Control of Networked Electric Vehicles (NEVs) to Enable a Smart Grid with Renewable Resources

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Prepared for the 2013 National Workshop on Energy Cyber-Physical Systems, December 16-17, 2013 in Arlington, Virginia under the topic **Interfaces between energy-related critical infrastructures (gas, transportation, water, etc).**

Abstract

Electric vehicles (EVs) with grid-to-vehicle and vehicle-to-grid power-flow capability, called networked EVs (NEVs), have the potential to absorb variations in renewable generation and lower maximum power transfer over transmission and distribution lines. Based on a four percent NEV penetration, the existing grid can be transformed into a smart grid exploiting the underutilized infrastructure consisting of EV batteries without the need for high-cost investment in new transmission lines, transformers, and protection systems [1]. This paper outlines the research, innovation and tasks necessary to develop (a) open-architecture hardware and software enabling NEVs, (b) methods to obtain grid operating constraints using ISO ancillary supply pricing, demand response, EV user preference data, and power quality requirements, and (c) smart charging and discharging algorithms to satisfy the grid operating constraints.

The University of California, Los Angeles, Smart Grid Energy Research Center (UCLA – SMERC) has installed over fifty smart EV charging stations spread over the LA region connected by way of WINSmartEV™ - a wireless communications and control network [2]. This infrastructure forms the basis of the current and proposed research on NEVs.

Communication Network for NEVs

The scalable wireless WINSmartEV™ network is interoperable with a variety of wireless protocols such as WiFi, 3G, 4G, Zigbee, and PLC. This network provides two types of bi-directional connectivity: (a) between any pair of charging stations and (b) between the charging stations and the Internet cloud based energy management system that hosts and executes smart charging algorithms.

Several protocols go into a single communication network where interoperability becomes important [3]. Ensuring that devices running within a single network can communicate with each other, and function as a single system, is a challenge. ZigBee and HomePlug alliances are working towards interoperability protocols [4]. Similarly, when the network size grows, data forwarding problems arise, which causes packet-loss [5]. This is commonly observed in mesh networks, and so a data forwarding path mechanism should be selected carefully [6]. Other variables that impact interoperability for low-power networks in the power grid are security and scalability. In this research, interoperable and scalable communication infrastructure represents an important area of research into NEVs [7], [8].

Connectors

An EV in the network is connected to the grid by way of a "connector" that carries communications for information and control, and also electricity. There is a lack of standardization in physical make and protocols that extend across all voltage sources and power ratings for connectors and this can limit the uptake of EVs. While 110V and 220V sources have standardized connectors – SAE J1772 - there is no standard for 440V. The proprietary 440V CHAdeMO connector that is prevalent is used in our research and our architecture supports both the SAE J1772 and CHAdeMO protocols within its network architecture. These connectors represent the first generation of technology and have a very basic protocol of communication that is based on power line communication or PLC. Substantial research is needed for enhancing the communications protocols so that the EVs an be made grid-friendly, and subsequently such protocols need to be standardized across various EV models so that aggregation of loads from multiple EVs can be offered to the electric grid operators for the creation of new markets. Our research is currently based on using the Mitsubishi iMIEV as an experimental test-bed for developing open-architecture connector approach and expandable protocols between the EV and the grid.

Novel Smart Charging and Discharging Algorithms

We envision a fundamentally novel and innovative NEV environment where each EV can charge and discharge or have a bidirectional power flow through the EVSE network [9]. That is, an EV functions as a mobile version of energy storage. It is clear that the dynamic charging of EVs must be related to the "navigation" needs and habits of the vehicle owner. Research in NEVs involves architecture and algorithm designs that are flexible for the demands of mobile energy unit service and palatable to large enough shares of vehicle owners to ensure feasibility and optimality of power flows between the grid and the EV.

Smart power flow scheduling for NEVs requires communication and computing infrastructure. Research in the development of a scalable and interoperable communication system includes: (a) exchange of data and commands with the cloud, (b) receiving ancillary requests from ISO (Independent System Operator) and SCADA (Supervisory Control and Data Acquisition) data, and (c) exchanging data with renewable resources and NEVs. Cloud computing is investigated for NEV power flow scheduling algorithms and represent a significant research opportunity. Design of the computing system within the NEVs as embedded computing, as well as within the EV charging stations to perform local computing for control and for interpreting and encoding communication signals represents an active area of research.

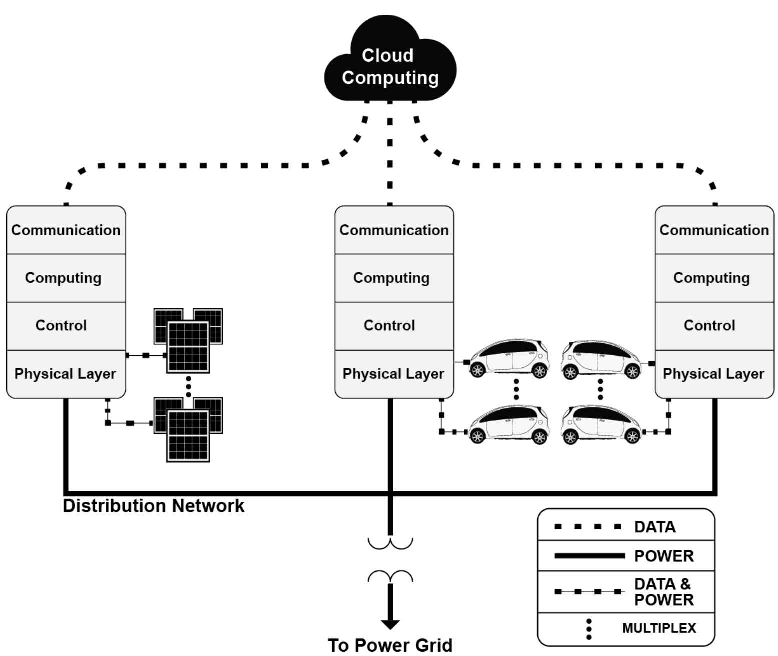

Figure 1: Distribution Network with NEVs and DERs

UCLA – SMERC has been researching and developing an algorithm-based EV monitoring, control and management system WINSmartEV™ [10], [11]. In this system, the server transmits regulation commands to a smart charging station and controls the charging rate while gathering and accumulating all the power information through the multiple protocol gateways. Based on user preference and the local power capacity in the local grid, optimized control schemes are investigated and developed. The framework for our research architecture is shown in **Error! Reference source not found.** and it enables research and development on the various challenges facing NEVs on the grid.

Control

The power flow control for NEVs is accomplished within the framework of a unified control of Distributed Energy Resources (DERs). This is achieved by exploring the representation of NEVs as DERs within the framework of IEC 61850 and ISO/IEC 15118 standards that are being accepted by utilities worldwide. Real power support to the grid is provided in response to ISO ancillary price signals and demand response events. Decentralized control algorithms are a potential research area for reactive power management based on optimal power-flows and communication from neighboring load nodes.

Standards and protocol development for NEV as a DER

UCLA – SMERC has installed a lab-scale microgrid composed of DERs such as solar PV, Battery Energy Storage (BES) and various loads such as EVs, LED lightings, and smart appliances. We are implementing the IEC 61850 [12], an international standard, in order to standardize the communication and operation within the microgrid. An important area of research is the integration of an NEV as a DER unit within IEC 61850 and this is a topic of investigation via mappings between the existing ISO/IEC 15118 for the V2G communication interface with IEC 61850-7-420 [13].

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