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Stabilizing Energy Demand in the Power Grid by Using Vehicle to Grid (V2G) System for Wireless Security

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***Abstract*—Vehicle to grid (V2G) systems can help the plugin electrical vehicle (PEV) users in reducing their energy costs and can also help in stabilizing energy demand in the power grid.**

In V2G systems, since the PEV users need to obtain system information(Eg. Location of charging/discharging stations, current load and supply of the power grid) to achieve the best charging and discharging performance, data communication plays a crucial role.

***Keywords*—vehicle to grid; automotive and power generation units; renewable energy integration; plug-in hybrid vehicle; battery.**

I. INTRODUCTION

Increasing pollution level and global warming are the major areas of concern as the era head deeper into the current century. Emissions of greenhouse gases, carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x) and unburned hydrocarbons (HCs) in large amount have caused environmental pollution and global warming. A lot of these emissions are caused for the fulfillment of the basic human requirements such as electricity production, transportation, industrial and commercial purposes. 28 percent of total greenhouse gas emission is caused by the transport sector in the United States [1]. 23 percent of total CO_2 emissions in the world are caused by the transport sector which is 87 percent in India. The modern transport sector relies on the internal combustion engine based vehicles which use petroleum to propel the vehicle and emit toxic gases; ultimately causing harm to the environment and human life [2]. Eventually, there has been a search for a more efficient and clean vehicle. Due to the continuous decreasing level of fuel and energy resources, hybrid and plug-in hybrid electric (PHEVs) vehicles are in the spotlight for quite a while now. They are being seen as the future of transportation with combustible fuel resources depleting fast.

Owing to the need of efficient electric drive systems and consumer interest in PHEVs, major automotive manufacturers began launching PHEVs in 2010. The number of PHEVs has grown over the years and the stored on-board energy in the electrical storage systems (ESS) can be harnessed to provide additional functionalities. Most of the customer-owned vehicles stay parked more often than they are driven. This offers an opportunity to utilize their stored energy while they are idle. The predictions reveal that, the vehicle fleet can contribute up to two-thirds of the forecasted peak load [5].

Since the ESS on board in an electric vehicle allows two- way power flow, they can be used to take power from or supply power to a connected grid. The Vehicle-to-Grid (V2G) concept stands on this principle. It describes a system in which plug-in electric vehicles communicate with the power grid when not in use and provide power to the grid during peak power requirements and get charged from the grid during off-peak hours. The fundamental idea is to set up an exchange system between the grid and a vehicle with electrical energy storage capabilities to benefit both the parties involved [3-4]. This is presented collectively in pictorial form as shown in figure 1 [6].

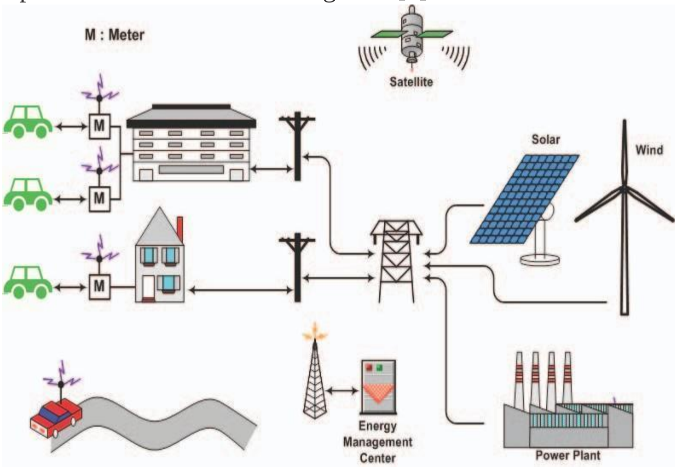

Fig. 1. Communication between Grid and PHEVs

While discussing and implementing the V2G technology, there are some key issues which need to be addressed. Even with the infusion of electric vehicles and other hybrids, There are questions as to what additional hardware and software would be required to deliver the

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stored energy outside the vehicle, what communication systems are necessary, what challenges may hinder the commercialization of the V2G technologies, what would be the infrastructure costs associated, what would be the initial target markets and so on. Such issues would be discussed in detail in this article. The article explores the current projects on this technology and many other aspects.

