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Technology roadmap for smart electric vehicle-to-grid (V2G) of residential chargers

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Abstract

Smart grid is defined as the overlaying of a unified communications and control system onto the existing power delivery infrastructure to provide the right information and the right entity at the right time. It helps even out demand spikes and uses resource mix more efficiently. It is a better integration, or “system balancing,” of variable resources, like wind power. Many of the advanced applications of smart grid are expected to develop in an evolutionary manner based on current technologies available and the needs of the market, for example, electric vehicles (EVs) or plug-in hybrid electric vehicles (PHEVs). It is likely that we will see a simpler associated application (i.e., smart battery charger) before the market matures to support a more complex form of the application vehicle-to-grid (V2G). The objective of this paper is to develop a technology roadmapping (TRM) process for smart electric V2G technologies in Oregon and the Pacific Northwest (PNW). The research focuses on the application of V2G in the residential chargers. It introduces the market drivers, products, and technology analysis and also provides research on the necessary resources needed within R&D in the coming years (next 10 years).

Background

One million electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) are expected to be in use by individuals and fleets by 2015 (United States Department of Energy 2011). Unmanaged EV charging will add to peak grid load and would require additional generation capacity (Kiviluoma & Meibom 2011; Kintner-Meyer et al. 2007). Charging must be scheduled intelligently in order to avoid overloading the grid at peak hours and to take advantage of off-peak charging benefits. EVs can also serve as an energy resource through vehicle-to-grid (V2G) operation by sending electricity back into the grid, thereby preventing or postponing load shedding (Kempton & Tomić 2005; Guille & Gross 2009a). Charging and V2G services must be optimized for grid load while guaranteeing owner schedule and range requirements are met. A system encompassing EV owner input via a mobile application, an aggregation middleware, a charge scheduling, and V2G operation algorithm, and radio-frequency identification (RFID) reader, is proposed (Ferreira et al. 2011).

Recent technological advances in electricity distribution and load management, referred to as “smart grids,” promise to facilitate the integration of EVs into electricity load and to lower costs. Electric utilities have already begun to deploy smart grid

technologies to better manage commercial and household load using intelligent metering and communications systems in order to save energy, cut emissions, and reduce peak loads. More widespread deployment would enable EV charging to be scheduled intelligently. In addition, it could—at least in principle—enable the storage capacity of the batteries in EVs to be used as a supplementary source of power at times of peak load; the residual charge in those batteries could be fed back into the network during the evening peak and the battery recharged at night. There may also be scope for exploiting this storage potential to compensate for the variability of electricity supply from variable renewable energy sources such as wind and solar. In this way, smart grids and EVs could be mutually beneficial: EVs could both benefit from and help to drive forward investment in smart grids (Trevor 2012).

In this paper is presented the technology roadmapping of a smart battery charger for EVs or PHEVs, aiming their integration in smart grids. The battery charging process is controlled by an appropriate control algorithm, aiming to preserve the battery lifespan. The main features of the equipment are the mitigation of the power quality degradation and the bidirectional operation, as grid-to-vehicle (G2V) and as V2G. The V2G mode of operation will be one of the main features of the smart grids, both to collaborate with the electrical power grid to increase stability and to function as a distributed Energy Storage System (ESS) (Vitor et al. 2012).

Therefore, EVs could play a central role in decarbonizing road transport in the near future. To establish the appropriate strategies for research and development (R&D) is required. According to Phaal et al., technology roadmapping is a proper tool to build up strategic and long-term planning by assessing potentially disruptive technologies and market changes (Phaal et al. 2004). Accordingly, the objective of this paper is to develop a technology roadmap for smart grid technology. In particular, this research focuses on the application of smart grids in the EV charging for the residence.

Methods

Our research is focused on the residential charging aspect of smart grids which entails technology in the car and at home, communication to the utility, the utility, and communication with other utilities. Since the residential chargers are estimated to account for 65–80 % of EV charging, this includes simple level 1 chargers using standard 110-V wall outlets, and level 2 chargers use 220 V and charge about twice as fast. These are residential chargers which apply to off-street parking in personal garages or assigned spaces in housing building. Payment is through the utility companies, so no complex new systems are needed for this. And, the equipment is user-owned.

