System Control and Communication Requirements of a Vehicle-to-Grid (V2G) Network

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Abstract

Market introduction and availability of electric and hybrid electric vehicles has prompted researchers to discuss the possibility that grid-connected vehicles could someday provide power back into the electrical grid, acting as Mobile Distributed Resources (MDR). EPRI has initiated a study of the potential impacts and issues of this technology, including electrical safety, communication with and control of Mobile Distributed Resources, and vehicle level requirements of the technology. This paper provides an initial look at the communication network requirements necessary to control Mobile Distributed Resources. Wireless and wired communications solutions are explained as well as a summary of the security requirements of these networks.

Keywords: Plug-in Hybrid, Charging, Energy Source

1. Introduction

1.1 Background

Market introduction and availability of electric and hybrid electric vehicles has prompted researchers to discuss the possibility that grid-connected vehicles could someday provide power back into the electrical grid, acting as Mobile Distributed Resources (MDR). The complexity of this concept is increased due to the mobile nature of these resources. Grid-connected automobiles would have variable availability, location, and capabilities. Researchers continue to be intrigued by the potential for modest numbers of grid-connected vehicles to be used in innovative ways to provide ancillary services [1][9]. This paper will briefly outline some of the issues and requirements of a Mobile DR communications network.

EPRI has begun to evaluate the potential impacts and issues of this technology, including electrical safety, communication with and control of Mobile Distributed Resources, and vehicle level requirements of the technology. EPRI has put together a group of stakeholders including electric utilities, system operators, academic researchers, vehicle manufacturers, and end-users as part of the Infrastructure Working Council[1].

There is an existing body of research on Mobile DR by such participants as Willet Kempton (University of Delaware), California Independent System Operator (CalISO), and the California Air Resources Board.

[1] For information on attending the next IWC meeting, please contact Jorge Emmanuel at jemmanuel@mindspring.com

Mobile DR is more commonly known by the catchphrase Vehicle-to-Grid (V2G). Most existing Mobile DR research focuses on the economic feasibility of Mobile DR and briefly discusses the technology required to make Mobile DR a reality.

Current thinking concerning economic feasibility has indicated that Mobile DR would be used for peak power, spinning reserves, and regulation services. It is widely accepted that Mobile DR is not suitable for base load power. The peak power models all show off-peak charging followed by discharging at peak demand periods when the cost per kWh is highest. Spinning reserves and regulation services would be provided on demand. From the economic analysis researchers have developed two business models. In one model the vehicle owner sells electricity directly to the grid operator. The other model introduces the concept of an Aggregator acting as a middleman between the vehicle owner and the grid operators. In some of the scenarios the vehicle batteries would actually be owned and maintained by the Aggregator.

Most researchers discuss similar electric drive vehicle architectures. Battery electric, hybrid electric, and fuel cell vehicles have been considered as the future participants in Mobile DR. Lipman [10] primarily focuses on fuel cell vehicles while Kempton [1] and Makarov [9] have considered all three types of vehicles. Several vehicle configurations [1][9] use wireless communication for the control signals. Most of the researchers expect that a 30 kW charging connection will be available in the future, while 6 kW is feasible for the near-term. In addition to the electrical connection, all researchers have explored the possibility of a gaseous connection of either natural gas or hydrogen for fuel cell vehicles.

1.2 Future Research

Previous Mobile DR research has introduced technical and economic benefits that indicate Mobile DR is worth further investigation. The following paragraphs discuss some possibilities for future research.

It has been determined from average daily driving statistics that roughly 95% of all vehicles are parked during hours of peak electricity use [1]. A more sophisticated estimate of Electric Drive Vehicle (EDV) owner driving habits and likely time-dependent distribution of vehicles is necessary. The percentage of available EDVs and their potential impact as a Mobile DR network must also be determined.

