The Impact of Smart Grid on Climate Change

Smart grid technology introduces mechanisms that can positively influence climate change through levers such as integration of more renewable energy, facilitation of Plug-In Hybrid Electric Vehicle adoption, and through energy efficiency

By The Climate Change Working Group, Global Intelligent Utility Network Coalition

Utility operators across the world are excited about smart grids and some of them are embarking on the deployment of smart grid technologies. A study of literature and discussions with industry experts suggest that today's utility companies working to deploy smart grid technologies are motivated by the need to modernize aging infrastructure, improve efficiency, and empower customers.

Scrutiny of literature on climate change and smart grids also reveals a consensus that smart grid deployment presents significant opportunities to further leverage these investments to reduce greenhouse gas emissions. The Pacific Northwest National Laboratory (PNNL) report, "The Smart Grid: An Estimation of the Energy and CO_2 Benefits" (January 2010), projects potential reductions in electricity and CO_2 emissions by 2030 attributable to smart grid at 12 percent*. In the Electric Power Research Institute (EPRI) report, "The Green Grid Energy Savings and Carbon Emissions Reductions Enabled by a Smart Grid," EPRI analysis shows that a smart grid could potentially reduce annual energy consumption by 56 billion kWh to 203 billion kWh in 2030, corresponding to a 1.2 percent to 4.3 percent reduction in projected retail electricity sales.

Experts around the world have defined many different smart grid capabilities (referred to as levers in this report). However, many of these interact or interfere with each other and therefore need to be orchestrated and optimized in order to achieve a full optimization throughout the grid value chain. Such optimization would ultimately lead to emissions reduction. In this context, the smart grid emerges as a critical tool to address global climate change.

Lever 1: Conservation Effect of Consumer Information and Feedback Systems

The interface of a smart grid with two-way communications and smart devices will make it easier for customers to participate in automated demand response (Auto-DR) programs. Auto-DR technology enables customers, either with or without assistance from their electric service provider, to pre-program load reduction strategies into smart devices such as energy management and control systems. Once programmed, load is then automatically reduced based on communication signals from the utility without the need for any further customer intervention, although a manual override option would generally be accommodated. The advanced control capabilities of devices operating within a smart grid will also make it easier for utilities to implement other types of load control technologies such as load-limiting devices and thermal energy storage systems that may yield more permanent peak demand reductions, as distinguished from demand response programs that yield temporary peak load reductions.

An examination of studies focused on consumer (primarily residential) feedback mechanisms provides convincing evidence that consumers will change their energy consumption behavior in response to feedback, and that the conditions surrounding feedback, such as frequency and specificity, are influential variables. This implies that a smart grid/metering system may yield considerable savings in terms of end-use conservation, with a basic goal of time-of-use load shifting.

Feedback tends to be most effective when it:

- is based on actual usage data;
- is provided on a frequent basis (daily is better than weekly, etc.);
- involves goal setting and choice;
- is provided over a year or more;
- involves specific behavioral recommendations regarding appliances;
- involves normative or historical comparisons.

The energy-use reductions achieved from various projects examined by Fischer (2008) range from 5 percent to 20 percent, with a median of about 6 percent. Similar results have been observed in utility field studies reviewed by Faruqui et al. (2009).

Level 2: Time of Use Tariffs

Communication of real-time prices to raise consumer awareness and integration of price signals with thermostats and appliances is an important lever for emissions reduction. Available reports on the subject of real-time pricing have combined the effect of Time of Use tariffs and conservation of electricity through feedback systems in order to quantify the resulting emission reductions. Two exceptions found in literature research were reports by the Climate Group and the Brattle Group, which handle the levers individually.

The Climate Group Report, "Smart Grid Energy Savings and Avoided CO_2 Emissions (2020)," has estimated a reduction in energy consumption due to real-time pricing within the range of 1 percent to 4 percent.

The Brattle Group Report, "The iGrid Project" (2009), also estimates a small conservation effect due to pricing at 2 percent for residential users. But the report projects no savings for the commercial and industrial user segment.