Our research methodology is a combination of in-depth literature reviews backed up by online research. By tapping into a diverse set of articles, along with online information, we were able to follow the many suggestions of previous roadmapping research techniques by not relying too much on one particular set of research findings to draw significant conclusions. We were able to cross-reference and corroborate findings among these articles/comments.

Literature research

Smart grid

A smart grid is an electricity network that incorporates a suite of information, communication, and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end users. Smart grids allow for better coordination of the needs and capabilities of all generators, grid operators, end users, and electricity market stakeholders in operating all parts of the system as efficiently as possible, minimizing costs and environmental impacts while maximizing system reliability, resilience, and stability (Energy Agency 2011a).

Battery electric vehicles

The EV, as defined by the Encyclopedia Britannica, is a motor vehicle powered by a battery that originated in the late 1880s and that has been used for private as well as public transportation. An electric vehicle can be a bicycle, a motorcycle, or any type of four-wheeled automobile, being private or commercial. Battery-powered electric vehicles are different than hybrid or fuel cell vehicles for this application in that they do not generate electricity. They are instead a distributed storage medium that time-shifts the generation and consumption of electrical energy, providing, for example, peak power, reliability, distributed storage, and reactive power (AC Propulsion, Inc. 2009a).

V2G

Electric-drive vehicles have within them the energy source and power electronics capable of producing the 60-Hz AC electricity that powers our homes and offices. When we allow this electricity to flow from cars to power lines, we call it “vehicle-to-grid” power or V2G (Thomas B. Gage 2003). V2G is a technology that makes clean and efficient electric-powered transportation possible by allowing electric vehicles to power and be powered by the grid. AC Propulsion is currently working with V2G research and development programs throughout the USA to supply V2G-capable vehicles, evaluate V2G functionality, and develop the communications and control systems that are necessary to enable electric vehicles to support the power grid (AC Propulsion, Inc. 2009b).

Results and Discussion

In developing our roadmap, we analyzed market drivers as they are indicators of the basic criteria to meet a potential buyer’s needs. In the recent decade, car buyers have inclined using EVs due to several drivers in the US environment. These drivers have emerged from social, technological, and economic environment. To explain how these drivers affect the electric car market, Table 1 demonstrates the primary market drivers behind V2G in an EV application as we have discovered through the research conducted for this paper. We also analyzed the challenges for regional V2G roadmap between the current state of technology against the EV context. The aforementioned efforts allow us to develop the technology roadmap as presented below.

Market drivers

Marketing is all about creating value for the customer and striving to meet and then exceed customer expectations. And, market drivers are considered at the time

Table 1 Market drivers

Info. object catalog	Market drivers
Environment	Electric cars
	Renewable (intermittent) generation resources online
	Differential cost of peak vs. off-peak power
Consumers	Prevent “empty battery” range anxiety
	Ease of use
	Lowest cost ownership
	Be green
Utility	Reliability
	Risk reduction
	Lowest operating cost

envisaging and establishing value of a product/service that is to be marketed. These drivers are primarily trends that cause an existing or new market to develop (William M. Luther 2010). Based on current research and development in the V2G industry, we identified three categories as the primary drivers behind this technology roadmapping (TRM). Table 1 demonstrates the primary drivers for regional V2G roadmap.

Market drivers—environment

Electric cars Rapid growth in the number of EVs in use would have a significant impact on the need for investment in electricity network capacity and smart grid technologies. EVs as one of the green transportation have been noticed widely by societies and governments, so that annual sales of different types of electric cars including EVs will have a remarkable growth by 2050 and the number of sold conventional gasoline and diesel cars will be decreased dramatically by that time (International Energy Agency 2011). International Energy Agency’s study shows that the number of EV and PHEV cars sold globally by 2050 would be around 106.4 million cars—Fig. 1.

