Integrating Vehicles and the Electricity Grid to Store and Use Renewable Energy

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Chapter X

Integrating Vehicles and the Electricity Grid to Store and Use Renewable Energy

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Abstract

The world could be powered by renewable energy: more energy from the sun hits the earth in one hour than all of the energy consumed on our planet in an entire year. Achieving a low-carbon economy is less technology dependent than it is dependent on new, well-designed energy law that broadly shifts private incentives towards efficient use of renewable energy using of "game-changing" technology such as Vehicle-to-Grid (V2G) motor vehicles that could shift the world to a low-carbon economy.

V2G vehicles integrate separate energy conversion systems: the electricity grid and light vehicle transportation fleet by storing electricity from the grid when it is not needed and returning it to the grid when it is needed. The total U.S. light vehicle fleet power capacity is about 39 times the power generation capacity of the U.S. electrical generation system. The grid could use power stored in idle V2G batteries whenever needed, yet each vehicle would be tapped only within the constraints of its drivers' specific schedule and driving needs. 20,000,000 V2G cars (just 10% of the U.S. fleet) with an average peak power rating of only 50 Kw would have the combined power capacity equivalent to the entire U.S. Electric grid. This fleet would be the backup system for a fully renewable (e.g., solar and wind) energy generation system. The benefits of a V2G system could be enormous: dramatic reductions in CO_2 emissions and the adverse health effects of air pollution from burning fossil fuels and a more robust electric grid. A renewable energy V2G system could replace fossil fuels in many regions of the world.

The world is awash in fossil fuels, plentiful largely due to technological innovations, such as fracking. Atmospheric concentrations of CO2 now exceed 400 parts per million. According to the International Energy Agency, carbon intensity (carbon emissions per $ of economic activity), which has been flat for 40 years, must decline 5.7% by 2020, 43% by 2035, and over 60% by 2050 to limit warming to 2°C.[2] This is a daunting challenge. Just as the stone age did not end due to a lack of stones over the next century the fossil fuel age will not end for a lack of fossil fuels, but will

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[2] International Energy Agency, *Tracking Clean Energy Progress* 2015 (2015)

only end when fossil fuel buyers switch to an economy driven by electricity produced from renewable energy, a trend that is already beginning.[3]

The world could be powered by efficiently used renewable energy. There is more than enough renewable energy to do this: more energy from the sun hits the earth in one hour than all of the energy consumed on our planet in an entire year.[4] We already capture some of this energy with solar, wind and hydroelectric technology and convert that energy into useful electric power. Critically, achieving a low-carbon economy is less technology dependent than it is dependent on new, well-designed energy law: "[National and international] policy and regulatory frameworks … will determine whether investment and consumption decisions are…low carbon."[5] Reduced fossil fuel use requires well-designed sustainable energy laws and policies that promote efficient use of renewable energy: a new legal paradigm is needed that broadly shifts private incentives towards efficient use of renewable energy.

A major renewable energy challenge is how to economically store solar and wind energy for use when it is needed as electricity. Another major challenge is how to power transportation with only minimal use of fossil fuels, while simultaneously adding at least a hundred million new cars and light trucks in India, China, and other economically growing nations. Vehicle-to-Grid (V2G) electric cars could be a "game-changing" technology to address these enormous challenges.

V2G vehicles offer the opportunity to integrate separate energy conversion systems: the electricity grid and light vehicle transportation fleet. The electricity transmission grid, the greatest engineering feat of the 20th century, is limited by its lack of electricity storage capacity; it must generate and deliver electricity the instant it is needed, at widely dispersed locations and at multiple, often unpredictable, times. To meet this demand, the grid has immense electric power generating capacity. Energy for the grid is stored in the form of coal piles, natural gas pipelines, nuclear fuel, and water behind large dams for use at stationary electric generation facilities to meet electricity demand. It does not matter which plant or fuel source generates the electric power, so long as the plant is connected to the grid.

