Economics of Vehicle to Grid (V2G) Technology

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Abstract-- **The concept of Vehicle-to-Grid (V2G) technology emerges to optimize the potential of all of these newly found all electric and hybrid-electric vehicles in use by the general consumer. Vehicle to grid technology, or simply V2G, is very easy to understand term, it is the practice of the customer selling power back to the electrical company. A customer of the electrical company can take his electric vehicle and plug it into the grid and send power back to the electrical company during peak demand at a high price and charge his car during off peak demand at low price thus making profit out of his electric vehicle, like the stock market buy low sell high.**

This paper will shed some light on the economic aspect of the V2G technology.

Keywords—V2G, economic analysis, electric cars

I. INTRODUCTION

Electric power system in today's world is on the verge of a significant transformation. For the past few years or so, "Smart grid" has been one of the hottest topics in the national news and professional conferences in the electric power industry. The next-generation of electricity grids, known as "smart" or "intelligent," is expected to accommodate all generation and storage options.

With sky rocketing oil prices, depleting oil reserves and environmental global warming, the world as a whole is forced to really consider using electric vehicle as part of the solution, they serve as distributed moving energy storage.

For V2G to take place there has to be four components: mature electric vehicles pure and plug in hybrid, advanced generation of batteries that can store energy to drive a car more than100 miles on a single charge, at the core of V2G is a reversible battery charger for electric vehicles with V2G function and associated control strategy for the power flowing between the grid and EV, Finally the most important gradient for V2G to work is the two way communication between the EV and the grid.

The benefits of vehicle to grid technologies are very clear. It is very efficient in the sense that a sitting car can become a power source for the electrical company. This way, during peak hours of demand, the electrical company can use customer's cars to help service their electrical grid's demands, thus creating less demand and stress on other areas of the electrical company's grid system. The car's battery ultimately acts as an energy storage system for the electrical company so that they can buy back energy from `EV owner whenever they want to. Ideally, the electric utility company will implement the idea of valley shaving, charging at night when demand is low, and peak shaving, sending power back to the grid when demand is high. Use of vehicle-to-grid (V2G) plug-in electric vehicles can be considered as partial solutions to the global energy crisis at present. A note of importance is that with so many more cars used as generators, the electrical company could build less coal and resource depleting power sources as backup power systems. The Utility Companies can Use EV to stabilize the frequency in the power system [1-2] and improve utility operation**.** It makes the Utility companies more efficient, less current flow in feeders, less loss because the energy is generated locally. Finally it will help the company use more of renewable energy [3]. That helps the environment with less pollution and reduction in the global warming.

On the other hands the operation of the Utility companies becomes more complicated, dealing with so many EVs. Some argue about Liability Problem: who is liable if the batteries were damaged due to a surge from the utility? Batteries cost $15k .The battery life issue mostly applies to when the battery is near maximal charge or maximal drain, so fluctuations in the mid-range shouldn't harm lifespan. Control of human nature: change of schedule, many EV not participating, caught in a major traffic jam, holiday causes many to travel.

Upgrading the EVs and the Utilities for V2G technology Cost Money so who is paying it?

II. COMPONENTS OF V2G TECHNOLOGY

For V2G to be implemented four components have to be there. These are:

A. *Mature electric vehicle technology*

In general there are three distinct types of electric cars [4-9]. First the pure electric vehicle (PEV) like the Leaf (Nisan) car, second the hybrid electric vehicle (HEV) which in terns classified as regular hybrid electric car like the Prius (Toyota) and plug- in hybrid electric vehicle (PHEV) like Volt (GM) and thirdly the fuel cell electric vehicle (FCEV) like FCX Clarity (Honda) .As it is seen from figure 1, only the pure electric car and the hybrid plug- in electric car are suitable for V2G without any modification because they can be plugged to the grid.

Pure- EV runs on an electric motor. The batteries size and cost issues are main challenge, figure 2 shows the energy flow diagram in PEV.

Regular hybrid electric vehicle runs on gasoline with an electric motor. However, the batteries are only charged by the generator that is located in the electric car, it has no access to the grid.