II. VEHICLE TO GRID DEFINITION

Vehicle to grid (V2G) technology can be defined as a system in which there is a capability to control, bi-directional flow of electric energy between a vehicle and the electrical grid [3]. The integration of electric vehicles into the power grid is called the vehicle-to-grid system. Any electric-drive vehicle has within them the energy source and power electronics combining making it capable to drive the power requirements of homes and offices. It has been calculated that 92% of the total vehicles remain parked even during the peak hours [7]. When a vehicle is not being operated, the on-board battery is connected to a nearby electrical grid via appropriate communication devices. The idea is to use the power from the idle vehicles to provide load-shedding and peak shaving and many other functions. The vehicle batteries can be fully charged during low-demand hours and the flow can be reversed at any time according to the requirements. This can be fulfilled by utilizing the concept of 'smart grid' which is an electricity network capable of processing the information, manages the electricity flow to fulfil the end users varying power demand and is able to provide communication between generation sources and end users. This concept works on the balance the 'off-peak' and 'peak' demand. The Vehicle can get charged during off-peak hours and can sell it back to the grid during peak hours [8].

III. MOTIVATION

In the Vehicle to Grid (V2G) power flow, the major stakeholders are participants (owners of the vehicle), the firms responsible for providing power, vehicle manufacturers and the society as a whole. In this section we analyze how each of these stakeholders is motivated towards a V2G power flow.

A. Economic Incentives for Participants

When the vehicles of participants are not in use, they can serve as storages connected to the power grid which provide power during peaks. In return, for the use of the vehicles the firms which provide power would pay the participants for their service based on the amount of power supplied from the vehicle. Companies simulating V2G predict that the participants can earn up to $300 per month (cost of recharging is taken into account).

B. Reduction in Investment for firms

1) Fixed cost: To meet the demands of excess power during peak hours, the firms use old fashioned plants. The implementation of V2G power flow would reduce the need for such plants, thereby saving a large amount of money. A conventional coal plant that can generate 600MW of power requires $2 billion. Even if V2G would account for the storage for one power plant it would save Billions of dollars for the firm.

2) Recurring costs: Apart from the extremely high initial cost of the power plant they require regular and elaborate maintenance. The reduction in the use of these plants would also mean reduced recurring costs.

C. Vehicle Manufacturers

The participant vehicles and grid would require bi-directional power flow as well as increased battery durability (repeated charging and discharging reduces battery lifespan). To cater an increased demand for such vehicle's sale will increase; higher sales implies higher revenue for the vehicle manufacturers.

D. Society

1) Increases overall productivity: Through the integration of V2G power flows the overall economic productivity of the society increases. The cars that would otherwise remain idle when parked are now acting as a power storage unit which generate revenue and investments, it would otherwise be spent on power stations is getting saved.

2) Scope for renewable energy: V2G technology can further be used with solar vehicles, as a result the excess power during peak does not depend on non-renewable energy sources (coal and fossil fuels used in power plants). This reduces the burden on the environment and adds to the ecological balance.

IV. ADVANTAGES AND APPLICATIONS OF V2G IN PHEVS

PHEVs can be operated as a load while charging, a distributed storage, including services like reactive regulation, motor starting or a standalone energy source such as peak shaving. Although care has to be taken while discharging the on-board batteries as excessive discharge might affect the battery life and its expectancy. PHEV fleet is large enough and if a particular portion of the vehicle’s stored energy could be tapped while parked, it would provide the power grid with large amounts of energy at a given time of the day. This section concentrates on the benefits of using PHEVs as a distributed storage.