Existing economic analyses have assumed that Mobile DR energy is worth market price [1]. Additional costs of controlling and delivering this energy and the local nature of its delivery will require a different set of assumptions. The validity of these economic models, under different possible scenarios with more accurate projections of infrastructure cost and vehicle availability, should be determined.

Battery dominant, plug-in Hybrid Electric Vehicles (HEVs) were not covered in these calculations. The HEVs discussed were scaled-up versions of commercially available non-plug-in HEVs. The feasibility of plug-in HEVs still needs to be determined using information from an actual plug-in HEV design architecture.The feasibility of plug-in HEVs, using information from an actual plug-in HEV design architecture, still needs to be determined.

The goal of this paper is to further explore a MDR technical issue that has only been briefly discussed in the past. Previous Mobile DR research has assumed a wireless connection for control signals. This paper will discuss some of the issues and requirements for a Mobile Distributed Resource Communication Network (MDRCN). The MDRCN communication requirements, infrastructure, and security will be discussed in the following sections. For the purposes of this paper, the Electric Power Grid will be referred to as Grid, and the Mobile Distributed Resource will be referred to as the Mobile Node. The act of participating in the Mobile Distributed Resource Network (MDRN) will be referred to as Mobile DR.

2. Infrastructure Working Council

EPRI has put together a group of stakeholders including electric utilities, system operators, academic researchers, vehicle manufacturers, and end-users as part of the Infrastructure Working Council (IWC). Within the IWC there is a Hybrid Electric Vehicle Working Group (IWC-HEVWG). The IWC-HEVWG goal is to support the development of Plug-in hybrid EVs by:

- Identifying infrastructure and utility issues for Plug-in hybrids to provide an attractive means of transportation for consumers and a cost-effective solution for manufacturers,
- Identify the infrastructure and utility issues for Plug-in hybrids to function as mobile distributed resources supporting the electric power grid,
- Focusing on safety, both personnel & utility system, for Plug-in Hybrids in their connection to and operation with the utility system,
- Providing recommendations to appropriate Industry and Standards Committees to promote the safety and function of Plug-in Hybrids.

The IWC-HEVWG has identified numerous infrastructure and utility issues for MDR, which include required changes to the National Electric Code (NEC) Article 625, and the Society of Automotive Engineers (SAE) J2293 standard. The IWC-HEVWG is also working with Institute of Electrical and Electronics Engineers (IEEE) on the introduction and development of IEEE P1547.

2.1 NEC 625

The 2002 NEC Article 625.25 prevents energy from being backfed in the case of voltage loss from the utility [2]. The IWC-HEVWG has suggested that the 2005 NEC Article 625.25 allow for bi-directional power flow by equipment specifically identified for this purpose. A new addition to the NEC, Article 625.26 Interactive Systems has also been suggested. The suggested Article 625.26 states that "Electric vehicle supply equipment and other parts of a system, either on-board or off board the vehicle, identified for and intended to be interconnected to a vehicle and also serve as an optional standby system and/or an electric power production source or provide for bi-directional power feed shall be listed as suitable for the purpose and shall comply with articles 702, 705 and the other applicable articles of this Code." IWC-HEVWG suggested changes to 2005 NEC Code have been submitted and in principle accepted, but are still out for comment.

2.2 SAE J2293

SAE J2293 is the Energy Transfer System for Electric Vehicles standard [3]. Currently J2293 describes physical system architectures and the communication, control and management for EV charging. J2293 currently does not cover bi-directional energy flow, nor does it incorporate the communication signals that would be required for MDR. Reworking of J2293 will require the involvement of both the utilities and the auto manufactures. The successor to SAE J2293 will possibly include portions of the developing IEEE standard P1547.

