VersiCharge-SG - Smart Grid Capable Electric Vehicle Supply Equipment (EVSE) for Residential Applications

Dong Wei, Harry Haas and Paul Terricciano

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Contents

Table of Contents

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List of Figures

1. Executive Summary

In his 2011 State of the Union address, President Obama called for one million electric vehicles on the road by 2015 [1]. With large-scale Electric Vehicle (EV) or Plug-in Electric Vehicle (PEV or EV for short) or Plug-in Hybrid Electric Vehicle (PHEV) penetration into the US market, there will be drastic reduction in fossil fuel consumption, thus significantly reducing our dependency on foreign oil [2-6]. There will also be significant reduction on Green House Gas (GHG) emissions and smog in the major US cities [3, 7, 8]. Similar studies have also been done other industrial counties [9]. For the fuel cost, with the home electricity rate around $0.13 per kWh, it would cost about $0.05 per mile for DC operation and $0.03 cents per mile for AC operation. But, assuming 25 miles per gallon for a typical vehicle and $4 per gallon, fossil fuel will cost $0.16 per mile [10]. The overall lifecycle cost of PEVs will be several folds lower than the existing fossil fueled vehicles.

Despite the above advantages of the EVs, the current cost of EVSE is not affordable for the average consumer. Presently, the cost of installing state-of-the-art residential EVSE ranges from $1500 to $2500 [11]. Low priced EVSE technology, which is easy to install, and affordable to operate and maintain by an average consumer, is essential for the large-scale market penetration of EVs. In addition, the long-term success of this technology is contingent on the PEVs having minimal excessive load and shift impact on the grid, especially at peak times. In a report [2] published by the Pacific Northwest National Laboratory (PNNL), the exiting electric power generation infrastructure, if used at its full capacity 24 hours a day, would support up to 84% of the nation's cars, pickup trucks and SUVs for an average daily drive of 33 miles. This mileage estimate is certainly much below what an average driver would drive his/her vehicle per day. Another report [3] by the National Renewable Energy Laboratory (NREL) shows that an increased PEV penetration would significantly increase pressure on the peak generation, if no controlled charging strategy was put in place. Investigations from Oak Ridge National Laboratory (ORNL) show that in many regions, additional power generation facilities must be put in place and operate in evening times to recharge the EVs [12]. By all accounts, large PEV penetration will bring to the power grid enormous challenges due to the excessive and stochastic demand, and can entirely change the peak time distribution and behavior, perhaps, into a bi-modal distribution capable of exhausting primary, secondary and even reserves (spinning or non-spinning). To minimize the infrastructure upgrade costs and risks to the grid, and to ensure that power quality and reliability remain within the set standards, the demand for EV plug-ins must then be controlled and coordinated locally and at regional levels. Novel control techniques must be devised to allow for close collaboration between neighboring plug-in requestors, between neighboring communities, and between these and more central power authorities.

The concept of electric drive vehicle is not new. The development of electric vehicle has been around since 19th century [13]. But due to a number of reasons and practical limitations at the time, including lower cost of gasoline compared to electricity, excessive refueling times, and abundance of gasoline, the automobile industry embraced gasoline-powered vehicles worldwide [13]. With the global warming, ever reducing reservoirs of fossil oil around the world and increasing political pressure to reduce the national dependency on foreign oil, the last decade of the 20th century witnessed major technological breakthroughs in *Alternative Fueled Vehicle* (AFV) technologies, including electric vehicles. With GHG emissions and carbon footprint in the minds of many more consumers and politicians, the first decade of the 21stCentury witnessed more breakthroughs with some real life experimentation and sporadic deployment of these technologies [14]. By many accounts, the second decade of the 21st Century is expected to be the time when mass volume production and popular usage of these AFV technologies, especially EV, will materialize.

The current DOE request for proposals recognizes the need for major technological changes to ensure that the above national goal is realizable. Two major challenges have been identified: (1) major reduction in the cost of ownership of EVSEs, and (2) managing additional EV loads in the power grid while maintaining power quality, reliability, and affordability. We note that the two challenges are closely linked – A holistic approach to true lifecycle cost of EVSE ownership will certainly include any taxes and surcharges that can be put in place for major potential investments in the grid, and higher electricity charges in case of more frequent and longer peak periods. From a societal perspective, this cost could also include the lost GDP (computed on a local basis) and revenue for businesses at local and regional levels when the grid is no longer capable of meeting the demand and unexpected outages occur.

