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Integrated Total Solution Model for Electric Vehicle Infrastructure Development: An Enabler for Electric Vehicle Adoption

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Abstract

A collaborative multi-company, phased approach model is proposed to demonstrate an electric vehicle (EV) charging infrastructure that will facilitate the accelerated adoption of EVs. The phased implementation begins as a limited deployment demonstration project to prove feasibility and proceeds through wider deployment, higher level charging, and advanced features such as smart grid demand/response, advanced metering infrastructure (AMI) integration, and grid-aware vehicles.

This paper details a model to enable and develop EV infrastructure and how the phased implementation will prove that EVs can provide the convenience of today's internal combustion vehicles, while making optimal use of existing grid assets and enabling increased use of intermittent renewable energy sources such as wind and solar power.

Keywords: electric vehicles, fast charging, time-of-use, DC connector

1 Introduction

Many countries and cities are aggressively pursuing multiple strategies to achieve healthy air quality and to attain their climate protection target of reducing greenhouse gases (GHG). In many cases transportation accounts for 51 percent of GHGs [1]. Thus, it is critical to reduce carbon emissions from the transportation sector. To facilitate the accelerated development for electric vehicles (EVs) and plug-in hybrids electric vehicles (PHEVs), it is necessary to develop the charging infrastructure throughout these regions.

The PosiNetEV™ is an integrated charging approach that allows for constant, real-time communication between the battery and the charger to deliver the safest charge at the maximum rate. The result is a fast charge system that reduces the battery/charger investment while delivering maximum battery uptime life.

This paper details a model to enable and develop an EV infrastructure and describes how a phased implementation will ease the transition to a future where EVs provide the convenience of today's internal combustion vehicles. The future EV infrastructure will make optimal use of existing grid assets and enable increased use of renewable energy sources such as wind and solar power.

2 Team Approach

A collaborative multi-company, phased model is described to demonstrate an EV charging infrastructure that will facilitate the accelerated adoption of EVs. The implementation of the Total Solution model suggests a team comprising:

- Charging Equipment Provider
- Software Network and Billing Provider
- Energy Management Provider
- Regional Utility
- Installation and Service Provider

A thoughtfully located and promoted network of managed chargers, the ability to 'fast charge', and smart grid control software will demonstrate that EVs can provide the convenience of today's internal combustion vehicles, while providing significant reduction of greenhouse gas emissions.

The philosophy of the collaborative multi-company team is to follow the lead of the vehicle manufacturers (OEMs) to ensure that the charging stations will be compatible with the vehicles the OEMs produce in the same timeline that the vehicles will reach the market.

The collaborative multi-company team would implement and deliver all the aspects of the infrastructure: charging equipment (all charging levels), software network for data, billing and energy management. The implementation approach would start as a limited deployment demonstration project to prove feasibility and proceeds through wider deployment, higher level charging, and advanced features such as smart grid demand/response with advanced metering infrastructure (AMI) integration.

3 Integrated Infrastructure Solution

An integrated infrastructure model (Fig.1) is Web-based software validated over the years in industrial application. PosiNetEV™ builds on existing system architecture that can link all chargers into a single network. The PosiNetEV™ automatically captures and analyzes the operational data and generates actionable fleet usage and warranty compliance reports, empowering the operators to efficiently manage their fleets by sending alerts and exceptions. This application service provider (ASP)-based monitoring and analysis software is currently being used in industrial electric vehicle environments by major distribution companies. It can provide analysis tools, issue service warnings via email, and generate standard battery/charger data charts for on-line battery maintenance and service.

PosiNetEV™ creates an independent and completely unconnected network (i.e., unconnected to the customers network) of chargers within a customer site. Within this network, every charger is connected via Ethernet to a central data hub and given its own unique IP (internet protocol) address. The data hub connects the charger network to the PosiNetEV™ Data Center.

An integrated infrastructure solution will provide survey services, charging hardware and controls, installation of equipment, grid management support and billing systems.