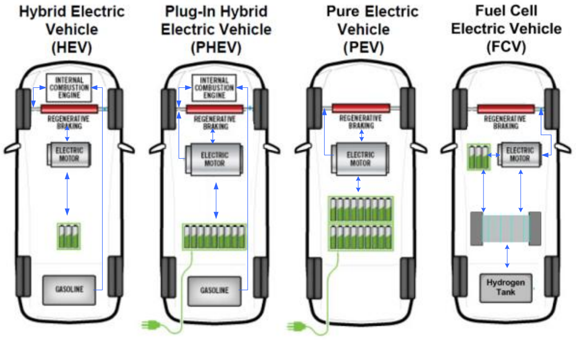

Fig. 1. Different type of Electric Vehicles

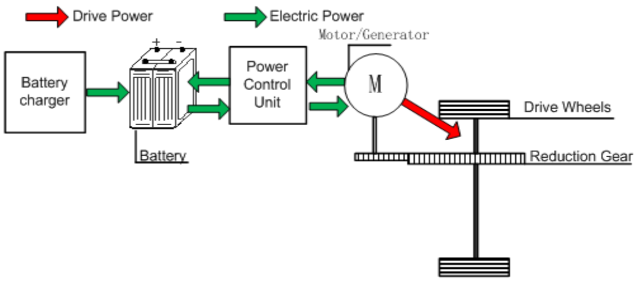

Fig. 2. Pure electric vehicle system energy flow diagram

Plug- in hybrid electric vehicle runs under engine power like the regular HEV, but the batteries can be charged from the grid, this will extend the range at which the car can run on electric power only. There are three ways in which electric motors and a combustion engine can be combined: parallel hybrid uses both an electric motor and an internal combustion engine to drive the wheels. The motor is also used to generate electricity while the car is running to recharge the battery. Series HEV only uses the electric motor to drive the wheels. An internal combustion engine is used to turn the generator, which produces electric power to drive the motor or recharge the battery as the car runs. Series parallel HEV, the most popular hybrid technology on the market today, is actually a combination of above two traditional approaches. It uses the dual sources of power (electric motors and/or gas engine) to drive the wheels, as well as to generate electricity while running on the electric motors, parallel PHEV energy flow diagram is shown in figure 3. Series PHEV energy flow diagram is shown in figure 4.

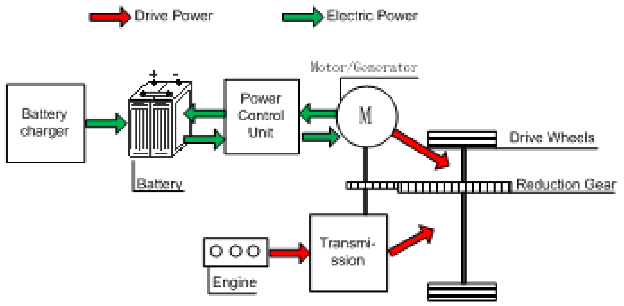

Fig. 3. Parallel hybrid electric vehicle system energy flow

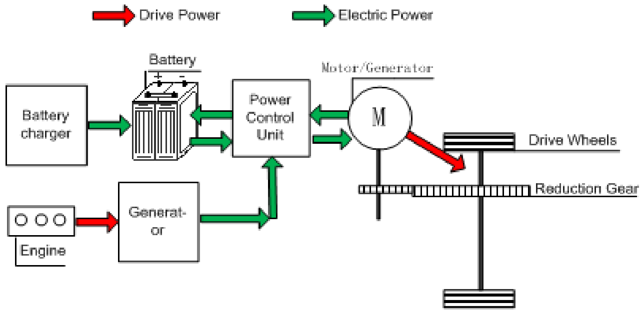

Fig. 4. Series hybrid electric vehicle system energy flow

Fuel Cell electric vehicle runs on an electric motor as Pure- EV. However, the difference is that FCEVs produce their primary electricity using fuel cells, which in turn are powered by hydrogen filled tanks.

B. Advanced batteries

Current generation of batteries can only store energy to drive 50 to 150 miles on a single charge compared to that ICE vehicle can drive 300- 500 miles with a full tank. Most potential battery manufacturers are looking at lithium ion batteries [10-16] because they have the best balance between cost and performance. And the USABC are investigating two systems, lithium polymer and the lithium-ion battery systems.