2.3 IEEE P1547

IEEE P1547 is the developing Standard for Interconnecting Distributed Resources with Electric Power Systems; IEEE P1547 has three parts currently being drafted[2]. The three draft parts of P1547 are:

- P1547.1 Draft Standard For Conformance Test Procedures for Equipment Interconnecting Distributed Resources With Electric Power Systems

[2] For information on IEEE P1547 or about attending the next IEEE P1547 working group meeting visit http://grouper.ieee.org/groups/scc21/dr_shared/

- P1547.2 Draft Application Guide for IEEE Std. 1547 Standard for Interconnecting Distributed Resources With Electric Power Systems
- P1547.3 Draft Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected With Electric Power Systems

P1547.3 when completed will encompass the communication protocols, information exchange requirements and security issues for DR. The IEEE P1547 Working Group is attempting to develop an Open Systems standard that will allow for the DR stakeholders to interact in reliable and secure manner.

3. Communication Requirements

The communication requirements for the MDRCN that must be defined are required signals, frequency of the signals, communication reliability, and Quality of Service (QoS). The required signals are the minimal information that must be exchanged between the Grid and the Mobile Node. Another important requirement is the frequency at which the required signals must be transmitted. The reliability of the communication corresponds to the ability to transmit a communication signal without error, or the ability to detect a communication error if one does occur. QoS refers to the latency of the Mobile DR communication signals, and the priority of the Mobile DR communication signals with respect to non-Mobile DR signals on the same network if any do exist.

3.1 Required Signals and Frequency

The signals that will be required from the Mobile Node for the Grid to properly control the Mobile Node are node identification, node available power, node available energy, node location, node currently provided power, and node cumulative provided energy. The node identification is essential for billing and may also be important for security reasons; a possible node identifier could be the Vehicle Identification Number (VIN), but the actual identification scheme is still to be determined. The node available power will need to be both a maximum charge and a maximum discharge power; maximum charge and discharge power is required because a node with a low State of Charge (SOC) may not be able to provide discharge energy into the Grid and a node with a high SOC may not be able to remove energy from the Grid by charging. Along the lines of the available power, the available energy must be a maximum charge and discharge energy, since the node storage capacity is finite. The node location is required for control, and may take the form of Global Positioning System (GPS) information or may be a charger identification number that is discussed later in this text. The node currently provided power may be necessary for Mobile DR to work properly, but this will need to be determined. For billing purposes the cumulative provided energy is required so that the net provider of energy can be reimbursed.

The signals that will be provided for command from the Grid to the Mobile Node are requested power, charger identification number, and the charger power capability. The requested power is the primary control signal for Mobile DR. Kempton discussed providing a charger identification number [1]. This identification number could be used in determining the Mobile Node location. The charger power capability is already provided and will be essential to protect both the Mobile Node and the charger from damage.

3.2 Reliability

Reliable communication is essential to the MDRN functioning properly and safely. Communication reliability encompasses both providing end-to-end error free communication and a guarantee of communication delivery. Providing end-to-end error free communication is possible even over an unreliable data channel, but requires the ability to detect a corrupted message so that the corrupted message can be either retransmitted or ignored. Guaranteeing every communication message is delivered may not necessarily be desired. For example, control signals are time-sensitive, making expired information useless. Furthermore, retransmission of expired messages may prevent valid messages from reaching their destination within their allotted time.

3.3 Quality of Service

As discussed before, QoS refers to the latency of communication signals, and the priority of the Mobile DR communication signals with respect to other Mobile DR and non-Mobile DR signals on the same communication network. Communication latency is a consideration that must be incorporated into the design of the MDRCN. As discussed in the previous section control signals are time-sensitive, and therefore are affected by communication latency. Communication latency for a particular message is affected by its priority; high priority messages should have lower latency. A signal such as requested power is much more time-sensitive than a signal such as the cumulative provided energy, and therefore the requested power signal should have a higher priority to reduce its latency. It is essential to the MDRCN to determine and provide a level of QoS.