A typical end-point electrical distribution system delivers power to a residential EVSE from the neighborhood distribution pole, as shown in Fig.1. This pole has a transformer (neighboring step-down transformer) that steps down the utility medium voltage to dual 120VAC single phase (also called 240VAC split phase). This voltage is fed through a meter into the residential load control center. The load control center consists of branch circuit breakers and distributes the power supply within various areas of the residential unit. One of the branch circuits from the load control center feeds EV charging station for the unit. An electric vehicle charger is plugged into the socket of the EV charging station and other end of this charger is connected to the vehicle during charging. Figure 1 illustrates a typical configuration of the power grid. The left side of the figure shows the power grid from the power generation to the neighboring step-down transformer, while the right side of the figure shows multiple EVs with the respective charging stations. The typical step-down transformer has an upper limit representing the maximum load that can be requested from these neighboring houses altogether (typically 24 kW). In case the total load increases beyond the supported limit, the protection system (e.g. a circuit breaker) attached to the step-down transformer gets activated automatically.

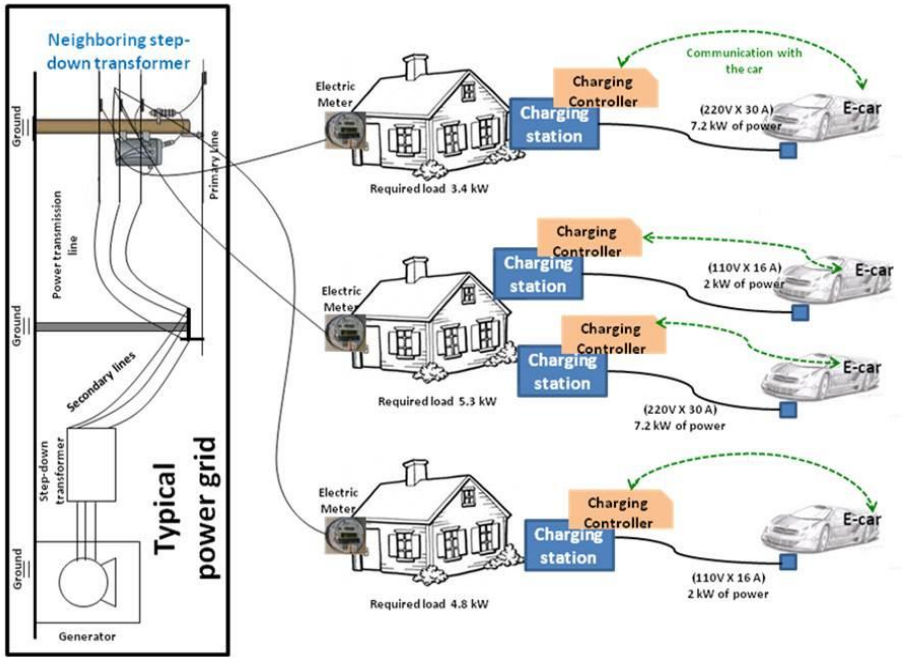

Figure 1: EV charging in a typical residential area

Depending on load sizes and types, distribution transformers typically range in size from 25kVA to 75kVA per phase. A typical 25kVA distribution transformer generally serves four to seven homes in a neighborhood [15]. According to Duke Energy, the average is about 4.2 houses per neighborhood step down transformer.

The traditional power grid has been supporting no or very limited bi-directional communication, especially with the end users and consumers. With the recent major developments in smart grid (information + electricity), smart metering, pricing exchange and *Demand Response* (DR), two-way communication between the distribution grid and its clients, including homeowners, will soon be reaching new heights [17]. With advances in home automation technology and its integration to the grid, some aspects of load management within residential units will soon be in the hands of homeowners. Through advanced business value proposition schemes, it will soon be possible for the owners at residential or community levels to actively participate in supply & demand dynamics of the distribution grid. With the anticipated market penetration of PEVs, end users and consumers will even have more abrupt and drastic impacts in the demand and response dynamics of the distribution grid to the extent that new infrastructure upgrades may become inevitable, unless some innovative new solutions are sought for the management of grid. The current load profile on the distribution grid follows some seasonal patterns, and peak loads are more deterministic over time for a given geographical location. With PEV penetration, it is almost certain that the load profiles will change drastically, and peak periods will behave more non-deterministic, unless EV plug-in loads are managed and smoothed out over a tempo-spatial space [15].