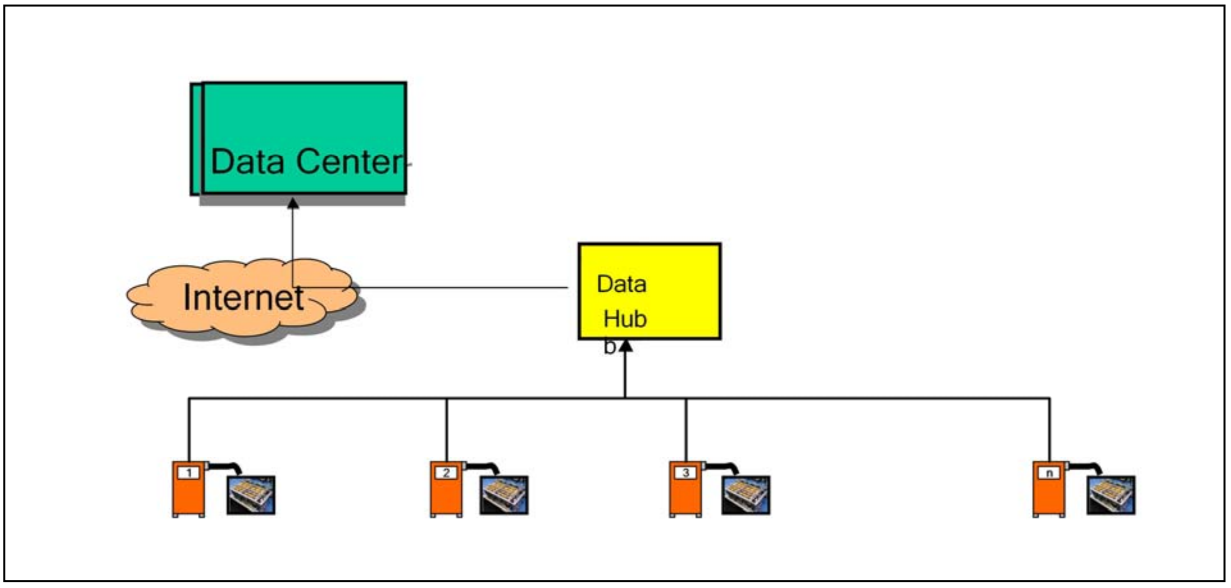

Figure 1: Integrated Infrastructure Solution

The network architecture for EV infrastructure, based on PosiNetEV™, is an intelligent charge control system that provides the user and the servicing agency insight into EV status, battery status, charger status and energy usage (Fig.2). Because it is a Web-based application, PosiNetEV™ is easily accessible, modifiable and supportable. It is capable of interfacing with AMI to provide local utility the control to optimize when and how fast EVs are charged, managing its grid and load service obligations.

The key components of the Total Solution are: PosiNetEV™, charging equipment and associated charger subnets. PosiNetEV™, the central server/portal of the network architecture is formed by a set of secured servers hosted on the internet. With flexible plug-in architecture it hosts the following modules:

- Utility Access Plug-in
- Consumer Access Plug-in
- Fleet Access plug-in
- Credit Card Payment Plug-in

3.1 Utility Access Plug-in

Utility access plug-in serves as a gateway using secure internet protocols (HTTPS, SCP, SSH, TLS, SSL) to connect the PosiNetEV™ to the utility command center. The local utility company can log into PosiNetEV™ using this module. The utility using the meter data management system software can:

- Monitor and control of charging equipment for demand response programs
- Monitor and control of charging equipment for emergency load shedding capability
- Supply relevant utility pricing signals to EVSE and/or EV (TOU rate, dynamic pricing, etc)
- Identify EV location/status and associated charger load requirements
- Identify compliance with command and control messaging and other functions
- Announcements to consumers, Upcoming CPP, DR and related data.

3.2 Consumer Access Plug-in

Consumer access plug-in is used to access the PosiNetEV™ by all the EVSE users who are connected to the Internet using a secure connection. This module can also be accessed using mobile phones. The consumer access module allows the user to see information regarding his account, update subscriptions information, and modify the subscriber credit.