4. Communication Infrastructure

The MDRCN infrastructure must be specified and implemented prior to Mobile DR becoming a reality. Infrastructure solutions can be placed into two categories—wired and wireless. Guided optical communication (fiber optics) are considered wired, but are not discussed in this paper. Some issues that must be considered in the MDRCN infrastructure design are reliability, QoS, data rate, cost, and backwards compatibility with existing infrastructure.

4.1 Wired Solutions

Wired solutions require a physical connection between the Mobile Node and the charger; in some solutions this will not only require modification to the chargers, but will also break backwards compatibility. Wired solutions typically are reliable, having bit error rates between 10^{-6} and 10^{-9}. Ethernet, power line communication, adapted charger pilot signal and ground-up solutions will be discussed, but they are not the only possible wired solutions.

4.1.1 Ethernet

Ethernet is a mature technology that can provide data rates from 10 Mbps to 1 Gbps. Ethernet solutions would either require changing the charger connection or a secondary connection from the Mobile Node to the charger. Since having two connections to the Mobile Node is probably unacceptable, an Ethernet solution would break backwards compatibility. Ethernet would also require either an Internet or Grid Intranet connection at every charger; the cost of providing Internet or Intranet connectivity could be a limiting factor.

4.1.2 Adapted Charger Pilot Signal

The Pilot line in the charger connection specified by SAE J1772 could be reused for MDRCN communication. Currently, the pilot signal from the charger is a 1kHz 12V signal with a duty cycle proportional to the charger current capability. A capacitor resistor circuit is typically used on the vehicle to notify the charger of the vehicle presence and battery type. A new backwards-compatible protocol could be developed to allow MDR vehicles and chargers to communicate digitally using a physical protocol such as J1850 or CAN. The adapted pilot signal approach would not break compatibility with existing chargers, nor would it prevent existing plug-in vehicles from using the new MDR capable chargers. This approach, like the Ethernet approach, would require either an Internet or Grid Intranet connection to every MDR capable charger.

4.1.3 Power Line Communication

Power line communication is a newer technology that can transmit wideband communication over the power lines [2][5]. Data rates of 2 Mbps are already commercially available for power line communication and data rates up to 24 Mbps are thought possible. Power line communication would not require any changes to the charger infrastructure since the communication would be transparent to the charger. Power line communication would probably require infrastructure changes in distribution transformers.

4.1.4 Ground-Up Solution

Ground-up solutions could be developed for the MDRCN for the sole purpose of enabling Mobile DR. Any ground-up solutions would need to be standardized for all Mobile Nodes so that a Mobile Node may participate in Mobile DR anywhere it could plug-in. Any ground-up solution would have unproven robustness compared to existing mature technologies. The cost of ground-up development would be greater than existing technologies and would be an added cost of implementing a Mobile DR network.

4.2 Wireless Solutions

Wireless solutions do not require a physical connection between the Mobile Node and the charger. All wireless solutions should not require modification to the chargers, and should maintain backwards compatibility. Wireless solutions typically are not as reliable as wired solutions having bit error rates around 10^{-3}. A discussion of 802.11, General Packet Radio Service, and ground-up solutions follows. Other wireless solutions—such as Bluetooth, 3G Cellular, and Cellular Digital Packet Data (CDPD)—will not be discussed.

4.2.1 802.11

802.11, also known as wireless Ethernet, is rapidly growing in acceptance among laptops and PDAs. The most popular version of 802.11 is 802.11b, which has a data rate of 11 Mbps. An 802.11 implementation would require the same Internet or Intranet infrastructure that Ethernet would, with the exception that neither a second connection nor modification to the charger connection would be required. The limited range of 802.11 would probably make it unsuitable for "telematics" connectivity, making it incapable of performing a dual role. Borisov [6] and Mishra [7] discuss some 802.11 security issues.