Renewable (intermittent) generation resources online The most important role for V2G may ultimately be in emerging power markets to support renewable energy. The

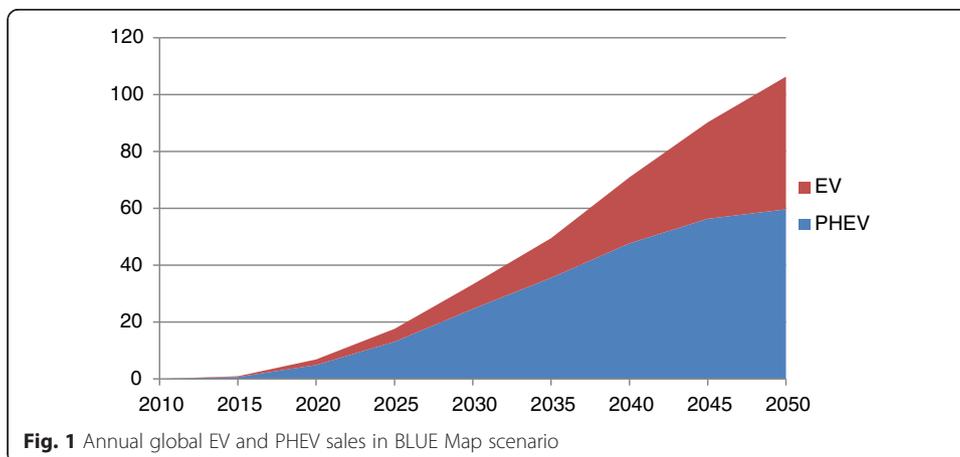


Fig. 1 Annual global EV and PHEV sales in BLUE Map scenario

two largest renewable sources likely to be widely used in the near future, photovoltaic (PV) and wind turbines, are both intermittent (Kelly & Weinberg 1993). Intermittency can be managed either by backup or storage. In terms of V2G, backup can be provided by the fueled vehicles (fuel cell and hybrid running motor-generator). Storage can be provided by the battery vehicle and the plug-in hybrid running V2G from its battery (Bossel 2004).

Differential cost of peak vs. off-peak power There are two main categories of grid support for which V2G might be useful. One of the categories is providing peak power because meeting the demands of peak power currently is a very expensive obligation for utilities. If EVs could be charged during off-peak times and then discharged selectively to “shave the peak,” the utility could potentially forego the need to start up a peaking plant, which would save on operation and maintenance costs and yield significant environmental benefits (Kempton et al. 2001). For the residential charging, it is expected that the majority of EV owners will decide to charge their vehicle when they arrive home from work whether immediately during peak load hours or overnight during off-peak hours (Smart et al. 2010) because the PUC will price peak power higher to get people to use energy off-peak.

Market drivers—consumers

Prevent “empty battery” range anxiety Range anxiety in EVs refers to “[road users] continual concern and fear of becoming stranded with a discharged battery in a limited range vehicle” (Tate et al. 2008). The existence of range anxiety is related to the technical limitations of the batteries of EVs (Botsford & Szczepanek 2009). The V2G technology allows EVs to both draw electricity from and return electricity to the grid. Furthermore, V2G technology may allow utility companies to increase their use of intermittent renewable energies, such as wind and solar (Guille & Gross 2009b). Therefore, we think early consumers will tolerate hassle, and later, consumers will not because there will be a new technology to resolve it. According to some experts, vehicle-to-home (V2H) technology is therefore likely to be successful in a shorter term, as the technology operates independently from the utility company and can already manage energy flows within the home effectively (Jorrit J. Bakker 2011).

Ease of use Ease of use is a major factor and can include the physical hardware, software programming, and integration of communications systems, V2G program administration, standardization of programs across utilities, and other issues. Ideally, there would be little or no additional hardware, so the customer could plug in as they would for a normal charge. The customer will need software tools to program when and what they need in terms of driving range. They also need these tools to be user-friendly and provide multiple means of access (i.e., at the vehicle, charger, online, home area network system, and through mobile applications). It is important for as much of the process to be automated as possible (Adrene et al. 2012).