A. Peak shaving and other electrical benefits

The stored battery energy can be used to provide power to help balance loads by charging at the night when the demand is low (valley filling) and providing power to the grid when the demand is high (peak shaving). Peak shaving also provides additional advantages such as reduction of a variety of unwanted factors like line losses, delay transmission, transmission congestion, etc. It also helps in reducing the stressed operation of a power system, thus adding to its longevity in terms of lasting. This leads to avoid heavy investments in installing peaking power plants. Power regulation authorities have a good ability of predicting the peak loads (mostly during summers due to the load of the ACs). Using the hybrid vehicles as a distributed storage acts as a robust alternative to expensive and capital demanding 'peaking plant' generators. Generally power-seeking bodies purchase electrical energy through long term contracts with generation companies or from spot electricity markets in the short run. Peak load periods, see the highest electricity prices. Peak shaving applications of PHEV fleet, reduces the cost of electricity during peak periods. The money saved in the case can be used to further propel the utilities of PHEVs by investing in research facilities and expanding their horizon. The average benefits from the V2G participation of an EV is estimated to range from $392 to $561 annually per vehicle [9]. Thus PHEVs offer the power system with a flexible, controllable load and could provide load leveling during off-peak periods [10].

B. Ancillary and Regulation Services

Ancillary services account for 5-10% of electricity cost, or $12 billion per year in the US; 80% of these payments are for regulation and spinning reserve [11]. The ability of PHEV to provide ancillary services leads to a more stable operation of the power system, a reduction in the operation of protection relays and possibly a reduction of the impact of some contingencies. These services are characterized by short-term high-value power flows to balance the constant fluctuations in load and to adapt to unexpected equipment failures [12].

In order to balance the grid around its frequency set-point, a sequence of control tasks is performed. The available power resources for the regulation are called control reserves. They may include various sources such as fast reacting gas turbines and pumped storage power stations. However, PHEVs can be used to provide these ancillary regulation services. The trip schedules for the vehicle are assumed to be known at least one day in advance, and the 'Distribution Network Operators' (DNO) are informed about the planned trip. When the vehicle is idle, it is connected to the grid for ancillary services. The DNO facilitates the charging and discharging actions appropriately, taking care of the state of charge (SOC) of the battery and ensuring its viability in further trips. The power-seeking bodies would thus benefit from a reduction in electricity tariffs. In addition, a compensation for the extra battery degradation caused by regulation-related operations are paid to the owner of the vehicle [4]. Thus, a PHEV can either be deployed as a power supply or as a load in order to regulate the frequency [10].

C. Renewable Energy Integration

One of the major problems associated with harnessing renewable energy resources is its storage. Energy storage has long been a subject of research within the electric community as it would take advantage of low cost periods of generation. Added storage would become a resource for the voltage regulation needs discussed previously. The remote and challenging locations also act as barriers to the procurement of energy. Solar energy peaks around 1 pm, whereas wind energy peaks overnight around 4.30 am [13]. The standard model for the peak electricity demand predicts highest demand between 4 and 8 p.m. The peak, is thus shifted from the optimal hours of the solar/wind generation capacities leading to major problems in integrating renewable energy resources. Wind curtailment also remains a big issue in harnessing wind energy. Sometimes the energy generation overloads the grid and some turbines are then shut down or temporarily impaired. The most important role for V2G may ultimately be in emerging power markets to support renewable energy [14].

V2G can help smoothen the fluctuations in output from the wind farms. Electric vehicles can prove as the required demand during the peak overnight hours of wind generation. Similar approaches can be taken towards solar energy as well. A Cal Berkeley study indicated that, an investment in 60MW of wind power and 60 MW of solar power can satisfy the energy needs of 580,000 vehicles [13]. Thus, hybrid vehicles and renewable sources would benefit each other by providing complimentary services [14].

D. Spinning reserves

Spinning reserves are known as the extra generating capacity that is made available by switching on additional generators already connected to the grid. This additional power supply is made available within a short time from the time of request. However, the capital costs of these reserves are higher. V2G integration solves this issue by meeting sudden demands for power. Connecting vehicles to the grid can go a long way in eliminating the need of maintaining spinning reserves. At any factory or workstation, where there are possibilities of sudden requirements of peak power, the vehicles which could be of the employees would remain connected to the grid and can be called upon to provide the additional power

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supplies. This creates a win-win situation for both the workplace and the employees. The employees can get their vehicles charged back during non-peak times and can also be paid a particular amount for the usage of the vehicle [12]. Thus, V2G can indeed provide a solution to reduce the need of spinning reserves.

E. Backup during power outage

The energy from the vehicle can be used for personal emergency power requirements of the owner as well. When there is an outage of power, the vehicle can be connected to the uninterruptible power supply unit of the house and most appliances with not very high ratings of power can be run. The Toyota Prius can produce at least three kilowatts of continuous power, which is adequate to maintain a home's basic function. Thus a home's basic functions can be quite easily met with a PHEV [15].

