and 11 pm.
Figure 15 - ‘Peak’ charge management event #1 – DiUS Lease Vehicle

Charge Event Details

<table>
<thead>
<tr>
<th>Event Details</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC Start</td>
<td>8 pm</td>
</tr>
<tr>
<td>LC Finish</td>
<td>11 pm</td>
</tr>
<tr>
<td>Connect Time</td>
<td>7:04 pm</td>
</tr>
<tr>
<td>Start of Charge</td>
<td>7:06 pm</td>
</tr>
<tr>
<td>Finish Charge</td>
<td>11:47 pm</td>
</tr>
<tr>
<td>Disconnect Time</td>
<td>7:28 am October 17</td>
</tr>
<tr>
<td>Total load (Wh)</td>
<td>9162.0</td>
</tr>
<tr>
<td>Total load during LC (Wh)</td>
<td>4232.2</td>
</tr>
<tr>
<td>Load Shift (Wh)</td>
<td>3263.0</td>
</tr>
</tbody>
</table>

c) ‘Emergency’ charge management event #2 (100% reduction between 7 and 10pm) – Participant ID VIC008EVT05

Figure 16 depicts a 100 per cent (‘Emergency’ charge management) load adjustment. As shown, the vehicle ceased charging altogether between 7 and 10 pm.
Figure 16 - ‘Emergency’ charge management event #2 – Participant ID VIC008EVT05

Charge Event Details

<table>
<thead>
<tr>
<th>Description</th>
<th>Time</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC Start</td>
<td>7 pm</td>
<td>Total load (Wh)</td>
</tr>
<tr>
<td>LC Finish</td>
<td>10 pm</td>
<td>Total load during LC (Wh)</td>
</tr>
<tr>
<td>Connect Time</td>
<td>17:59</td>
<td>Load Shift (Wh)</td>
</tr>
<tr>
<td>Start of Charge</td>
<td>6:00 pm</td>
<td></td>
</tr>
<tr>
<td>Finish Charge</td>
<td>12:57 am, October 19</td>
<td></td>
</tr>
<tr>
<td>Disconnect Time</td>
<td>9:55 am, October 19</td>
<td></td>
</tr>
</tbody>
</table>

d) ‘Peak’ charge management event #3 (50% reduction between 7 and 10pm) – Participant ID VIC008EVT05

Figure 17 depicts a Mitsubishi i-MiEV undergoing a ‘Peak’ charge management event, where 240Vac duty cycle control is required to achieve a reduction in average load (refer to Section 5.2.3). Effectively the vehicle charges at 100 per cent for half of the three hour load control period, resulting in a 50 per cent overall average reduction in load.

Charge Event Details

<table>
<thead>
<tr>
<th>Description</th>
<th>Time</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC Start</td>
<td>7 pm</td>
<td>Total load (Wh)</td>
</tr>
<tr>
<td>LC Finish</td>
<td>10 pm</td>
<td>Total load during LC (Wh)</td>
</tr>
<tr>
<td>Connect Time</td>
<td>5:30 pm</td>
<td>Load Shift (Wh)</td>
</tr>
<tr>
<td>Start of Charge</td>
<td>5:30 pm</td>
<td></td>
</tr>
</tbody>
</table>
e) ‘Emergency’ charge management event #4 (100% reduction between 7 and 10pm) – Participant ID VIC009EVT05

Figure 18 shows a 100 per cent (‘Emergency’ charge management) load adjustment for a Mitsubishi i-MiEV, where the vehicle ceased charging altogether between 7 and 10 pm.