Lowest cost ownership An EV or PHEV uses its excess rechargeable battery capacity to provide power to the electric grid in response to peak load demands. These vehicles

can then be recharged during off-peak hours at cheaper rates while helping to absorb excess nighttime generation. The vehicles serve as a distributed battery storage system to buffer power. The recharge scheduling is to minimize the generation cost which includes generation production cost and V2G discharge payment (Siddhartha et al. 2012).

Be green The results of the study show that V2G, in addition to providing valuable grid services, could also prove to be a prominent application in the global transition to the emerging green and sustainable energy economy (Willett et al. 2008a). Consumers will want to be green. Americans are becoming increasingly concerned about the environment. Studies have shown that the percentage of Americans who worry about the environment “a great deal” or “a fair amount” has increased from 62 to 77 % between 2004 and 2006 (Bill 2006). More people are making their homes energy efficient, driving more fuel-efficient cars, focusing more on recycling, and buying products that are healthier and less harmful to society and the environment.

Market drivers—utility

Reliability Most cities have embarked on policies to encourage the development and spread of electric-drive and low-pollution vehicles. The goal is to reduce air pollution from mobile sources. These policy initiatives, advances in power electronics, and the opening of electricity markets across the country create opportunities for electric-drive vehicles to reduce air pollution and at the same time increase the reliability and efficiency of the electric power system. This opportunity is based on using the electric storage of battery vehicles, or the generation capacity of hybrid and fuel cell vehicles, for ancillary services and/or peak power (Letendre & Kempton 2002).

Risk reduction Developing V2G technology of residential chargers will help to reduce the environmental risks. At the same time, V2G vehicles also could provide their owners with greater security, by using the V2G connection for vehicle-to-building (V2B) operation in an emergency and by knowing that the environmental benefits of V2G decrease the risk of political and financial disruptions due to global warming (Zpryme 2010).

Lowest operating cost The V2G system can provide the operating reserve. The operating reserve is the generating capacity that is available to come online within a short time in cases of generator failure or other disruptions to the electricity supply (Letendre & Denholm 2006). There are two types of services, known as ancillary services, which apply to V2G systems and operating reserve—regulation and spinning reserve. The services that are potentially available from V2G would have the effect of reducing the electrical utilities’ capital costs of building power plants and reducing the operating costs of these plants (Adrene et al. 2012).

Product analysis

The value of a product reflects the owner(s)/buyer(s) desire to retain or obtain a product (Halil Shevket Neap & Tahir Celik 1999). The best product value propositions focus on the key benefits—not features or attributes—that matter most to buyers in the target

market. Moreover, the best value propositions specifically document the worth/superiority of the seller's offering, relative both to competitors and to customer needs (Jakki Mohr 2016). According to the researched market drivers in V2G industry, we have pointed out two main features of the key product features: customer and utility (see Table 2) for short- and long-term viability within the market place. Based on these features, we grouped and concluded the features, factors, and its needs and defined our future product (see Table 3).

Table 2 is an overview of the key product features. There is a need to schedule vehicle charging. It needs to evolve from current simple (or dumb) technology to smart technology communicating the grid and interacting with it efficiently. Then, ultimately, products could also be made more aware of the users' personal schedules. Therefore, the key needs for EV charging include dealing with the range anxiety issue, ease of use, low cost, and green products. For the utility feature, it includes demand management, such as at least limited abilities to control loads, incorporation of real-time pricing, and dealing with green signals. This allows utilities to increase reliability, decrease cost, and decrease risk. Furthermore, the increased system control, such as power feed-in, and better ability to deal with time of use pricing can further help deal with reliability, cost, and risk.

Technology analysis

How to utilize or develop existing or new technologies to realize future products is a critical problem. We pointed out the existing technologies to support each product component where permissible. Then, we tried to find the opportunities for the future development of existing or related technologies and threats from the development of new technologies which may cause the potential substitution on existing technologies. We discussed an overview of some of the technologies needed to fill gaps and enable our products. Table 4 maps the existing or developed technologies to the defined product features.