Lever 3: Enabling Mass Deployment of Diagnostics in Residential and Small/Medium Commercial Buildings

A smart grid's real-time sensing and communication assets coupled with end-use information enable automated profiling of systems to detect malfunctions

"As a fully integrated energy company with both production and distribution of electricity, DONG Energy can and will contribute to carbon emission reductions in the full value chain. On the production side, this results in a gradual change from power plants fired with carbon-emitting fuels to a production platform based on 85 percent renewable energy. Regarding the distribution grid, it is much more difficult to define the effect of different initiatives. It is important to highlight all benefits derived from smart grid solutions when we communicate our vision and ideas to shareholders, customers, and authorities. This includes a quantification of the possible CO_2 reductions. The research in the IUN group has contributed to quantifying the carbon emission reductions in our process moving towards smart grid and can be used to prioritize actions following this direction."

Anders Vikkelsoe
Director, Power Grid Strategy, DONG Energy

and alert the consumer immediately. In addition to detecting malfunctions, improvements in operation can be identified, such as verifying the operation of night setback of thermostats or identifying abnormal lighting and plug loads. Of interest are two examples mentioned in the PNNL report (2010) cited above.

First, smart grids can be used to diagnose and re-calibrate HVAC systems. A property of the refrigerant cycle in heat pumps and air conditioners is that their output and efficiency tend to drop together, while their

input remains relatively constant. Thus, using the slope of the cooling curve and the run-times established by thermostat on/off status signals, declining efficiency can be detected long before complete failure of the equipment makes it obvious.

Another diagnostic check involves the economizer function of commercial building ventilation systems. The economizer enables the building to supply 100 percent air from outdoors to obtain "free cooling" when air conditioning is required and the outside air is cool and dry enough. Economizers are notorious for failing because the moveable air dampers tend to become stuck if not properly maintained. When not working properly they do not provide energy savings and can even waste additional energy by remaining in the open (100 percent) position all the time. The "hole" that proper economizer operation leaves in the heating/cooling curve can be a simple basis for diagnosing these problems.

The diagnostic services can be delivered by a smart grid in two ways:

- By sending the necessary data to the utility or a third party for analysis at a central location;
- By downloading the required software applications onto a platform within the customer premise.

The PNNL report (2010) estimates that this lever can reduce energy consumption by 10 percent to 20 percent, while the EPRI's"Green Grid" report (2008), also cited above, puts the median figure at 9 percent.

Lever 4: Marginal Efficiency Measures Enabled by Accurate Measurement and Verification

The precision measurements obtainable by leveraging a smart grid can be used to provide additional value by offering measurement and verification (M&V) of energy savings from end-use efficiency programs. This can be done on a real-time basis, for all participants, with great transparency and accuracy in the calculation of energy and CO_2 emission reductions.

According to EPRI report (2008), the mechanism that forms part of marginal efficiency measures is reduced transportation requirements through automated meter reading (AMR). In addition, M&V devices also yield operational benefits for utilities through real-time observation of system performance, early detection of system problems, and analysis of system behavior.

The PNNL report (2010) estimates the reduced energy consumption due to this lever at 5 percent to 20 percent.

Lever 5: Shifting Load to More Efficient Generation

A smart grid facilitates shifting load from peak load to shoulder or off-peak-load periods using demand response and distributed generation and storage, which along with demand response or storage can save energy and carbon emissions depending upon the mix of base, intermediate, and peak load generating resources under use.

The smart grid can provide reductions in primary energy and CO_2 emissions by shifting peak load to more efficient lower emission base and intermediate generation resources. Load shifting enabled by a smart grid can shift electricity production from less efficient peak load generating resources (less than 30 percent) to more efficient intermediate resources (~40 percent) that have lower carbon emissions per unit of energy supplied. In cases where the load is shifted to base-load power plants that are not coal-fired, even greater carbon savings can be realized. Utility programs have shown that shifting load from peak load generating power plants to more efficient off-peak-load power plants provides such reductions. For example, the California "Shift & Save" initiative quantifies the reduced CO_2 emissions at between 10 percent and 20 percent. The carbon footprint of base-load generation is likely to be reduced in the future as more renewable and clean-coal-fired power plants enter the system to join nuclear and natural-gas-fired power plants to displace current coal-fired power plants.