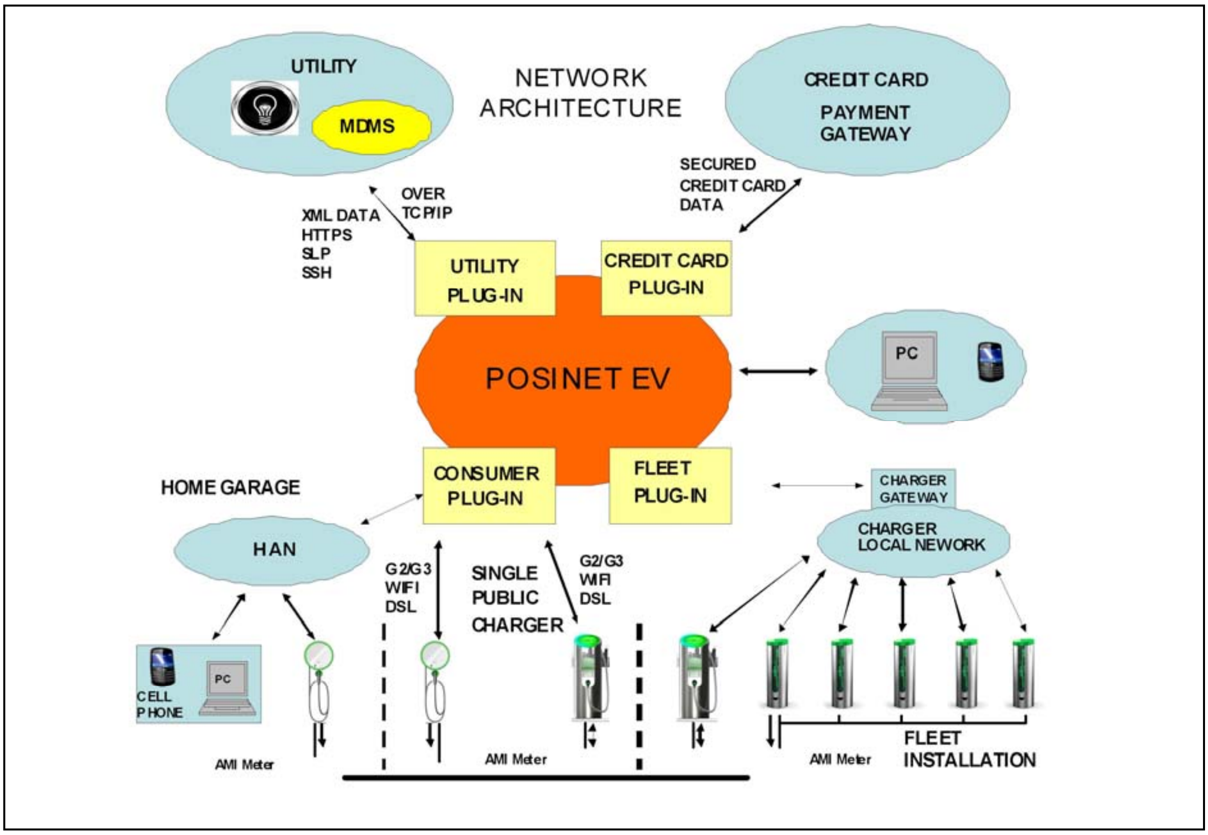

Figure 2: EV Network Infrastructure Based on PosiNet EV^{TM}

3.3 Fleet Access Plug-in

The fleet owner or service provider can log into the PosiNetEV™ using this plug-in. The fleet owner can access the information regarding status of the chargers, update all EVSE with latest data from the MDMS and maintain the subscriber database.

3.4 Credit Card Access Plug-in

Credit card data from the consumer using EVSE will go through this plug-in to the credit card payment server to authenticate and charge the card.

The charging stations (EVSE) will play an integral role in the proposed architecture. The following scenarios are identified:

- Single family residence installation
- Apartment complex installation
- Commercial parking structure installation
- Curb side installation

4 Network Management and Security

Interconnected networks provide greater control and reliability to the electricity providers, hosts and customers. Accordingly, each charger communicates through WiFi or other communication protocol to a central command center. The command center can access information about the charger at any time and has the ability to ascertain the charger's current state, history log, and any faults. The charger can be made responsive to the command center and have the ability to be turned off or limited in its power output if the need for a power saving event arises. In the unlikely event of a fault, the charging station signals the command center and shuts itself down.

The charging station features incoming and outbound communication of the following data types:

- Surcharge revenue (from remote location)
- Software upgrades (from central location)
- Usage (from remote location)
- Video and audio content – e.g., advertising and other content (from central location)
- Location signal to GPS systems using standard date link – e.g., via satellite or RFID (from remote location to other remote locations or to a central location)
- Smart-grid communication (from remote location to central location and remote location to vehicle)
- Vehicle to charger communication to define power return (from remote location – vehicle to remote location – charger)
- CAN-enabled vehicle communication (remote location to vehicle)
- Vehicle, battery pack and owner identification data (remote location – vehicle to remote location – charger)

The charger system satisfies all standard communication protocols between charger and on-board vehicle communication and control devices, including the battery management system.