This project fulfilled the primary DOE objectives of: (1) reducing by 50% the cost of EVSE for the residential domain; (2) assuring that high penetration of EVs does not degrade power quality and reliability in the distribution power grid.

Our specific objectives are:

- Re-design the Siemens level 2, 240V residential charging station:
  - To reduce the total lifecycle cost of EVSE (including software and equipment) by 50% relative to the current baseline market price of EVSE, which ranges from $1500-2500;
  - To significantly reduce the battery charging time and facilitate the charging process by providing a technology that operates on-demand in amperage range of 16A-70A at 240V.
- Minimize the residential and utility infrastructure upgrade requirements and costs needed to support massive EV penetration by deploying smart residential and neighborhood level load management that controls the EVSE charging level and scheduling.
- Develop a new intelligent collaborative control and collaboration software platform with flexible and configurable architecture which allows for deployment solutions ranging from centrally controlled configuration by utility providers to fully distributed system over the residential premises. The proposed platform will be developed on the basis of Siemens existing technologies.
- Build prototypes, perform lab and pilot testing, and work with the DOE national labs, Idaho National Laboratory (INL) and Argonne National Laboratory (ANL) for detailed performance testing and certifications.

VersiCharge SG, the EVSE product developed under this project, has been successfully tested by ANL and INL. It has been also demonstrated successfully in SAE (Society of Automotive Engineers) World Congress in Detroit in April 2015 [18-22].

2. Background

The Low Voltage Product division of Siemens Industry is in the business of designing and manufacturing Low Voltage AC distribution products for the residential market. This includes circuit protection devices such as arc fault and ground fault breakers, as well as enclosures for AC circuits. In considering our expertise in both ground fault protection and AC enclosures, Siemens decided to produce its first EVSE product in 2010. In late 2012, Siemens introduced the VersiCharge EVSE into the market. This was our first generation residential EV supply product. At the time, we were also selling brand labeled versions of the Coulomb Technologies industrial chargers. At that time, Siemens recognized the importance of automation and load control. Thus our first generation residential charger shipped with provisions for connecting an external device to control the charger for demand response programs. It was also clear that the industry was young and that our first generation charger could be greatly improved upon.

In early 2013, Siemens determined that more work was required to improve the cost effective nature of the EVSE product offering and that some enhancement of the communications capability would greatly benefit the consumer and provide for utility control. It was at this time that Siemens teamed with Duke Energy and Ford Motor Company to respond to the Department of Energy's challenge to increase the intelligence and reduce the cost of residential EV Charging.

2.1. Initial Concepts

Siemens' initial concept for Smart EV charging was focused on Utility demand response programs and ZigBee communications. As development of the Smart EVSE continued, two shifts were happening in the market and with technology. The first shift we noticed was that consumers were becoming much more engaged and were responding to market trends at a much greater rate than expected. At the same time, utilities were not implementing their demand response programs as quickly as anticipated. On the technology side, ZigBee was falling out of favor and the concept of the Internet of Things was gaining strong market acceptance. As a result, Siemens decided to shift its focus for the initial release of the Smart Charger. We would now focus on a Wi-Fi implementation with consumer engagement through the use of cellular telephone applications and a cloud based service. At the same time, this implementation would provide a platform for utility communications and control using the OpenADR protocol with later expansion to include the Smart Energy Profile (SEP) 2.0B.

It was also determined that the ZigBee capability would be retained in the hardware but not implemented in software, and that the Wi-Fi capability would be added by way of a removable module. We initially considered using the U-SNAP interface, but rejected that concept for several reasons, not the least of which was the fact that this interface was not backed by standards organizations.

2.2. Implementation

During the development of the VersiCharge SG, the Consumer Electronics Association adopted the USNAP concept as a standard and introduced CEA-2045. After several discussions with Duke Energy and the Electric Power Research Institute (EPRI), Siemens decided to adopt the CEA-2045 standard for use with the Siemens developed Wi-Fi module as well as third party communications devices. This decision opens up the possibility of using the Siemens VersiCharge SG with a variety of communications networks across the industry. It also allows other vendors of CEA-2045 capable appliances to utilize the Siemens Wi-Fi module, cloud application and OpenADR implementation.