In contrast, motor vehicles are mobile and unlike electricity, transportation energy needs are fairly predictable. The energy, however, must be in the vehicle when it is driven. Vehicle to Grid (V2G) electric (or hybrid electric) vehicles offer a technology that could symbiotically integrate the electric grid and transportation energy systems. V2G technology, which uses electric vehicle batteries to store and return energy to the electric grid based on real-time signals that communicate the grid's instantaneous needs to the vehicle, would meet the needs of both the grid operator and the vehicle driver. The grid needs power (instantaneous flow from an energy source) at varying times, but does not care which power plant (or V2G vehicle) supplies the power. While the vehicle needs stored energy at fairly predictable times (when trip begins) but the (non-fleet) average vehicle is

[3] Electricity is the fastest-growing final form of energy, yet the power sector contributes more than any other to the reduction in the share of fossil fuels in the global energy mix. International Energy Agency, *World Energy Outlook 2014* Executive Summary, 1 – 4 (2014)
[4] Nathan Lewis 'Powering the Planet' (2007) 32 MRS Bulletin 808
[5] International Energy Agency, *World Energy Outlook 2009* (2009) 5

idle 96% of time.[6] The grid could use power stored in idle V2G batteries whenever needed, yet each vehicle would be tapped only within the constraints of its drivers' specific schedule and driving needs.

It is useful to compare the power capacity of these systems. The U.S. electricity grid power generation capacity is about 993 GW (gigawatts).[7] The U.S. light vehicle fleet has about 234 million gasoline and diesel fuel vehicles.[8] The average vehicle could generate 222 horsepower, which is equivalent to 165.6 Kw_m (mechanical Kw).[9] The total light vehicle fleet power capacity, 38,892 GW, is about 39 times the power generation capacity of the entire U.S. electrical generation system!

A comparison of the power capacity of the electric grid with electric vehicles is similarly instructive. For example, the Nissan Leaf battery can deliver 85 Kw peak power and the Tesla Model S 85 performance can deliver 310 Kw.[10] For purposes of this analysis we can conservatively assume a fleet of V2G cars with an average peak power rating of just 50 Kw.[11] In that case, 20,000,000 V2G vehicles would have the combined power capacity of around 1000GW, which is equivalent to the entire U.S. Electric grid power capacity, even though these cars would amount to less than 10% of the U.S. light duty vehicle fleet.

A V2G system could not only supply the grid's electricity storage needs, but could also promote broader integration and more efficient use of intermittent renewable energies, such as wind and solar power. A well-integrated combination of wind power, solar power and V2G battery storage could power the grid up to 99.9% of time.[12] This storage would virtually eliminate the intermittency problem renewables face – they do not generate electricity when the sun does not shine or the wind does not blow, and they may not be able to sell all the electricity when solar and wind energy is high because the grid may not need it then. In a V2G system, solar and wind facilities could have a much higher grid capacity rating, directly lowering the financial cost of renewable electricity. Moreover, V2Gs can improve power grid stability and robustness.[13]

The business model for V2Gs would first tap high value, time critical electric power services, spinning reserves and frequency regulation. As the regulation and spinning reserves markets saturate, V2G vehicles could begin providing peak power and renewable energy storage capacity. Over

[6] Camron Gorguinpour, Office of the Assistant Secretary of the Air Force 'DOD Electric Vehicle Program: The DOD V2G Pilot Project' (2013)
[7] US Energy Information Agency, *Annual Energy Outlook 2015* (2015) Table: Electricity Generating Capacity
[8] US DOT Bureau of Transportation Statistics, National Transportation Statistics, Table 1-11 (2014)
[9] US EPA, *Light Duty Automotive Technology, CO_2 Emissions and Fuel Economy Trends 1975-2013* (Dec 2013) ES5
[10] E. Rask et al 'On Charging Equipment and Batteries in Plug-In Vehicles: Present Status' 2012 IEEE ISGT Conference (2012)
[11] A.A. Pesaran et al, 'Battery Requirements for Plug-In Hybrid Electric Vehicles – Analysis and Rational' National Renewable Energy Lab Conference Paper NREL/CP-540-42240 (July 2009)
[12] C. Budischak et al, 'Cost-minimization combinations of wind power, solar power and electrochemical storage, powering the grid up to 99.9% of time' J of Power Sources 225 (2013) 60-74.
[13] Andrej Gajduk et al, 'Improving power grid transient stability by plug-in electric vehicles' (2014) 16 New Journal of Physics 115011

time, about ½ to ⅓ of the fleet would be V2G vehicles serving as back-up power and storage for renewable energy, thereby virtually eliminating the renewable energy intermittency problem.[14]

As noted, the first stage of implementing a V2G system would be to use V2G vehicles to provide frequency regulation services to the grid operator. Frequency regulation refers to maintaining a consistent level of voltage at all points in the grid. Today, frequency regulation is expensive and relatively slow because it requires turning power plants on or off, or up and down in response to voltage or frequency problems detected in the grid. V2G cars could provide the same service, but much faster, more precisely and where it needed. The energy stored in the vehicles would be available to provide electricity to the grid when parked at home or work, and most cars are driven less than one hour per day. When power is needed to raise frequency, V2G vehicles would be signaled to supply power immediately. When the grid has too much power, the excess power would be sent to V2G vehicles to lower the frequency and store energy for future use. These V2G vehicles, when parked, would be mini-power plants.[15] Vehicle owners would be paid for the services provided. Recent pilot tests of this system indicate that vehicle owners, who would be paid for the services provided, could earn about $210/month.[16]