The system will be capable of:

- Storing all data, both discreet and cumulative, for a minimum period of six months
- Sending and receiving time critical data in real time (e.g., service alerts)
- Sending and receiving non-time critical data in daily batches (e.g., usage data)

Charging systems feature security mechanisms against the following:

- Data breach (e.g., performance, credit card, charger performance data)
- Hardware/software breach
- High voltage power electronics breach
- Breach of defacing or key user interfaces
- Breach of transformer hardware.

All the network transactions that involve private information such as credit card information, customer data and all other non-anonymous data regarding the customer are transferred in a separate channel with SSH and HTTPS secured protocols. On the physical layer, the strongest encryption standards are applied over the communication media.

Security specific protocols, languages, objects and transactions will be used to guaranty the data management and security:

- X.509 – public K-key Infrastructure
- Transport Layer Security (TLS)
- HTTPS – secure hypertext transport protocol
- SCP – secure copy protocol
- SSH – secure shell

5 MDMS and AMI Network

The AMI is the critical component of the Total Solution. The PosiNet portal as well as the charging equipment allows for easy interface with AMI and non-AMI meters. Using the networking capabilities, charging equipment will interface with the utility meter data management system (MDMS) using existing HAN (home area network), DSL or cable modems. This capability allows for customer billing, servicing and energy management activities. The Total Solution in conjunction with AMI meters allows obtaining all the essential information to support customer billing and dynamic rate structures. The following charging activities should be measured and recorded:

- Time, date of charge
- Direction of charge
  - To the grid
  - Off the grid
- Amount of charge
- Tariff at which charged
- Amount saved, if any, by participating in Demand Response program
- Quantity charged in kWh
- Amount earned by reverse charging

The information recorded by AMI network and transmitted to the PosiNet EV Portal is accessible to the users. The user communicates with the Portal through the Web to:

- Connect to the EVSE or fast charger
- Select the time of charging
- Select target pricing for electricity
- Access extensive reporting
  - Reporting on charging process
  - Reporting on pricing
  - Reporting on charging pattern
  - Other miscellaneous reports

Another key component is the MDMS. Utilities can read all of their AMI meters and manage the data to reduce field service customer service, marketing, operations and engineering. The Total Solution with MDMS provides the utilities with the ability to manage:

- Demand Response – monitor and control of the charging equipment for demand response programs
- Load Shedding – monitor and control of the charging equipment for emergency load shedding capability
- Pricing Signals – supply relevant utility pricing signals to the users of the charging equipment and electric vehicles
- Load Diagnosis & Location Awareness - identify EV location/status and associated charger load requirements
- Override Tracking - identify override request at individual and system wide levels
- System Integrity – identify compliance with command and control messaging
- Customer Information - supply customers with relevant energy usage information, historical usage data, charging profile, etc.
- Roaming Tracking and Charge Authorization – track and authorize charging of EVs outside of user's registered primary address
- Roaming Settlement – calculate cross settlement charges between service entities for customers who are authorized and have charged their EVs outside of the primary address and or service area
- Load Management – reduce the loads of individual residential and commercial users to satisfy the aggregate pledged amount of the load reduction

6 Level I and II Charging Equipment

The charging equipment is a crucial component, capable of operating with all charging levels listed in Table 1[2].

6.1 Level I Charging

Level I charging typically uses a standard electrical outlet (NEMA 5-20R), which in the United States is 120 volt, single-phase, and grounded. It uses a standard 3-prong plug (NEMA 5-20P) with a ground-fault circuit interrupter (or other listed interrupting personnel protection

Table 1: Charge Voltage Levels in the United States

	Voltage (V. AC)	Max. Continuous Current (Amps)	Min. Branch Circuit Protection (Amps)	Frequency (Hz)	Phase
Level 1	120, 120, 120	12, 16, 24	15, 20, 30	60, 60, 60	single, single, single
Level 2	208/240	32	40	60	single
Level 3	480	400	500	60	three

system) located in the power supply cable within 12 inches of the plug. Although 3-prong standard electrical outlets are present almost everywhere, Level I charging is not the preferred means of charging. Depending on the battery type and capacity, it can take from eight to 30 hours to fully recharge a battery. In addition, several studies conclude that for some battery systems, Level I charging reduces battery life and performance [2],