![Figure 18 - ‘Emergency’ charge management event #4 – Participant ID VIC009EVT05](image)

**Charge Event Details**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC Start</td>
<td>7 pm</td>
</tr>
<tr>
<td>LC Finish</td>
<td>10 pm</td>
</tr>
<tr>
<td>Connect Time</td>
<td>6:20 pm</td>
</tr>
<tr>
<td>Start of Charge</td>
<td>6:20 pm</td>
</tr>
<tr>
<td>Finish Charge</td>
<td>12:21 am October 26</td>
</tr>
<tr>
<td>Disconnect Time</td>
<td>8:02 am October 26</td>
</tr>
<tr>
<td>Load Shift (Wh)</td>
<td>5329.7</td>
</tr>
<tr>
<td>Total load (Wh)</td>
<td>7093.9</td>
</tr>
<tr>
<td>Total load during LC (Wh)</td>
<td>0</td>
</tr>
</tbody>
</table>

### 6.4 Participant acceptance

To gain insights into the Household Participants opinions and experiences, a qualitative survey was delivered to those who took part in the charging demand management events.
The survey assessed the Household Participant:

- Background understanding of electricity use and Smart Meters
- Feedback on the guidance information provided
- Opinions of the charge management events and the associated technologies

Refer to Appendix H for the survey design.

The survey was delivered using online survey software within the week that followed completion of the charge demand management. A total of seven responses were received from the eight Household Participants who took part in the charging demand management activities – refer to Appendix I for the results.

The limited number of participants/responses entails that the results be treated as anecdotal. Nevertheless, some observations can be made as follows – Participants:

- believed the main reason they had received Smart Meters was to allow meter readings to be done remotely
- were concerned that Smart Meters may lead to increased electricity costs in future
- found the guidance information helpful in preparing them for the charge management activities
- received the ‘Peak’ charge management event notifications, and where affected took steps to manage their charging/vehicle use
- were only occasionally aware that the ‘Emergency’ charge management events were taking place, and were largely unaffected by them
- were mostly accepting of charge management as load control by the utility, even if there were no financial benefit
- were less likely to accept mandatory load control, but could be influenced by a financial benefit
- mostly felt that the ChargeIQ terminal was a key enabler for charge management
- found the SMS charge management event notifications to be the most useful of the user-facing applications
- were very satisfied with their experience of the charge management project
7 Implications

Overall the demonstration was a success – electric vehicle charging was controlled using Victoria’s Smart Grid. However, the true value in the project lay in the insights gained through the demonstration and their interpretation.

Accordingly, the breakout boxes below highlight a range of recommendations for consideration to promote successful deployment and operation of the Victorian Smart Grid, including specifically demand management of loads such as electric vehicle charging.

7.1 Victoria’s Smart Grid

Key findings from the demonstration project with implications for Victoria’s Smart Grid (and Smart Grids more generally) included:

- System integration – for all elements of the end-to-end system
- Consumer HAN connectivity and reliability – arrangements, responsibilities and performance
- System response times – to support the various Smart Grid functions

7.1.1 System integration

In order to deliver the Smart Grid demand management demonstration there were a range of inputs associated with the system integration. Most of these tasks would be expected for successful deployment of any Smart device into Victoria’s Smart Grid:

- **Smart device system integration** (Section 4.1/ChargeIQ system) – integration of the various elements of the Smart device that provide information and control to the user – tasks that will either be the responsibility of the device provider for the specific market context, or will require DNSPs to test each device before approving for consumers to use within their network

- **Demand management system integration** (Section 4.1/Charge management system) – integration of the Smart Meter, Smart device and (if necessary) the electrical load, including specifically for the demand management messages and mapping to the electrical load management interface – undertaken by the device provider for the various combinations of meters, devices and electrical loads that they are supporting

- **Consumer HAN system integration** (Section 4.1/Consumer HAN system) – registration and binding of the Smart device to the household Smart Meter, and detailed mapping of the demand management messages for electrical load adjustment; registration and binding could be undertaken by the consumer using instructions tailored to the specific requirements of their operating environment (for example, reflecting the utility web portal and device acceptance arrangements), whereas mapping of the demand management messages will be undertaken by the device
provider according to whatever arrangements apply to the network operator (for example, according to AS 4755\(^6\))

- **User integration** (Section 4.2/’Household participant guidance’) – instruction provided to the consumer to guide their successful commissioning and operation of the Smart device; will be prepared by the device provider taking the specifics of the operating environment into account (for example, to guide the user registration and binding process for the network in question)

There are a range of issues arising from this list of tasks, but one of the most significant is the workload associated with integrating individual devices into each AMI network context. The experience from this project indicates that the system integration overheads, particularly arising from differences between the arrangements adopted by different utilities, may act as a deterrent for provision of devices into markets with small volumes.