The final EVSE system design is represented in Fig. 2 below. In addition to the SAE J1772 based EV charging function, this system implementation includes:

- Revenue accurate Energy Metering to ANSI C12.20 Class 0.5
- A CEA-2045 Interface for Industry Standard Communications Modules
- A Siemens Developed CEA-2045 based Wi-Fi Module
- A Siemens Cloud based OpenADR Virtual End Node (VEN) Implementation
- Provisions for adding Utility Rate Plans for calculation of true energy costs
- A Siemens Cloud Service and Customer Web Browser Interface
- An Android Cell Phone application available in the Google Play Store
- An iPhone application available in the Apple App Store
- A Siemens only USB interface for to implementation of future Communications devices

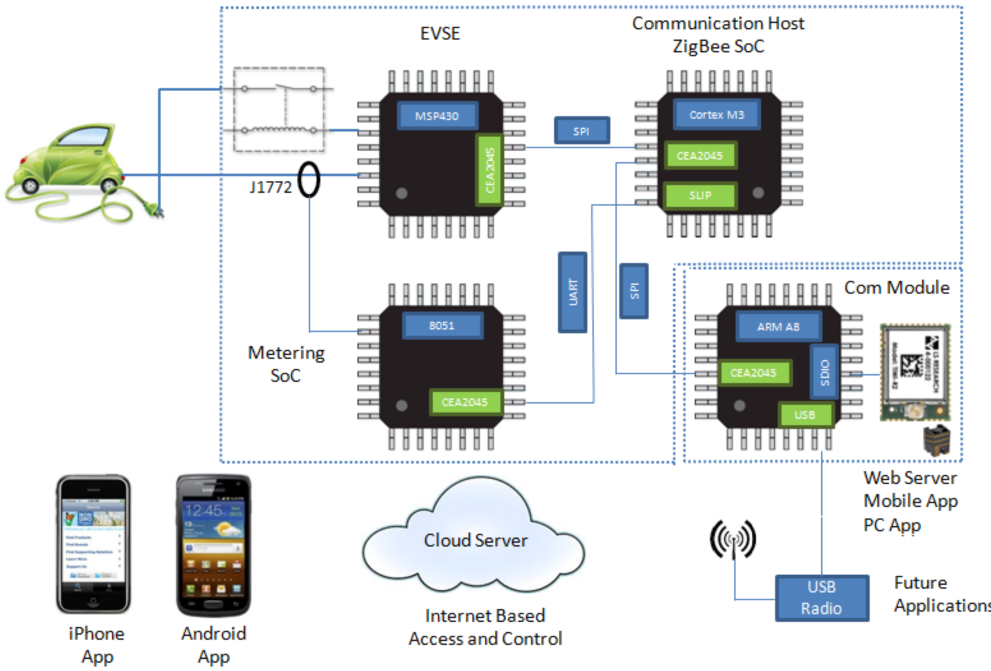

Figure 2: VersiCharge SG System Implementation

The Siemens Cloud implementation includes the ability for the consumer to monitor and control the EVSE from their phone or any internet enabled device with a web browser. In addition to monitoring the status and energy use, the user can change the charge level and set a charging and power level schedule. When configured to work with a Utility OpenADR Server, the user also has the ability to opt in or out of their Utility's demand response or other incentive rate programs.

Utilities have the ability, working with Siemens engineers, to connect an OpenADR Virtual Top Node (VTN) from their server to the Siemens cloud base VEN. Using OpenADR, they can then control the Siemens VersiCharge SG state and power level settings via the OpenADR 2.0b protocol.

3. Cost-Effective EV Charger

The development of the VersiCharge SG was more than just adding smart charging capability to the current production Siemens VersiCharge. Siemens also created a second generation VersiCharge platform as a basis for the SG. The second generation platform used lessons learned from the first generation product offering as well as industry research to improve the design and reliability of the VersiCharge platform while also reducing to cost of manufacturing, installation and use.

Below is only a partial list of improvements made to the VersiCharge SG. These improvements are being applied across the board to the VersiCharge SG, the non-communicating VersiCharge, and eventually to the IEC based WB104B. These improvements were made without sacrificing and product feature or reduction of product quality.