6.2 Level II Charging

Level II charging comprises permanently wired and fastened electric vehicle service equipment (EVSE) sited at a fixed location. It requires grounding, ground fault protection for users, a no-load make/break interlock (which prevents vehicle start up while charging takes place), and a safety breakaway for the cable and connector. Depending on the battery type and capacity, Level II can recharge an EV in two to six hours.

Electric vehicle service equipment (EVSE) for residential and commercial use (Fig.3) are advanced intelligent power processing units designed to charge EVs and PHEVs in residential and public applications. The EVSE transfers AC power from an electrical outlet to the EV or PHEV via a charge cable and Level II connector. EVSE is designed to operate as a Level II charger, incorporating many features to guarantee safe and reliable operation.

EVSE safety is of utmost importance and is provided by multiple features such as: ground fault circuit interrupter (GFCI) for charger circuit interrupt devices (CCID), service ground monitor, CCID self-test and automatic re-closure. The residential and commercial EVSEs have a feature allowing input for utility control.

Enhanced EVSEs have features that enable the unit to operate and provide information on a smart grid. In addition, the user will be able to access data on the web regarding the energy used to charge their vehicle as those grid capabilities become available to individual consumers/customers.

The EVSE unit can be mounted on a wall, on a pedestal or, in the case of the commercial unit, to a light pole or existing structure. The commercial unit is reinforced to prevent theft and vandalism. In addition, the charging cable can be completely stowed away.

Typical EVSE Specifications:

- Input voltage and current :
    - Level I: 120V at 15 Amps
    - Level II: 208V-240 VAC up to 70 Amps
- Single Phase (2-wire, with ground), 50/60 hz

Figure 3: Commercial and Residential ESVE

EVSE system functions and features include:

- Safe and reliable interface with EV (PHEV, all electric, NEV)
- Bi-directional power flow and metering
- Power monitoring, display and network alerts
- Charging and fault indicator – tri color LED
- Industrial and safety standards compliance
- Ground fault protection - GFCI
- Automatic charge restart option
- Scalable, easily adaptable and upgradeable for future functionality
- Single and Network multiple installations
- Load balancing feature
- Locking door for cable protection (if necessary)
- Outdoor NEMA 4 enclosure
- Long-term durability

6.3 Level I and II Installation

6.3.1 Residential Level I and II Installations

The EVSE, with its built-in WiFi/LAN networking capability, will connect through the HAN to the smart utility meter (part of the HAN). In the absence of a HAN (Zigbee) and/or smart utility meter, a phone line may be brought out to the EVSE to enable communications with an integrated system controller.

The integrated system controller will act as a gateway to the utility MDMS for bi-directional data communications and enable AMI data such as demand response, dynamic pricing, time of usage (TOU), critical peak period data and others. Consumers can log-in to a consumer EVSE plug-in Web page using their home PCs. A consumer logged into the EVSE Web page can see all the information regarding his/her account, chargers and vehicle (battery state of charge). Consumers could also use the site to change several charging settings, select time of charge, check the target price of power and generate various reports listed in the specifications of the charger.

6.3.2 Commercial Level I/II Installations

An isolated installation of a commercial charger (Fig.4) will be built with a smart/magnetic card reader for payments. This installation will connect to the MDMS through integrated system controller using G2/G3 or a DSL network for all AMI data. This installation will prompt the user, upon connecting the vehicle to the EVSE, on current pricing, list of dynamic pricing hour-by-hour for the day, current battery condition, battery level and other related data. The consumer can then make a choice of the time of charging based on how long he/she is going to leave the vehicle at the charger. In this case, there may be additional charges for leaving the vehicle in the parking spot for longer and as well as privilege of availing a target pricing.

Once the choice is made, the consumer can pay for the service using a credit card or a subscriber card. In case of a credit card, the EVSE will contact the PosiNetEV™ server, which in turn will connect to the credit card payment gateway. In case of a subscriber card, EVSE will contact the PosiNetEV™ server for authentication information and credit balance enquiry. Once the authentication and credit balance is approved, EVSE will post the updated value of the subscriber card to the PosiNetEV™ server.