C. Reversible battery charger

At the core of V2G is a reversible battery charger for electric vehicles with V2G function and associated control strategy for the power flowing between the grid and the EV, it essentially requires some form of a power interface between the electric vehicle (EV) and the grid. In contrast to a' hard wire' power interfaces, a user-friendly and secure 'wireless or contactless' power interfaces with no physical contacts are preferable

To achieve the Vehicle-to-Grid technology, a bi-directional electric grid interface is needed that allows plug-in electric vehicles, such as EVs and PHEVs, to take energy from the grid or put it back on the grid.

Figure 5 is the block diagram of a reversible battery charger for V2G type EVs , a version of that was designed at UMass Lowell [17].

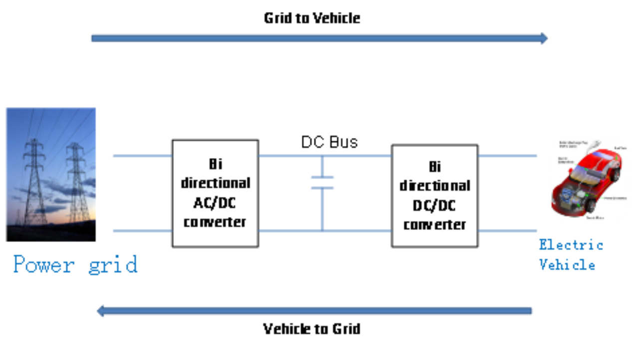

Fig. 5. Block diagram of a reversible battery charger

Although there are already so many types of EV battery charger on the market, none of them has the ability to reverse the power flow. However, in the Vehicle to Grid application, power flows in both direction between the EV and the Grid. Thus, a reversible battery charger is imperative.

D. Communication between the EV, the grid and the driver

Finally the most important gradient for V2G to work is the two way communication between the EV and the grid. Data (such as battery state of charge, EV position, time, distance for next trip, ...) from the EV is periodically and wirelessly transferred to a server which holds a data base of a cluster of EVs, in the same data base, data (such as tariffs for sold or bought energy, available energy..) from the grid suppliers is regularly updated. These data are accessible to the EV users through a web interface. Based on this information the EV user can optimize his cost, charge or discharge.

III. THE ECONOMICS OF V2G TECHNOLOGY

Conventional thinking suggests that PEVs and PHEVs would plug in at night and recharge during the late evening and early morning hours for next day driving. This perspective is limited, and misses a significant fact that vehicles are parked over 90% of the time. From this, it is possible to use these idle resources to provide power back to the grid. If every car was pluggable, the power available is much larger than the current generation capacity [18].

Vehicle-to-grid (V2G) is the concept of supply power to the grid. V2G technology is an interface between the power grid and electric vehicle that allow electricity flow in both directions.V2G implies that the EVs owner charges the vehicles off peak at night when the demand for electricity is low and the electricity price is low but sells electricity back to the utility during the peak demand on electricity when the price of electricity is very high. Figure 6 depicts this V2G scenario.

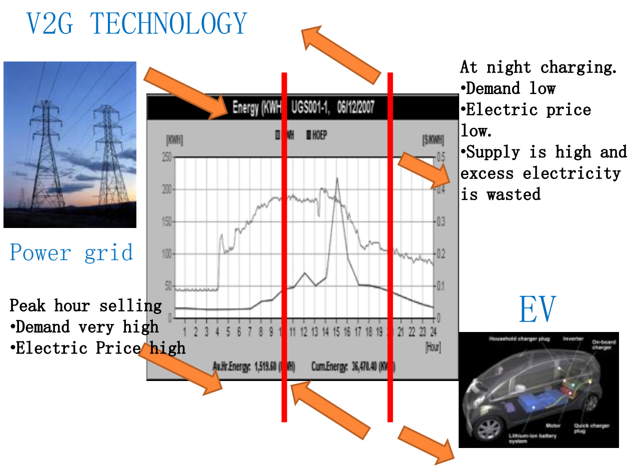

Fig. 6. V2G scenario

As V2G-capable cars could provide peak power or serve as a demand-response resource, like a buy and sell process, the economic benefit for the EV car owns cannot be underestimated.

There are several factors impacting the economic benefit. One is that the batteries size. For a PEV, it has larger batteries size but not all the energy stored could be applied to the V2G. From the same survey done by Pike Research, an 82% of respondents drive 40 miles or less per day [13].

Thus a certain batteries capacity much be saved for normal driving. For a PHEV with smaller batteries size, but it can use the liquid fuel to drive the vehicle and use the batteries energy for V2G application. So for the Nissan Leaf in our analysis, after driving 40 miles, 14.4 KWh battery energy is available for V2G application compared to 16 KWh of Chevrolet Volt. The second factor is the efficiency of the plug circuit, for the analysis we consider the efficiency of it is 90%.