- Addition of Under Voltage and Over Voltage detection
- Precision Pilot Generation & Detection for improved EV interoperability
- Improved Case: Stronger / less brittle
- New button design that is more robust and reliable
- One Design for Rear and Bottom Feed for easier installation
- New PCBs for better EMI & assembly, eliminating costly ferrites
- Improved Cable Routing for easier manufacturing
- Improved Holster Angle
- Improved and lower cost Terminal Blocks
- Reduce Product Size with lower material content
- Improved Gasket Design for lower material and manufacturing cost
- Reduce Number of Plastic Parts
- Added ANSI C12.18 based Optical Interface to improve manufacturing test time
- Sandwiched PCB Design for cost and improved EMI/EMC performance
- Reduce Number and cost of LEDs
- Added CEA-2045 Module Compatibility
- Accommodates 2 PLC boards (future development)
- Combined UL, IEC and SG Code: One Code
- Added Factory Configuration: One design that is configured at final production.

The Siemens cost saving measures designed into the Siemens VersiCharge SG, when applied to the non-communicating version of VersiCharge, yielded a reduction in overall cost to product by more than 25%. Based on the goals of the DoE Grant as outlined in section 1, the target sales price for the Siemens VersiCharge SG would be between $750 and $1250. The sales price for the VersiCharge SG is currently set to be under $700 when released later this year. This sales price exceeds the entire target range as defined in the initial grant application.

In addition to the reduction in actual sales price, the cost of installation has been reduced with the simplification of mounting through the use of a single bracket and two screws. The addition of metering to monitor the in-home charging costs is predicted to lead to reduced operational cost for the consumer through energy awareness. For those consumers that require metering, and for utilities that allow non Under-the-Glass metering, the build in ASNI C12.20 capable energy meter eliminates the high cost of installing a separate external utility meter.

4. Smart Grid Capable EV Charger

In order to make the EVSE smart grid capable, the project team developed a cloud service based on Microsoft Azure platform. There are three major platforms in this software-as-a-service architecture, as show in Fig. 3 – the cloud server, mobile application, which supports both Android and Apple mobiles, and VersiCharge SG.

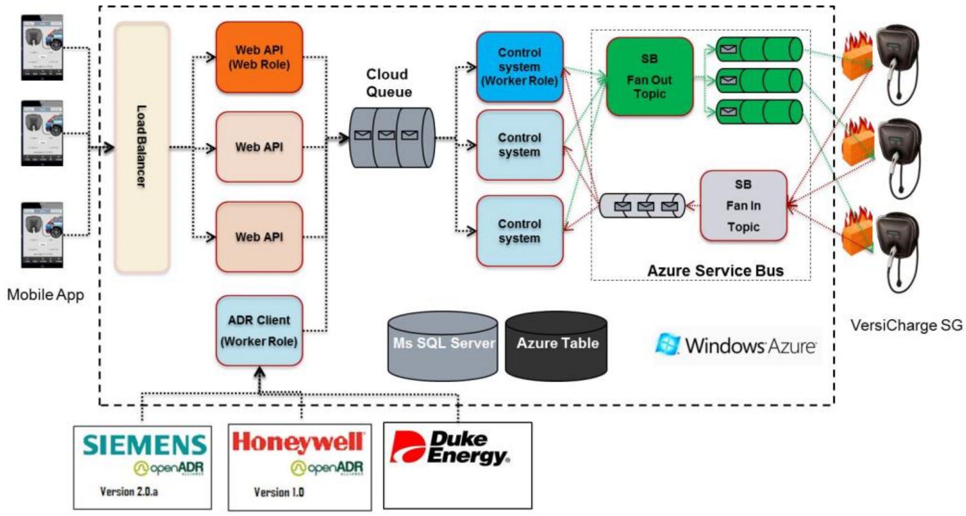

Figure 3: Architecture of the Cloud Service of VersiCharge SG

The cloud server connects chargers, customers, vendor (Siemens) and utilities. There are three roles in this application – customers (VersiCharge SG user), vendor (Siemens) and utility (Such as Duke Energy). Each role can benefit as follows –

- For Customer:
  - EVSE charging schedule
  - Various reports & tools
  - Remote control
  - Notifications
- For Manufacturer:
  - Remote diagnostics
  - Services for customers
  - Web & Mobile Apps
  - Integration with other EV cloud services (for additional info: e.g. battery %, battery, capacity, etc.)

- For Utility company:
    - Analytics: macro and micro level
    - Capacity management
    - Demand response
    - Prognosis
    - Integration with other services

At the end of this project, the project team has developed to support three different demand response signal protocols – openADR 2.0 implemented by Siemens, openADR 1.0 implemented by Honeywell and customized demand response protocol run by Duke Energy.