Table 2 Product features

Product features	Factors
Customer features	Scheduling: dumb (L1/L2)
	Scheduling: smart (L1/L2)
	Scheduling: aware (L2)
	Scheduling: green
	Pricing: dumb time of use (TOU)
	Pricing: smart time of use (TOU)
	Pricing: R/T (real time)
	Pricing: feed-in
Utility features	Demand management: limited load control
	Demand management: R/T (real time)
	Demand management: green
	System control: feed-in
	Pricing: time of use (TOU)
	Pricing: R/T (real time)

Table 3 Product and needs

Product	Features	Factors	Requirements
Smart residential EV charging	Customer	Scheduling	Anxiety, ease, cost, green
		Pricing	Cost
	Utility	Demand management	Reliability, cost, risk
		System control Pricing	

Charger/car (consumer)

It is important to perform intelligent scheduling for charging and discharging of EVs. Intelligent scheduling for EV charging and discharging has become a vital step towards smart grid implementation. The essential principle in intelligent scheduling is to reshape the load profile by charging the EV battery from the grid at the time when the demand is low and discharging the EV battery to the grid when the demand is high (Li et al. 2010; Shireen & Patel 2010). We will spend three periods to develop the scheduling of the EV charging.

V2G is a continuum, ranging from simple remote “on/off” management of the charger to adjustable high-power electricity feed-in during peak demand periods. One of the extended forms of V2G is the ability of the system to use a large part of the battery state of charge (SOC) for power feeding to the grid (SPINNOVATION 2012). Our final aim is to develop a standard connector.

Communication (both)

Unlike other communications networks, the V2G communication has its own characteristics that the vehicular network differs in size and vehicular speed, as well as relevance of their geographic positions (Huaqun et al. 2011). It also has the ability to adapt the EV charging process in near real time in case of grid violations through V2G communication by rescheduling or demand-limit renegotiations (Sebastian et al. 2011). V2G communication enabled EVs to serve as ideal actors for demand- side management (DSM) systems (International Energy Agency Demand Side) because of their high battery capacities, high charging powers, comprehensive availability with increasing market penetration, and their capability to quickly adapt charging currents to given demand boundaries (Kempton & Tomic 2005). The TRM will focus on the EVs’ residential charging speed and information for both consumer and utility.

Table 4 Technology analysis

Technology features	Technologies	
Charger/car (consumer)	Schedule	1.0, 2.0, third party API
	Feed-in	Standard connector
Communication (both)	Speed	1-way, 2-way; minutes, seconds
	Information	Usage, demand requirements, TOU rate, R/T price, demand shedding, green, system control
Computing (utility)	Data	Data warehouse, R/T availability
	Management	Demand management
	Market	Local rate market, regional imbalance market

Computing (utility)

In most areas of the USA, the Independent System Operator (ISO) provides an electronic signal to request frequency regulation, reserves, and other forms of fast-response, high-value power. Additionally, a local utility may want to signal for other V2G services, such as peak load shedding or relief on targeted parts of the distribution system. V2G needs the computing to mediate driver and grid. There must be intelligent mediation between driver and grid operator needs (Zpryme 2010). We will develop our TRM in three aspects for utility: data, management, and market.

Resource analysis

After integrating technology roadmapping process, the three main levels of the road-map, which are market driver, product feature, and technology, also require extra factors in order to increase market opportunity and approach the development of new technologies. Technology resources are addressed as significant sources because they have potential to fill the technology gaps and deliver good roadmaps. Moreover, having sufficient resources will allow capability of technology to overcome the barriers of technology application and also improve the diagnosis and treatment of patients. To realize the product features, we need to understand the current and required level of technological capabilities and its gaps. We developed the resources requirements (see Table 5) to analyze the technological capabilities, i.e., the resources, which are composed of a variety of sources of knowledge. The resource analysis must not only give attention to economic costs but also has to determine if it is feasible to obtain the needed physical material and manpower in the required time period.