V. MODES AND FUNCTIONALITIES IN CHARGING

The power flow to and from the grid can be useful to the grid only if it is provided at the right time and in the right manner. There are various modes in which the PHEV can be charged. The Society of Automotive Engineers' (SAE) and 'National Electric Code' (NEC) recently have established the AC and DC charging levels [3].

VI. IMPLEMENTATION ISSUES

While V2G may present a wide range of applications and advantages, there are also certain implementation issues that have to be addressed. Few implementation issues are stated below.

A. Scalability

V2G would require the setting up of dedicated lines that would link the vehicles to the power grid. The cost of setting up these lines is very high and significant returns can only be expected if the number of participating vehicles is high, i.e. as the number of participating vehicles increases the average cost of the dedicated lines goes on decreasing and the capacity of

power generation and storage goes on increasing. Thus, V2G can only be profitably implemented in the large scale.

B. Uncertainty of charge

V2G uses the charge stored in the vehicles to supply power during peaks. This may lead to complete or partial discharge of the (storage system) vehicle, thus causing inconvenience to the owner. It would also require a larger number of vehicles to be

charged at the charging stations, thus adding to the inconvenience of the owners. This inconvenience is the major de-motivating factor for vehicle owners.

C. Reduced battery life

The life of the battery of an electric vehicle depends on its charging and discharging cycle. As the depth of discharge (DOD) increases, the life of the battery gets reduced significantly. DOD is complementary to state of charge and is denoted as the percentage of the capacity to which the battery is discharged. Reduced battery life further adds to the cost that the owner has to incur for participating in V2G.

The expected average cycles (equivalent to battery life) is related to the depth of discharge as illustrated in fig. 2 [15]. Consider that the vehicle is initially in a state of 30% DOD, its expected average cycles is 2050. After participating in the grid power transfer its DOD becomes say 50%, the expected average cycles falls to 1150. A 20% increase in DOD over a long period of time can reduce the battery life to about half its initial value. This is an issue that needs serious consideration.

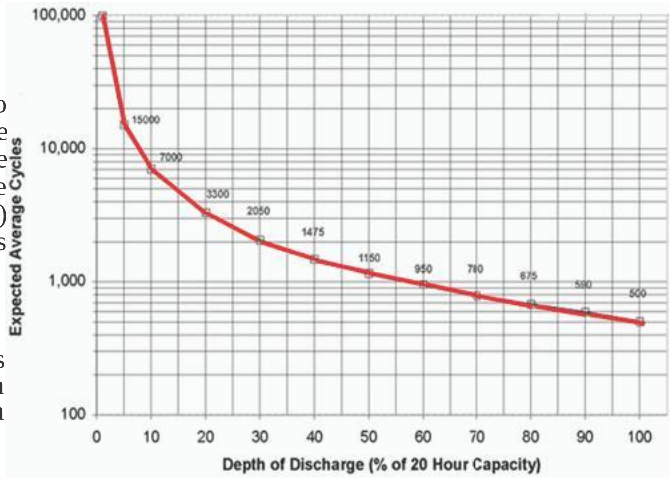

Fig.2. Battery life decay with depth of discharge

D. Thermal issues

Rapid charge and discharge leads to heating up of the battery. Prolonged exposure to heated environments can cause the components of the vehicle to be damaged. This affects the vehicle owner, as his vehicle needs to be serviced. This also implies that the efficiency of operation is reduced (Heating may damage the battery and may lead to distorted/inefficientcharging cycles). The heat generated is given by I^2Rt where t is the time, charging/discharging current is I and R is the load i.e. engine. If the rate of charge/discharge is high, it would mean higher I and higher heat generated. If the process lasts for prolonged periods, i.e. higher t, it would also lead to higher heat and elevated temperatures. The relation between temperature and battery life is given in the fig. 3 [16]. If we assume that the operating temperature is 30ÛC. An increase of just 10ÛC reduces the battery life from 90% to 60%. This causes a huge impact on the owners of the vehicle.