Usually, the cloud server receives real-time electricity rate signals and demand response signals from utilities via OpenADR communication connections. The cloud server then sends this information to users via the mobile application. The users can schedule their charging with received information. If they receive a demand response signal, the user is able to decide they should stop charging to get some credits from the utilities or continue charging. The users are also read reports of their charging records and receive advice from the cloud server on how to minimize their charging cost.

5. Test results

The prototype of VersiCharge SG has received onsite test by Argon National Laboratory (ANL) and Idaho national Laboratory (INL).

The ANL test, performed in September 2014, was focused on compliance, as in the attached Excel sheet (Attachment I). The major results are presented in Table 1.

Table 1: ANL Test results

Test Item	Measured	Results
Available Current	30.04 A	Pass
Charge Voltage	242.92 V	Pass
EVSE Type	AC Level 2	Pass
GFI Trip Current	20.0 mA	Pass
GFI Trip Time	29.3 ms	Pass
Safety & Functionality per SAE J1772™ JAN2010		Pass

The INL test, performed in summer of 2015, was focused on vulnerability related to cyberattacks (Attachment II).

In the next section, we will discuss how to improve the performance of VersiCharge SG in terms of cybersecurity.

6. Future Work

There are several improvements to consider for the current design that is planned for release in the 4th quarter 2015. Many of the improvements are a direct result of testing provided by the Idaho National Laboratory (INL). Accommodations have also been designed into this product to address features that are anticipated to be added in future evolutions of the product.

The VersiCharge SG has been designed to be easily updated with improvements after the product is installed. The Wi-Fi module and the internal communications processor have been designed to allow over-the-air (OTA) firmware updates. The Cloud application, OpenADR, Cloud based web pages and cell phone application is also easily upgraded. This allows for a wide array of potential upgrades as well as provides an ability to address potentially unknown security issues. Should the ZigBee radio be activated in the future, the ZigBee communications could be tailor to a particular utility – over the air – after the unit has been installed.

6.1. Improvements to the Current Design

The bulk of improvement that will be implemented at this time is related to the cyber security. Initially, some aspects of the security configuration were setup for ease of development while most other parts had not been addressed at that time. From the report prepared by Idaho National Laboratory the following mitigations have been recommended.

- Encrypt the microSD card and boot using a chain of trust.
- Configure U-Boot to have protected environment variables.
- Disable JTAG interface.
- Update algorithm to a secure hashing algorithm.
- Implement HTTPS with a signed certificate for the local website.
- Implement Django’s user authentication middleware.
- Implement HTTPS with a signed certificate for the remote website.
- Use certificate pinning in mobile applications.
- Use stronger session management than Basic Authentication.
- Updates should be cryptographically signed, the transport should be encrypted, and the device should verify the signature before updating.

- The update server should be secured and updated to allow for encrypted transfer of updates.
- Enable application and kernel level protections.
- Revamp the commissioning process to add a second factor of authentication located on the physical device.
- Plaintext passwords should never be stored or transmitted at any time.
- Operate using the principle of least privilege for user accounts running applications.
- Review all source code and implement secure coding practices.
- Enforce input validation from all sources (users and other processes).

The most critical of these, the update process has been addressed initially through the use of secured FTP site and ultimately will be addresses thought the use of BLOB storage on the cloud side for updates. This connection is via an https connection and requires the devices registration credentials. We also plan on cryptographically signing the package.

Other mitigations which have been implemented include disallowing root logins remotely, operating all the application software as a user with restricted access levels. All python source code has been removed from the distribution.

Planned on further enhancements include reconfiguring the local web pages to use HTTPS and once the charger is commissioned the users login and password are required. The use of certificates shall be supported as part of our effort to meet the Open ADR 2.0b requirements. We shall propagate the use of certificates to the cloud access, local and remote web sites and use certificate pinning in the mobile apps. Also considered is migrating to an encrypted file system on the SDIO card. As long as the SDIO card is removable this will be relatively high priority mitigation

Physical access to the JTAG port has been removed effectively disabling access. Soldering the SDIO card to the board is a decision to be made in the future.