Implementation would be relatively easy, depending on the legal and business model chosen.[17] One approach would have a company contract with V2G owners, aggregating them into bundles representing at least 1 MW. The grid operator would contract with the aggregator to supply frequency regulation services in bundles of at least 1 MW. The grid operator would buy the regulation services as needed through the aggregator. The aggregator would deal directly with pay the individual V2G owners. In terms of legal implementation all that would be needed initially is the statutory and regulatory authority for this contracting system. In the United States, the grid operators already have the federal and state authority to purchase regulation services, which they do many times every day from gas-fired power plant owners. However, state utility laws must be modified to permit V2G aggregation.

Much of the V2G work has been located in state of Delaware where a statute was enacted in 2009 establishing the legal framework for V2G technology.[18] The law creates the legal concepts of

[14] W. Kempton and J. Tomić, 'Vehicle to grid power implementation: From stabilizing the grid to supporting large-scale renewable energy' (2005) 144 J. Power Sources 280-290

[15] Jim Motavalli, 'Electric Cars Provide Power Back to the Grid (And Get Paid for It)' (26 April 2013) <http://www.plugincars.com/payback-v2g-electric-cars-provide-power-grid-and-get-paid-it-127091.html> accessed 11 May 2015

[16] Gorguinpour (n 6). See also Scott Shepard et al, Vehicle Grid Integration: VGI Applications for Demand Response, Frequency Regulation, Microgrids, Virtual Power Plants, and Renewable Energy Integration (Navigant Research 2015)

[17] W. Kempton, et al, 'Business Models and Control and Management Architectures for EV Electrical Grid integration,' Electric Vehicle Integration Into Modern Power Networks (R. Garcia-Valle and J.A. Pecas Lopes, eds. Springer Science + Business Media 2013) 87-105

[18] 26 Del. Code § 1001 (1) and (14), and 26 Del. Code § 1014

"Aggregator"[19] and "Grid-Integrated Electric Vehicle,"[20] and specifically authorizes payments from the Aggregator to Grid-Integrated Electric Vehicle (V2G) owners.[21]

Beyond this first step, there will be legal and policy questions as investment shift to a renewable electricity system linked to V2G. Federal, regional, and state statutory and regulatory aggregation policy instruments will be needed, along with new net and smart metering laws and regulations. Grid challenges such as cyber-security and reliability standards (national and international) will need to include V2G. Law will need to address a variety of V2G infrastructure issues, such as the widespread availability of V2G connections in parking lots and on-street parking, property and tax laws relating to building owners, home owners, tenants, employers and employees. Transmission capacity and electricity distribution networks will need to be upgraded to 21st century standards, a present need even without V2G.

The benefits of a V2G system could be enormous, dramatically enhancing the prospects of shifting to a low-carbon energy system. As renewables replace coal, gasoline, and natural gas, CO_2 emissions and the adverse health effects of air pollution from burning fossil fuels to generate electricity will rapidly reduce. In addition, pollution from fossil fuel powered motor vehicles will greatly reduce, as electric and hybrid-electric V2G cars replace existing vehicles. A renewable energy V2G system, when combined with improved electricity efficiency, could replace fossil fuels in many regions of the world.

[19] "'Aggregator' means any person or entity who contracts with an … electric supplier or PJM Interconnection … to provide energy services which facilitate battery storage systems for grid-integrated electric vehicles and related technologies." 26 Del. Code § 1001 (1)

[20] "'Grid-Integrated Electric Vehicle' means a battery-run motor vehicle that has the ability for two-way power flow between the vehicle and the electric grid and the communications hardware and software that allow for the external control of battery charging and discharging by …an … electric supplier, PJM Interconnection, or an aggregator." 26 Del. Code § 1001 (14)

[21] "A retail electric customer having … one or more grid-integrated electric vehicles shall be credited in kilowatt-hours (kWh) for energy discharged to the grid from the vehicle's battery at the same kWh rate that customer pays to charge the battery from the grid, as defined in (e)(1) of this section… To qualify… the grid-integrated electric vehicle must meet the requirements in… Connection and metering of grid integrated vehicles shall be subject to the rules and regulations found in …" 26 Del. C. §1014(g)