E. Immaturity of V2G

V2G is still in the early stages of development, thorough testing needs to be done before complete implementation. Moreover the above issues continue to be a concern in the implementation of V2G. These concerns are viewed as factors of risk by the investors, thus they are reluctant to participate.

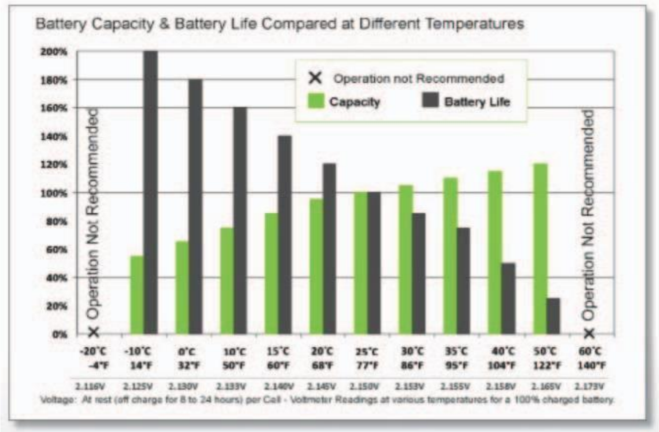

Fig. 3. Battery life and capacity at different temperatures

VII. NOTABLE STEPS TOWARDS V2G IMPLEMENTATION

V2G is being implemented in many countries in the world to move towards the green tomorrow with the participation of government bodies and automobile industries.

A. Hydro-Quebec, Montreal (July 26, 2012)

Hydro-Quebec's research institute (IREQ) awarded GRIDbot Canada the contract for the development and supply of an advanced bidirectional charging station for an experimental project on V2G and vehicle-to-home (V2H) power exchanges [17]. According to this, IREQ will assemble an electric test vehicle that will showcase Quebec-designed technologies. TM4, a Hydro-Quebec subsidiary, will supply a latest-generation TM4 MӰTIVE™ electric power train system for this project. B3CG Interconnect, a company from Saint-Eustache, along with its partners, developed a bidirectional charger that will be integrated into the charging station built by GRIDbot. This project received significant support from the Quebec government as part of its 2011-2020 action plan for Electric Vehicles.

B. University of Delaware first implementation (May 2, 2013)

University of Delaware along with NRG Energy Inc. started its own small scale power grid. The power grid consisted of 15 electric vehicles that were successfully integrated with the campus power supply [18].

C. University of Delaware and Honda (Dec. 5, 2013)

Honda joined a demonstration project for experimental V2G technology. The following are the significant points of

this initiative [19], according to which the Honda technology builds off the research conducted by the University of Delaware and now supported by NRG Energy Inc. Honda is supplying an Accord Plug-In Hybrid with added V2G capabilities to investigate the potential of this technology to benefit the electrical grid, vehicle owners and society. The participation of global automakers like Honda will ensure renovation and refine the technology.

D. Green Gears (since 2007)

Green Gears was contracted by Google and PG&E to perform hands on installation of parts and equipment for V2G and PHEV demonstration and testing. Google 's philanthropic foundation invested about $10 million to accelerate the development of battery technology, plug-in hybrids and vehicles capable of returning stored energy to the grid. These initial proofs of concept demonstrations have spurred on further development and integration by Nissan and other automakers [20].

VIII. CONCLUSION

The applications of V2G are vast and provide a wide array of possibilities for reliable power generation and storage. V2G also promises a more sustained approach where the environment is also a major concern. However, it still faces a lot of criticism. The major reasons for this criticism are high initial cost, lack of government subsidy, resistance to change, be the people and manufacturers. The view of most people can be considered as narrow and negligent as they are only looking at the initial situation, they are ignoring the future prospects of V2G. The recent projects in the V2G implementation have shown promising results and encouraged further research in the field. As and when more durable batteries and cost efficient grid lines become common, V2G will become a widespread phenomenon. Until then the views of people and manufacturers must be monitored. Lastly, a widespread propagation of the V2G idea, its prospects and opportunities by the governments of developing and developed countries will make the path of V2G implementation much easier. And definitely, smart grid technologies have the latency to meet up the future power demand, which will support V2G.

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