Labs

From the viewpoint of public role in technology innovation, the investment or funds in the V2G technology have been drawn by governmental organizations and the academic world (university labs) in the USA, for example, Sandia National Laboratories and University of Delaware. In May 2007, the University of Delaware, PHI, and other partners, established the Mid-Atlantic Grid Interactive Car Consortium (MAGICC) to prove the V2G concept. MAGICC activities are funded by awards of \$200,000 of the Delaware Green Energy fund, \$250,000 from PHI, and \$150,000 from Google.org, for R&D and demonstration purposes (Willett et al. 2008b). Their goals are to educate about the environmental and economic benefits of V2G and enhance the product market.

Third party S/W

In common with governmental organizations and academia, numerous companies who have the V2G technology trials like PG&E and Xcel Energy companies have developed and invested some products in the V2G technology. Furthermore, automobile companies have announced new products adopting the V2G technology such as Ford and Toyota's PHEVs. By showing their future concepts or applications, they can not only advertise their ability but also lead markets and suppliers.

Standards

V2G is in an early stage, which means companies such as auto, smart grid technology integrators and telematic manufacturers can prepare themselves for market entry by closely monitoring government legislation, standards, smart grid and charging station

Table 5 Resources analysis

Resources		Requirements
Labs	Government and university labs	Demand management/data Demand control Feed-in charger Feed-in car Imbalance/power market
Third party S/W	Independent S/W company	R/T data collection Demand management Demand control Imbalance/power market
Standards	Standards organizations: IEEE, ITU, NIST, ANSI	Demand management Demand control Feed-in charger Feed-in car Imbalance/power market
Utility	Local utility company	Third party API R/T data collection Demand management Demand control Imbalance/power market
Charger	Residential charger companies	Charger schedule S/W 1.0 Demand data Feed-in charger Feed-in car
Car	Auto companies	Car schedule S/W 1.0 Car schedule S/W 2.0 Third party API Demand data Feed-in car

rollouts, and security (Zpryme 2010). Especially, typical automotive component markets require more strict standards in quality management. There are several standards organizations: IEEE, ITU, NIST, and ANSI. V2G technology advancement and adoption will be driven by universal standards adoption in the near future. Also, universal standards adoption will play a significant role in driving down R&D costs. Further, commoditization of core technologies will allow auto manufactures to lower their overall production costs, thus reducing the overall price of V2G EVs for consumers and business customers (Zpryme 2010).

Utility

There are lots of local utility companies like DTE Energy in Detroit and REV Technologies who have already started their research on V2G technology for EVs. For example, REV Technologies’ vision is something called intelligent charge control, which involves harnessing a fleet of at least 100,000 electric vehicles and, in response to signals from the grid operators, taking energy out of the grid or putting energy into it (REVE 2015).

Charger

For the next 5 years, the market for residential charging stations will provide a greater opportunity than commercial charging stations. The hardware/software industry is relatively untapped in the V2G space, but companies such as AC Propulsion and Azure Dynamics are two that have established footprints in this industry. AC Propulsion is currently the only manufacturer of V2G-capable power electronics, but Azure Dynamics, Siemens, and even GM have given indications that they are thinking about the market (Zpryme 2010). They are keeping their cards close to their vests as well as according to the marketing trends.

Car

More and more automobile companies are committed to research and develop V2G technology for EVs. For example, AC Propulsion of California has designed an electric-drive system using mass-produced 18,650 lithium-ion batteries and a patented power electronics unit that is ideally suited for V2G. They have also created electric and plug-in hybrid vehicles by converting existing gasoline vehicles (Willett et al. 2008b). Other manufacturers, including global auto manufacturers such as Renault/Nissan, Mitsubishi Motors, and BMW, are producing all-electric vehicles for some markets and have announced full-scale production plans for all-electric vehicles.