The PNNL report (2010) estimates the reduced energy consumption due to this lever can be from 0.04 percent to 0.06 percent. The EPRI Report (2008) estimates that energy savings corresponding to peak load management could be as high as 3.7 billion kWh per year by 2030, which is equivalent to a 0.08 percent reduction in the retail sales of electricity across the residential, commercial, and industrial sectors.

Lever 6: Support Additional Electric Vehicles/Plug-In Hybrid Electric Vehicles (PHEVs)

Replacing gasoline-fueled Light Duty Vehicles (LDV) with vehicles that derive a significant fraction of their energy from electricity is one option for reducing the dependence on oil and the carbon footprint of transportation at the same time. Compared to burning gasoline in an engine at relatively low operational efficiency, power plant-generated energy placed into an on-board battery to propel a vehicle is significantly more fuel efficient. It is estimated that with today's mix of power plants and vehicles in the United States, this would provide an approximate 30 percent improvement in energy consumption per vehicle miles traveled (VMT) and a 27 percent reduction in CO_2 emissions, while reducing imports of foreign oil by 52 percent (Kintner-Meyer et al. 2007).

"We at PHI are excited about the prospect of a new energy future, and our pivotal role in its creation. The critical energy and environmental challenges facing this nation spurred PHI's development of our Blueprint for the Future–a partnership between the utility and the customer that leverages technology and information to drive energy efficiency, increase reliability, and create a cleaner environment. That combination of advanced technological equipment and state-of-the-art system communications is called the smart grid. The Blueprint is our vision, and developing the smart grid is how we are making that vision a reality."

Joseph M. Rigby
President, Chairman & CEO Pepco Holdings, Inc.

According to the PNNL report (2010), with today's load shape and generation capacity, it should be possible to supply over 70 percent of the energy for the U.S. LDV fleet (cars, vans, SUVs, and light trucks) without building additional generation or transmission—if their charging times are carefully managed to strictly avoid charging during peak load hours. Accomplishing this would place downward pressure on electricity prices because the cost of the existing grid infrastructure would be spread over more unit sales of energy (Scott et al. 2007), which would help keep electricity an affordable and viable alternative to gasoline. The ability to manage the charging time period and shift the vehicle load off peak load hours is the enabling characteristic of smart charging technologies that a smart grid would supply.

Thus, from a utility perspective, the ability to charge PHEVs overnight provides operational benefits through improved system load factor and utilization of base load resources. The PNNL report (2010) estimates the reduced energy consumption due to this lever at 3 percent to 5 percent. A joint study conducted in 2007 by EPRI and the Natural Resources Defense Council (NRDC) concluded that PHEVs will lead to a reduction of 3.4 billion metric tons to 10.3 billion metric tons of greenhouse gases by 2050, as a function of PHEV fleet penetration and the carbon-intensity of the electricity generation mix.

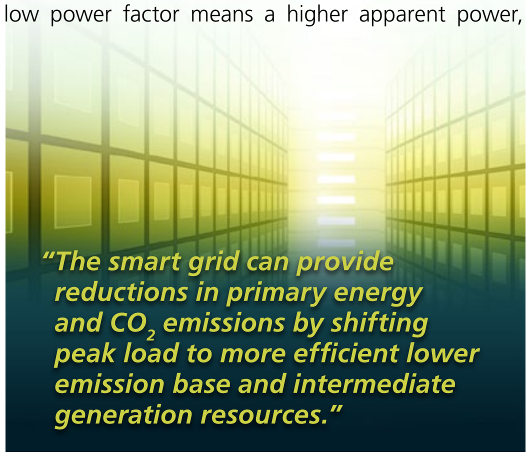
Lever 7: Conservation Voltage Reduction and Advanced Voltage Control

End-use energy consumption has been shown to drop when the electric service voltage is reduced. This strategy, termed conservation voltage reduction (CVR), occurs primarily because the energy consumption of certain end-use loads, such as incandescent lights and certain electronics, decreases as the voltage decreases. Conversely, electric losses in distribution systems tend to increase as voltage drops because motors and other constant power loads tend to draw more current to compensate, and losses are proportional to the square of the current. Electric distribution system losses average around 5 percent, but rise to 8 percent or more during peak load periods when voltage drops and current increases.