6.2. Features Considered for Future Releases

Additional product features have been anticipated for future releases of the current product. Where feasible, accommodation in the product design has been made to allow for these additional features. Below is a list of known features that may be added in the future:

- EVSE to Car Digital Communications based on ISO 15118
- Power Line Communications (PLC) to the Home protocols such as Home Plug, G.hn, G3
- Proprietary AMI Radio Communications via the Wi-Fi USB port
- Meter reading and calibration through use of the existing ANSI C18.18 optical port

7. Conclusions

As a result of a grant from the US Department of Energy National Energy Technology Laboratory, Siemens Industry will be releasing a Smart Grid Capable residential EVSE to the market in late 2015. There were two primary goals desired as an outcome of this funding. These were to reduce the cost of ownership by 50% and to provide a Smart Grid Capable EVSE. In cooperation with Duke Energy and Ford Motor Company, Siemens has achieved these primary goals. The Siemens VersiCharge SG is one of, if not the 1st, UL listed, Smart Grid capable residential EVSE with high consumer engagement through phone and cloud applications.

References

[1] President Barack Obama, “One Million Electric Vehicles By 2015”, State of the Union 2011.

[2] Michael Kintner-Meyer, Kevin Schneider, and Robert Pratt, “Impacts Assessment of Plug-In Hybrid Vehicles on Electric Utilities and Regional U.S. Power Grids Part 1: Technical Analysis”, PNNL Report, Nov 2007 [Online]. Available: http://www.pnl.gov/energy/eed/etd/pdfs/phev_feasibility_analysis_combined.pdf.

[3] K. Parks, P. Denholm and T. Markel, "Costs and emissions associated with plug-in hybrid electric vehicle charging in the Xcel Energy Colorado Service Territory", Technical Report, NREL/TP-640-41410, May 2007.

[4] T. A. Becker, I. Sidhu, “Electric Vehicles in the United States A New Model with Forecasts to 2030“, Center for Enterpreneurship & Technology University of California, Berkeley, 2009.

[5] Simpson, “Cost Benefit Analysis of Plug-In Hybrid Electric Vehicle Technology”, National Renewable Energy Laboratory (NREL), 2006.

[6] Fuel Economy, “Electric Vehicles”, http://www.fueleconomy.gov/feg/evtech.shtml, DOE, EPA.

[7] Arthur Kressner, C. C. Hoyes, A. F. Barna, “Hybrid Vehicle Recharging System and Method of Operation”, United States Patent Application 20090062967A1, publication year 2009.

[8] R. Gadh, “Electric Vehicle (EV) Integration into Smart Grid of the Future with UCLA WINSmartGridTM Technology”, http://smartgrid.ucla.edu/ev/

[9] F. Carlsson, O. Johansson-Stenman, “Costs and Benefits of Electric Vehicles – A 2010 Perspective”, working papers in economics no 73, department of economics, Göteborg University, 2010.

[10] Venta alternative environmental solution, “ Benefits of electrical Vehicles”, http://www.ventainc.com/Products/BenefitsOfEV.html

[11] U.S. Department of Energy, “ Installing Charging Equipment in your Home”http://www.afdc.energy.gov/afdc/vehicles/electric_charging_home.html

[12] Stanton W. Hadley, “Impact of Plug-in Hybrid Vehicles on the Electric Grid”, ORNL Report, Oct 2006 [Online]. Available: http://apps.ornl.gov/~pts/prod/pubs/ldoc3198_plug_in_paper_final.pdf.

[13] D. A. Kirsch, “The Electric Vehicle and the Burden of History”, ISBN 0-8135-2809-7, Rutgers University Press, 2000.

[14] M. Eberhard, M. Tarpenning, “The 21st Century Electric Car”, Tesla Motors white paper.

[15] S. Shao, M. Pipattanasomporn, S. Rahman "Challenges of PHEV Penetration to the Residential Distribution Network" IEEE Power & Energy Society General Meeting, 2009.

[16] Siemens Charging Stations, "http://www.energy.siemens.com/us/en/power-distribution/e-car.htm"

[17] S. M. Amin, B. F. Wollenberg, "Toward a smart grid: power delivery for the 21st century", IEEE Power and Energy Magazine, pages 34-41, 2005.

[18] http://www.greencarcongress.com/2015/04/20150421-siemens.html

[19] http://www.businesswire.com/news/home/20150421005313/en/Siemens-Introduces-VersiCharge%E2%84%A2-SG-Wi-Fi-Enabled-Cloud-Based-Electric#.VTkvsSFVhBd

[20] http://www.ngtnews.com/e107_plugins/content/content.php?content.10677#.VTkwBCFVhBe

[21] http://chargedevs.com/newswire/siemens-introduces-versicharge-smartgrid-wi-fi-enabled-charging-station/

[22] http://www.autoblog.com/2015/04/24/sae-world-congress-siemens-versicharge-sg/