Technology roadmap

The method of roadmapping consists of time usage in connection with dimension gathering for a technology strategy structure. Once the overall characterization of technology roadmaps had been described, the structural pattern of exploring and communicating the relationships among markets, products, and technologies evolved and developed into an easier implementing tool (Choomon & Leeprechanon 2011).

The integrated roadmap of smart electric V2G of residential chargers is shown in Fig. 2, and we also attach the complex TRM in Additional file 1.

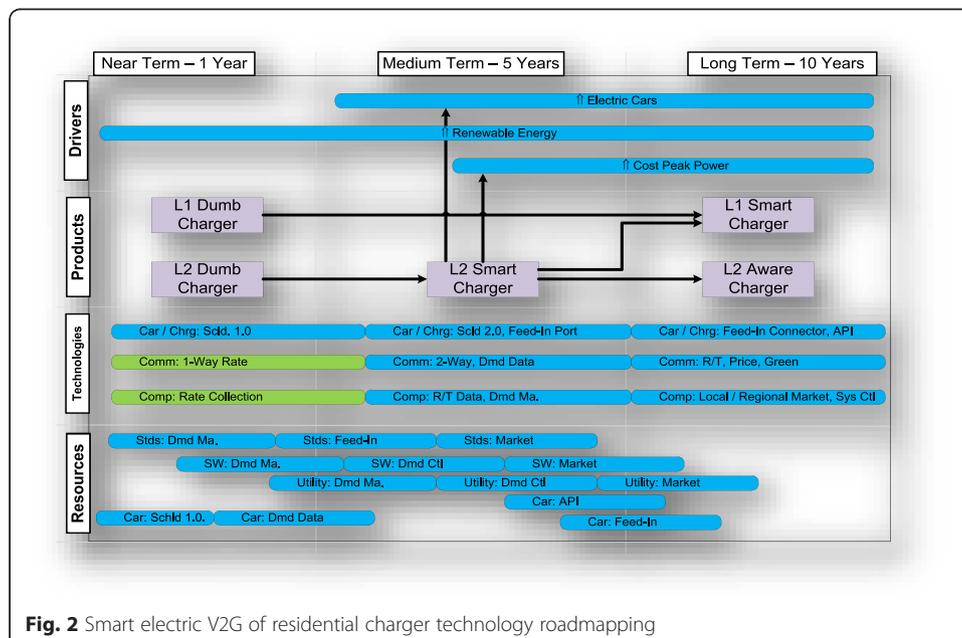


Fig. 2 Smart electric V2G of residential charger technology roadmapping

Conclusions

Electric-drive vehicles can become an important resource for the electric utility system, with consequent air pollution, system reliability, and economic benefits. Both consumers and utilities will benefit from efficient V2G. The V2G features meet both consumer and utility requirements. The technical requirements are needed to realize the most value from vehicle power. There are some gaps that exist in all three key technology areas: computing, communication, and residential V2G components. V2G technology development needs to progress from labs to commercialization to deployment. To set up some standards for the V2G technology is necessary because the smart grid will touch so many aspects of life in the twenty-first century and the development of standards involves a wide range of stakeholders—national and international, private and public, large and small. Also, early development of standards is the key to not delaying deployment. Preparing for rapid growth in electric vehicle use is necessary since new and upgraded supporting infrastructure, whether charging stations, generating capacity, or enhanced transmission systems, require time for deployment.

As stated in the beginning, the objective of this report is to develop a roadmap for the smart electric V2G of residential chargers. The research met the goal by collecting, analyzing, and presenting the research data in the form of a technology roadmap. The paper presents the current state of V2G technology in the automotive industry and where the industry should and will be heading in the next 5 years. Factors like V2G technology and the related research by industry and government-industry-academia partnership are well accounted.

Additional file

Additional file 1: A. The marketing driver roadmapping in details. B. The product/feature roadmapping in details. C. The technology roadmapping in details. D. The resource roadmapping in details. (DOCX 263 kb)

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All authors contributed to this project equally from the inception to the end. All authors read and approved the final manuscript.

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