Victoria’s 2.66 million Smart Meters are divided between five Distribution Network Service Providers (DNSPs). In the global context, this is a relatively small market for Smart devices which cannot afford to be disaggregated by the differences between networks. On this basis it is recommended that the barriers to market entry for Smart device providers through efforts to:

<table>
<thead>
<tr>
<th>1. Facilitate Victorian AMI Consumer HAN device interoperability</th>
<th>Victorian DNSPs work together to streamline market access arrangements for Smart device providers, and consideration be given to coordinating these arrangements at a national level</th>
</tr>
</thead>
</table>

### 7.1.2 Consumer HAN connectivity and reliability

Many of the demand management benefits associated with the Smart Grid rollout are dependent upon the Consumer HAN. For this reason the issues with the Consumer HAN connectivity and reliability identified during the demonstration project are potentially significant:

- **Consumer HAN connection** (Section 6.1.1/’Consumer HAN connection’) - Consumer HAN connectivity was not able to be established for one of the eight properties taking part in the demonstration project; although the sample size is insufficient for this result to be extrapolated, further investigation into the Consumer HAN connectivity is warranted

- **Consumer HAN commissioning** (Section 6.1.1/’Consumer HAN connection’) – the Victorian AMI rollout does not include commissioning of the Consumer HAN or verification of operability – based upon the experiences within this project, this would suggest that there are conflicting provisions within the Victorian AMI rollout guidelines\(^9\):

> “For customers where the meter is installed on an external wall of the customer’s premise, the role of the Distribution business is fulfilled once the AMI meter is installed, the ZigBee Energy Services Portal has been tested to verify that it is providing the

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\(^6\) AS4755 = Australian Standard 4755 Demand Response Capabilities and Supporting Technologies for Electrical Products

\(^9\) Department of Primary Industries; Advanced Metering Infrastructure Home Area Network (HAN) Functionality Guideline; 20 November 2008, Victorian Government
required ZigBee signal levels, and there is the reasonable expectation that signal will be available at adequate strength inside the customer premise.”

“...it is intended that end customers should be able to install HAN devices in their own premises without the need for specialist advice”

- **Binding issues** (Section 6.1.1/'Consumer HAN connection') – the ‘binding’ process set out in Section 5.2.1 assumes that a Consumer HAN connection can be made reliably – with reference to the Victorian AMI rollout guideline provision above, the roles and responsibilities are unclear should fault diagnosis and remedy be required

- **Sub-optimal architecture** (Section 6.1.2/'System response times') – closer integration of user-facing systems (web/notification server) to the utility Demand Response management system would provide significant gains in response times; direct integration would result in more consistency between the AMI and device response times

- **3G data service** (Section 6.1.2/'System response times') – reliance on a simple 3G data service is not ideal for large-scale production use, given it is not guaranteed that it will always be connected – alternatives for consumer interaction may include the consumer’s existing internet connection or using the AMI system where capacity allows

- **Consumer HAN reliability** (Section 6.2.1/'Aggregate charging behaviours') – three out of 64 charge management messages despatched as part of the demonstration failed to be delivered through the Consumer HAN; as the Consumer HAN may be put to a range of uses by any number of technology/service providers, better insights into the Consumer HAN operation including expected service performance may be critical to ensuring the Smart Grid investment benefits can be fully realised

Suggested actions to help remedy these issues and improve consumer access to and confidence in Victoria’s Smart Grid include:

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<table>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2. <strong>Establish Consumer HAN service levels</strong> – clarity is needed around the expected service levels for the Consumer HAN, particularly once the connection has been established; an investigation into the service levels under various scenarios should be considered to inform the standard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. <strong>Formalise responsibility for Consumer HAN operation</strong> – clearly define the entity responsible for ensuring minimum level of service by the Consumer HAN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. <strong>Formalise a mechanism for remedy of Consumer HAN connection issues</strong> – the roles, responsibilities and cost-ownership/recovery associated with remedy of Consumer HAN connection issues should be clarified, for instance to facilitate installation of a Smart Meter range-extender to enable participation in utility demand management</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5. **Develop guidelines for Consumer HAN alternatives** - in some situations connectivity may not be possible using wireless techniques (for example, apartment buildings with meters located in a basement); third-parties could play a role by providing technical solutions for connectivity, however this may require arrangements whereby access to facilities is granted, both from the premises owner (or body corporate) and the DNSP

7.1.3 **System response times**

Depending upon the intended outcome, a rapid and reliable system response time may be critical for various uses of Victoria’s Smart Grid. Observations of relevance from the demonstration project included:

- **Demand management suitability** (Section 6.1.2/'System response times') - the United Energy (UE) Advanced Metering Infrastructure (AMI) network and the ChargeIQ Consumer HAN interface showed response times that appear to be adequate for electric vehicle charging demand management, however the minimum performance requirements should be known to Smart device providers to assist with planning and implementation of network-level demand management strategies.

- **Demand management performance** (Section 6.1.2/'System response times') – while around 70 per cent of the charge demand management events were received by the charging terminal within 30 seconds of despatch from the utility back-office, the remaining 30 per cent of messages took much longer (some up to 42 minutes); improved Smart device system performance is likely to be necessary depending upon the intended outcome.

It was also noted that the existing UE AMI Network has the capability to differentiate and prioritise (low/medium/high/critical) specific messaging above other traffic. Systematic application of this capability is likely to be crucial for ensuring predictable and consistent performance in congested periods.

Victoria’s Smart Grid is a potential innovation platform. The Smart Meter mandate provides a unique communications pathway into Victorian households which may be utilised for much more than remote meter reading. By way of example, Smart Meters may communicate with customer-facing devices that include in-home displays, smart appliances, thermostats, and HAN clients including PCs\(^{10}\).

For this reason performance standards should specified as an input into device design, adoption and operation – a recommendation which may be expressed as follows:

6. **Establish Consumer HAN system response performance levels** – the Victorian AMI functional performance specification established performance levels for the AMI system upstream of the Smart Meter; additional performance levels should be considered for the meter to the HAN device.

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\(^{10}\) Department of Environment, Water, Heritage and the Arts; Smart Grid, Smart City: A new direction for a new energy era; Australian Government 2009
7.2 Demand management

Demand management is seen by governments and utility operators around the world as an essential next step in the management of our energy use. Being able to control not just the amount, but also the timing of energy demand is essential for efficient use of existing generation, transmission and distribution assets.

Observations of note from the demonstration project with implications for demand management can be divided into two basic categories:

- **End-user behaviour** – as relates to both the electric vehicles and the household participants
- **Demand management effectiveness** – for both the Demand Response and Load Control aspects of the demonstration

7.2.1 End-user behaviour

For effective deployment of network-level demand management strategies, an understanding of and design for the spectrum of electricity end-user behaviour is necessary. For this reason a notable finding from the demonstration project related to the behavioural variation of both the electric vehicles (EVs) and the household participants:

- **Vehicle behaviour** (Section 5.2.3/’ChargeIQ charge management system’) – contrasting approaches were required to manage vehicle charging load from the Mitsubishi i-MiEV versus the Nissan LEAF; it is unclear as to whether this variation applies to other electric vehicles in or soon to be entering the market, or whether this was simply an early-market issue confined to these vehicles alone – this is an issue that will need to be addressed by charge management technology manufacturers, both in terms of system design/validation/certification, and to support drivers in the event that troubleshooting is required for charging of different vehicle types from the same terminal.