The third factor is the charge rates adopted by the utility company. In our analysis we will adopt the National Grid Time-of Use (R-4) Rates shown in table 1.

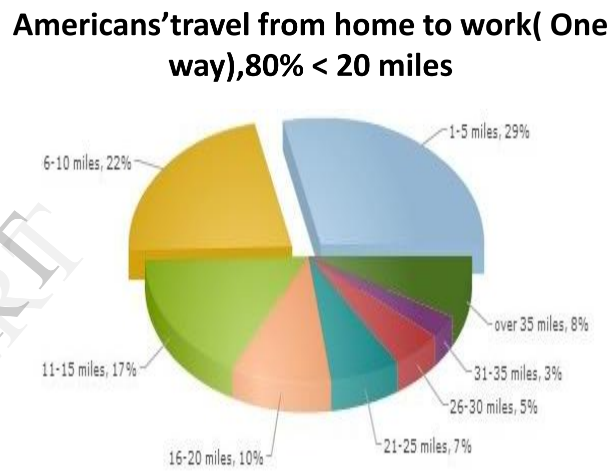

Fig. 7. Americans' travel statistics

The calculation will be done to the Leaf car from table 1, for it is easy to consider the energy is spent on driving. The PHEV might spend some of its electric energy on driving and the rest gasoline fuel, but once the portion of electric drive is known the calculation will be the same.

From Table 2 we can calculate the peak hours' rate which is 9.3 cents per kWh compared with off- peak hour's 3.2 cents per kWh. The difference is almost three times. According to the rate tariff of National Grid, On-peak hours are from 8:00 a.m. to 9:00 p.m., Monday through Friday. Off-peak hours are from 9:00 p.m. to 8:00 a.m., Monday through Friday, all day Saturday and Sunday, and holidays.

With the assumption that the owner drives 40 miles and the charger circuit efficiency is 90%. The calculations are shown in table 3.

It is clear from table 3 that the owner of a Nissan Leaf car in Massachusetts can drive free and make a profit of $128.47 a year.

TABLE I EV SPECIFICATION

Manufacturer	Model	Type	Electric Range (miles)	Mpg without battery	Battery type	Battery size (kWh)
Chevrolet	Volt	PHEV	35	31.4	Lithium-ion	16
Nissan	Leaf	PEV	100	NA	Lithium-ion	24

TABLE II NATIONAL GRID TIME-OF USE (R-4) RATES

Customer Charge	$20.87/month
Distribution Charge Peak Hours* Off-Peak Hours*	 7.268¢/kWh 1.206¢/kWh
Transmission Charge	1.243¢/kWh
Transition Charge Peak Hours Off-Peak Hours	 0.100¢/kWh 0.100¢/kWh
Energy Efficiency Charge	0.596¢/kWh
Renewable Charge	0.050¢/kWh

TABLE III V2G ENERGY FOR TRADE AFTER 40 MILES DRIVE OF NISSAN LEAF

Available capacity C* after drive kWh	Sold energy C×0.9 kWh	Sales/cents charges kWh× peak rates cents 9.3	C/0.9 bought energy in kWh during off peak	Bought charges kWh× off peak rate 3.2	Daily profit in cents	Yearly profit in /$
14.4	12.96	120.528	26.666	85.331	35.197	128.47

*C= the EV battery capacity in kWh

IV. CONCLUSION

PEV and PHEV are ready for V2G, their owners can make money using them, V2G Helps the Utility companies meet the peak demand without the need of constructing expensive new power plants. It makes the Utility companies more efficient, less current flow in feeders, less losses. The energy is generated locally.

Vehicle-to-Grid (V2G) technology emerges to optimize the potential of all of these newly found all electric and hybrid-electric vehicles in use by the general consumer. The electric vehicle technology is mature enough, with the manufacturing of the plug-in and the pure electric cars in great numbers by almost all car companies. The lithium iron phosphate and lithium polymer batteries factories are producing and installing these batteries with high energy density in the PHEV and PEV,. Most of the car companies are working on producing reversible battery chargers, researchers are working on the communication aspect between the EV and the grid. It is a matter of time before a use of V2G is widespread.

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