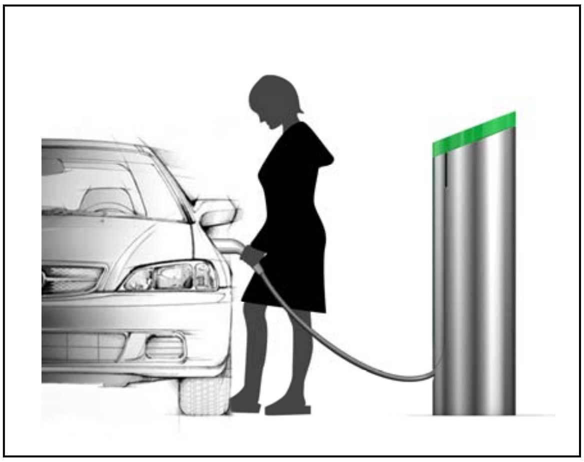

Figure 4: Commercial Level I and II Installations

6.3.3 Apartment Complex/Parking Structure Installations

In case of chargers installed in a Fleet charging area or a parking lot, the chargers form a local area network (LAN) using wired or wireless communications. In this network, one of the chargers can work as a network gateway to this sub-net and connect to the integrated system controller, using secure internet protocols defined in the charger specifications. The service provider, who owns this installation, can log into this EVSE using a remote PC connected to the Internet by logging into PosiNetEV™ server , the service provider can then push or pull settings and data.

This installation inherits all the functionality of single installation except for G2/G3 or DSL connection, which can be found in only the Gateway EVSE.

7 Level III Charging Equipment

The Level III charger (Fig.5) is a power-electronics based charging system that converts AC utility power into controlled DC power to charge EV batteries.

Based on proven industrial smart-charging technology, EV fuelling stations will be the safe, convenient standard for public and fleet charging – and will enable large volume adoption of the cleanest vehicles on the road.

A 250kW Level III fast charger is capable of operating from 3-phase utility input voltage ranging from 400-600VAC (50or 60Hz) and delivering up to 600Amps DC to charge battery packs up to 500VDC (higher voltages are optional). The charger is capable of charging a 35kWh battery pack (0 to 100 percent SOC) in less than 10 minutes.

Some of the notable features are:

- 10-minute charge for a 35kWh battery pack
- Support multiple battery chemistries
- Very high reliability
- All weather enclosure
- Simple enough for consumers
- Durable enough for fleets

Table 2 shows the relationship between the charger size, time to charge, state of charge, and type of vehicles.

Figure 5: Level III Charger

Another key component in Level III charging is the connector (Fig.6). The Society of Automotive Engineers (SAE) J-1772 committee develops EV charging and connector standards. A sub-committee of J-1772 is developing the Level III connector standards. With SAE's Level III connector, drivers can take advantage of public EV fast fuelling stations without being tethered to an overnight home charger. Level III charging can be completed in as little as 10 minutes.

Figure 6: Level III Connector

8 Total Solution and Renewable Energy Sources

The Total Solution makes optimal use of existing grid assets and enables increased use of intermittent renewable energy sources such as wind and solar power – a source of electricity that likely will become more significant as technologies evolve. For example, small,

Table 1: Relationships Among Charge, Charger Type and Different Vehicles

Type of Charge	Charger Power Level, kW		
	Heavy Duty	SUV/Sedan	Small Sedan
Fast Charge, 10 minutes, 100% SOC	500	250	125
Rapid Charge, 15 minutes, 60% SOC	250	125	60
Quick Charge, 60 minutes, 70% SOC	75	35	20
Plug-In Hybrid, 30 Minutes	40	20	10

modular wind turbines have been designed for installation on buildings in urban and suburban areas [4].

Each wind tur-bine generates up to 1000W with start up wind speed as low as 2.2m/s and is designed to with-stand winds up to 120 mph. The turbines, which are equipped with internal DC-DC converters to pro-vide constant 250V DC output, can easily be connected in a parallel configuration as well as in conjunction with other renewable sources like solar panels.

Installed on buildings close to the charging station or on the roofs of charging stations themselves (Fig.7), solar panel and turbine outputs could be connected to a battery bank to allow for battery-to-battery charging.