- **Driver behaviour** (Section 4.3/’Household participants’ and Section 6.2.2/’Individual charging behaviours’) – the wide variation in behaviour observed between individual Household Participants and within the individuals themselves should also be noted – given that consumer behaviour cannot be reliably forecast, this underscores the importance of two-way communication between the consumer and their electricity supplier (for example, anecdotal results from the Participant survey/Section 6.4 suggest that some consideration should be given to the use of SMS messaging to households as part of a Demand Response strategy – this is discussed further in Section 7.2.2 below)

- **EV network behaviour** (Section 6.3/’Charging demand profiles’ and Appendix A) – as a consequence of both the vehicle and driver behaviour, a second EV ‘Smart’ charging demand peak is experienced at the network-level that goes from zero to maximum on

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commencement of the off-peak charging period – this is an outcome that has already been observed in both San Francisco and San Diego\(^\text{13}\).

- A significant proportion of drivers adopted Smart charging as their default charging strategy (Section 6.3/Table 7)
- The vehicle charging profiles (Section 6.3) show that charging rates are highest at the outset of a charging event

This issue may be remedied through network-level management of EV charging (as outlined in Appendix A). This approach will improve asset utilisation for not only the networks but also electricity generators, improving the return on existing investments\(^\text{14}\).

Accordingly, recommendations to promote improved uptake and effectiveness of electricity demand management are as follows:

| 7. **Certify demand management device capabilities** – EV charging device manufacturers certify demand management capability for specific vehicle types (this may also apply to other demand management devices) |
| 8. **Design effective communications strategies for demand management** – consumer-oriented approaches should be taken to communication of demand management events |
| 9. **Define the preferred approach to demand management** – utilities should consider their preferred approach to network-level demand management and define this for the specific demand management application |

7.2.2 Demand management effectiveness

Effective design and implementation of demand management strategies will deliver improved asset utilisation, reduced need for investment and improved returns on existing investments. While the scale of the demonstration project limits the certainty with which conclusions can be reached, some useful insights were gained to inform consideration of demand management.

In terms of householder impacts, the cost savings through adoption of ‘Smart’ (off-peak) charging are significant. Table 10 below provides a summary of impacts from ‘Smart’ charging based upon the aggregate charging behaviours (refer to Section 6.2.1).

Although these calculations do not take into account the wide variation in behaviour within and between households, they indicate that ‘Smart’ charging would cost a typical household around $290 for the entire year – representing a saving of around 50 per cent on their EV charging costs without impacting their use of the vehicle. By way of context, the average amount spent by Victorian drivers on petrol in 2011 was $1,264\(^\text{15}\), or over three times as much as a ‘Smart’ charged EV even if using GreenPower\(^\text{16}\).

\(^{13}\) EV Project EVSE and Vehicle Usage Report: 4th Quarter 2012
\(^{16}\) GreenPower residential tariff assumed to be $0.05/kWh
### Average connection (plug-in) time
5:46pm

### Average charging duration
2:35

### Average disconnection (plug-out) time
10:37am

### Typical flat-rate electricity tariff
$0.30/kWh

### Total charging costs / flat-rate tariff (ten participants/three months; projected)
$1,333

### Total charging costs / flat-rate tariff (one participant/one year; projected)
$533

### Typical off-peak electricity tariff (11pm to 7am)
$0.16/kWh

### Total charging costs / off-peak tariff (ten participants/three months; projected)
$711

### Total charging costs / off-peak tariff (one participant/one year; projected)
$284

### Percentage saving from ‘Smart’ charging (projected)
47%

### Average charge finish time / flat-rate
7:21pm

### Average charge finish time / off-peak
1:35am

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**Table 10 - ‘Smart’ charging household impacts and projections**

An interesting implication however relates to the payback period for a grid-integrated ‘Smart’ charger for household use. Based upon a survey of home charging equipment\textsuperscript{17}, the market rate for a dedicated home charging unit was between $2,500 and $5,000 in 2012. This equates to around 10 times the saving that would have been made by the Household Participants based upon the analysis above, thereby highlighting the imperative to:

\textbf{10. Consider the consumer business case} – the cost versus benefit argument for consumer adoption of demand management technologies should be considered by device suppliers, utilities and policy-makers

For most households who took part in the project these findings are moot – only one household was actually on an off-peak tariff (the rest were on flat-rate). It is significant therefore that nearly all households adopted ‘Smart’ charging in spite of having no financial incentive to do so. Possible explanations for this include:

- The ChargeIQ terminal being set to ‘Smart’ charge as the default charging mode – studies in behavioural economics have revealed the importance of default settings in overcoming apathy and a lack of engagement by users\textsuperscript{18}

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\textsuperscript{17} Home charging equipment procured as part of the Victorian Government Electric Vehicle Trial

\textsuperscript{18} For a highly readable account of this, refer to Thaler, R.H. and Sunstein, C.R., ‘Nudge – Improving decisions about health, wealth and happiness’, Penguin books 2008
• There was negligible impact on the household use of the vehicle from having the charging delayed to off-peak periods (as evidenced by the average connection/disconnection times as compared to the average charging duration – Figures 10 and 11, and Table 10) – effectively meaning there was no cost to users in adopting the default operating mode.

• The ChargeIQ system supplied users with real-time/remote information and control over the charging of their vehicle, including likely charge completion time – this allowed users to easily and conveniently manage their vehicle charging.

Load control by the utility was also found to be largely successful, both in terms of load shift of those available to be shifted and Household Participant acceptance of the load control. To a large extent these findings highlight the interrelationship of Demand Response and Load Control – information from a utility about an upcoming load control event likely increases acceptance of load control strategies, and demand response by drivers who manage their vehicle use/charging accordingly.

Although these issues/opportunities have been partly addressed in recommendation 8 above, additional recommendations include:

11. **Consider consumer behaviour** – device providers and utilities should design demand management strategies that reflect demonstrated user behaviours, include the use of ‘default’ settings to promote preferred behaviours, and take a holistic approach to the demand management strategy design that includes consumer information, feedback and response.
8 Concluding Remarks

Demand management of electric vehicle charging has been successfully demonstrated using Victoria’s Smart Grid. This represents the first occasion Victoria’s Smart Grid has been used for electricity demand management, and one of the earliest worldwide.

The project used DiUS Computing’s ChargeIQ home charge management system as the means to integrate cars and households participating in the Victorian Government’s Electric Vehicle Trial with United Energy’s Advanced Metering Infrastructure.

Demand management events were designed drawing upon both demonstrated consumer behaviours and network-level scenarios. The holistic deployment plan engaged and educated participants, and took differences in vehicle behaviour into account.

The project demonstrated that demand management benefits are both real and accessible. Current technology can deliver worthwhile outcomes for consumers and utilities alike. Measurement of the system performance found that demand management of electric vehicle charging can be achieved at the network-level. Many of the insights gained through the project are applicable to other electrical loads that might be considered for demand management, including pool pumps, refrigeration and air-conditioning.

As an outcome from the demonstration project, a range of recommendations have been identified for consideration that will aid in fully realising the benefits from Victoria’s Smart Grid investment:

Smart Grid

- **Reduce the barriers to market access** for Smart device providers by facilitating AMI Consumer HAN device interoperability across Distribution Network Service Providers (Recommendation no.1)

- **Improve consumer access to and confidence in Victoria’s Smart Grid** by addressing issues relating to the AMI Consumer HAN connection, performance and governance (Recommendation no’s 2 – 5)

- **Promote Smart Grid innovation** by establishing performance levels for various applications based on system response time (Recommendation no.6)

Demand management

- **Promote electricity demand management** through consideration of consumer costs, benefits and information requirements (Recommendation no’s 7, 8 and 10)

- **Reduce uncertainties relating to demand management effectiveness** through by clarifying utility expectations and device capabilities (Recommendation no’s 9 and 11)