A smart grid's measurement and communication capabilities provide an opportunity to continually optimize tradeoffs in service voltage and energy use by precisely controlling voltage within acceptable limits. This optimization process, which includes CVR, is known as advanced voltage control. Using advanced voltage control, the PNNL report (2010) estimates that it is possible to reduce the existing consumption of electricity by about 2 percent to 4 percent with little incremental investment for distributors with existing heavy investment in voltage control using reactive power.

Lever 8: Power Factor Correction

Although reactive power is needed for all the magnetic devices found in any electrical system, it's nevertheless undesirable because it causes a low power factor. A low power factor means a higher apparent power,



which translates into excessively high current flows and inefficient use of electrical power. These currents cause elevated losses in distribution lines, excess voltage drop, and poor voltage regulation. Additionally, transformers must have sufficient capacity to conduct both the active and the reactive power. (Many utilities apply a penalty to users with a low power factor as a way to get reimbursed for supplying the total apparent power.)

At 0.8PF, for example, series losses are 56 percent higher than at unity power factor (UPF). The most common method for improving power factor is to add capacitor banks to the system. Capacitors are attractive because they're economical and easy to maintain. Not only that, they have no moving parts, unlike some other devices used for the same purpose.

However, fixed capacitors cannot correct power factor to unity all the time as loads vary continuously. In a smart grid situation, static compensators (STATCOMs) can be used to inject reactive power in order to maintain unity power factor and minimize losses, and in the event of transient voltage sags or swells can be used to inject or absorb reactive power to stabilize voltage.

Power factor correction can be a consequential benefit arising from the use of capacitors to control voltage. In some countries, however, network characteristics are not always suited to control voltage in this manner. The use of capacitors and/or STATCOMs to improve power factor to minimize losses therefore remains, in some countries, an untapped initiative to reduce carbon emissions.

Lever 9: Support Penetration of Generations from Renewable Sources

A smart grid facilitates more seamless integration of renewable resources and other distributed energy resources including energy storage due to its advanced control and communications capabilities.

Some of the current challenges of grid integration relate to the inherently less controllable nature of certain important renewables, such as wind power and solar photovoltaics, which intermittently feed energy to the grid. Deployment of a smart grid infrastructure combined with electric energy storage and discharge options will help reduce the variability in renewable power sources by decoupling generation from demand. This will increase resource dispatchability and allow intermittent renewable resources to operate during periods of maximum efficiency.

In addition, the control capabilities of a smart grid will also increase the ease with which customers can integrate their personal renewable generation sources (e.g., rooftop photovoltaic systems) into the grid.

Lastly, the integration of distributed generation sources reduces network losses by reducing the amount of power that flows from centralized power generation plants.

The "Connecting Smart Grid & Climate Change" report by Silver Spring Networks estimates that the smart grid-enabled mechanisms could facilitate an additional 10 percent of renewable generation in the overall generation mix by 2030.

Conclusion

A smart grid is the key enabler of mechanisms needed to reduce carbon emissions, using levers such as integration of more renewable energy, facilitation of PHEV adoption, and energy efficiency. This study describes nine levers enabled by smart grid that can cut CO_2 emissions and hence positively influence climate change.

A smart grid will enable tools for everyone—from consumers to energy service providers to regulators—to help bring energy savings and greenhouse gas reduction goals closer to fruition for society's benefit.

To view references and sources please visit www.generatinginsights.com

About the Global Intelligent Utility Network Coalition

In 2007, IBM formed a coalition of innovative utility companies to accelerate the use of smart grid technologies and move the industry forward to a sustainable energy future. The coalition pioneers changes in the way power is generated, distributed, and used by adding digital intelligence to the current systems to reduce outages and faults, manage demand, and integrate energy from renewable sources such as wind and solar, and also empowers consumers to make more informed decisions about their energy use.

Members include CenterPoint Energy, Country Energy, CPFL, DONG Energy, Liander, North Delhi Power Limited, Oncor, Pepco Holdings, Inc, Progress Energy, San Diego Gas & Electric, and Southern California Gas Co.

For more information about the Global IUN Coalition, please visit www.ibm.com/ideas.

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