Figure 7: Charging Station Roofs Could House Alternative Energy Systems

A charging system (Fig.8) for simultaneously charging the batteries of a plurality of battery powered vehicles would include one or more DC-DC power converters with one or more charging ports configured to plug into the batteries [3].

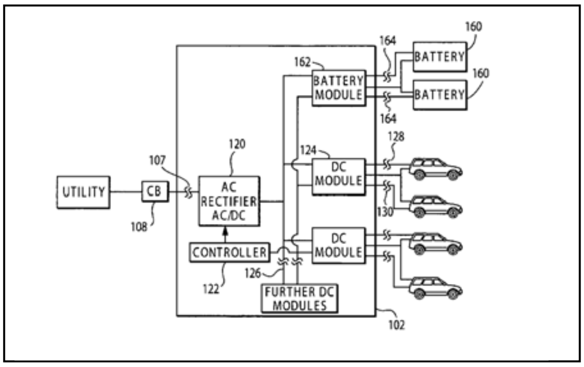

Figure 8: Multi-battery Charging System

Such battery-to-battery charging systems with DC input from intermittent renewable resources would provide many system level benefits including grid regulation. The battery banks could be based on the salvaged lithium batteries used in EVs. Such a solution offers a very attractive return on investment (ROI).

9 Implementation Approach

The infrastructure implementation would be based on a phased approach that could be implemented at the city or state level.

The first phase could start any time depending on stakeholder readiness. As envisioned, the first phase would begin with a demonstration project to which each subsequent phase could incorporate additional functionality and expand the reach of the charging and subscription network. In addition, each phase could include an educational and public outreach component to maximize the effectiveness of the demonstration program. Upon a successful demonstration, the project would culminate with a deployment phase.

9.1 Phase I – Initial Demonstration

The first phase will prove the feasibility of the EV charging infrastructure and provide a practical network for EV users. This phase would include the installation of a low number of Level I, II and III chargers. These chargers would be located in areas with high visibility, subject to coordination with the stakeholders.

These charging stations could be equipped to charge:

- Personal electric vehicles such as electric bikes
- NEVs – Neighborhood electric vehicles
- PHEVs – Plug-In hybrid electric vehicles
- EVs – Highway capable

The subscriber network could be fully deployed but user fees would not be charged. Charging stations could be equipped for integration and communication with the grid..

9.2 Phase II – Expanded Demonstration

The second phase would expand the existing demonstration. It would feature the installation of additional Level I, II and III chargers for fleet operations and an expanded subscription network. Also, AMI should be installed at those locations. The network of smart meters would allow for initial energy management demonstration. The subscription network would be fully functional and activated. Users could begin paying subscription fees for the use of charging stations. Smart grid integration software would demonstrate facility for utility to manage demand through messaging and utility communication. Additional charging station locations could include stakeholder fleet motor pools, hotels, parking lots and curbside.

9.3 Phase III – Full Implementation

The third phase would broaden into deployment as all elements of the program are expanded to accommodate the range of electric vehicles entering the market. Additional Level I and II chargers would be installed in private homes and the subscription network would be expanded. Additional Level III chargers would be installed to support heavy duty vehicles (buses, heavy duty line fleet, etc.) and fast/rapid charge BEVs (battery electric vehicles). By this phase, most vehicles would be equipped to be "grid-aware" and would communicate with the grid to demonstrate smart grid demand/response functionality. Additional charging station locations could include stakeholder motor pool, bus and utility fleets, as well as taxi stands at hotels and airports.

10 Conclusions

This paper was aimed at providing an overview of the key elements of an integrated EV infrastructure solution. The EV infrastructure solution could be implemented at any government or other stakeholder level and would include flexibility for drivers relative to charging time, location and rate. EV infrastructure provides the local utility with the control that it needs to manage its grid and load service obligations. For charger owners/hosts the system would provide ongoing tracking on usage history and performance as well provide access to new services and business opportunities at the charging point.

In summary, the integrated EV infrastructure solution provides:

- Universal access to all EV drivers, whether or not members of a subscription service
- Charging infrastructure that meets or exceeds all standards
- All levels of charging equipment. Charging EVSE architecture that is scalable and adaptable to evolving opportunities and requirements
- PosiNetEV™ data exchange portal that is secure for the utility, the host and the consumer
- Integrated controls for the utility to manage its load

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