4.2.2 General Packet Radio Service (GPRS)

GPRS is a packet based communication that supplements two existing technologies—Circuit Switched Data and Short Message Service. Since GPRS is packet switched, it does not require a persistent connection like some other cellular technologies. Kempton [1] suggests using GPRS for Mobile DR communication. The range of GPRS is not limited like 802.11; therefore, it would be capable of performing the dual role of Mobile DR communication and "telematics" connectivity. GPRS has a theoretical maximum speed of 171.2 kbps [8]. The use of GPRS may bind the communication to a limited number of service providers, as Global System for Mobile communications (GSM) is not the only standard for cellular communication in the Americas.

5. Security

Security must be an essential part of the MDRCN, and must be considered at every step of the design process. Grid power control signals and billing information will be transmitted over the MDRCN; these messages require security. The communication medium is a key decision in the design of the MDRCN.

The communication medium must be either wired or wireless, keeping in mind that wireless networks are more susceptible to security problems.

5.1 Wireless

Wireless networks are more prone to security breaches because the medium can be "tapped" from anywhere in the proximity of the network. Session hijacking, Denial of Service (DoS), and "rogue" access points are just three forms of attack on wireless networks. Session hijacking is the act of taking control of the communication session after successfully obtaining authentication. After a session is hijacked the hijacker can forge any information. This would prevent the Mobile Node from participating in Mobile DR, while the Grid believes that the Mobile Node is participating. DoS of a wireless network could be accomplished by transmitting at high power on the frequencies that are used by the communication channel. Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) are multiplexing schemes for wireless networks that are susceptible to DoS attacks, but Code Division Multiple Access (CDMA) is inherently more resilient to this form of DoS attack. The attack that potentially could cause the most damage is the "rogue" access point. A "rogue" access point is an attacker that masquerades as the Grid in the case of Mobile DR. If an attacker successfully masquerades as the Grid the attacker could request Mobile Nodes to either supply or draw current from the Grid. This could adversely affect grid stability in the area of the "rogue" access point. It should also be noted that most wireless access methods mentioned in the literature would use the public Internet [1][9].

5.2 Wired

Wired networks like wireless networks can be "tapped", but it requires a physical connection to the network. A wired network could either communicate via the Internet, or it could be a private network one which only the Grid has access. Session hijacking can be accomplished on a wired network by placing a "man-in-the-middle" that drops the Mobile Node once authentication has been obtained. Broad attacks in private networks require "tapping" the network physically close to the control room.

5.3 Internet

There are many issues with Mobile DR using the public Internet, but primarily any node on the public Internet can be the target of an attack, from anywhere in the world. If the MDRCN was to include the public Internet it would be susceptible to any form of Internet attack. For example, many Internet DoS attacks have successfully brought powerful servers down in the past few years. Another issue with the Internet is QoS. MDRCN would require a minimum QoS. The current Internet Protocol version 4 (IPv4) does not provide any provision for QoS. However, the proposed successor to IPv4, Internet Protocol version 6 (IPv6), has provisions for QoS.

5.4 Security Considerations

The need for security considerations at every step of the design process can be seen in 802.11b and 802.1X security failures. The encryption algorithm along with the implementation of the encryption algorithm must be secure. The 802.11b Wired Equivalent Privacy (WEP) protocol has security holes that are discussed in Intercepting Mobile Communications: The Insecurity of 802.11 [6]. It shows that poor implementations of an encryption algorithm can lead to security issues. The 802.1X security successor to 802.11b even has security issues as shown by Mishra and Arbaugh [7]. Without security considerations at all design phases of the MDRCN could lead to an insecure system.

6. Conclusions

The development of the MDRN will require the cooperation of the utilities, auto manufacturers and standards organizations. The IWC-HEVWG has started modifying existing standards to allow for MDR as well as aided in the development of new standards. New standards such as IEEE P1547 will need to incorporate the minimum signals described in this paper as well as consider the reliability, QoS, and security of the MDRCN. The development of the MDRCN requirements will need to consider the communication needs, the infrastructure update costs, and backwards-compatibility with existing equipment. The journey to a fully functional MDRN is a long one that is at its beginning.

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