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Developing a Smart Grid for Virginia

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ENERGY TRANSITION INITIATIVE
University of Virginia

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Weldon Cooper Center for Public Service

How can Virginia take advantage of a smarter grid?

This report explores how a smarter grid can enable Virginia to take advantage of clean energy resources, energy storage, and demand management technologies. It discusses the costs and benefits of smart grid applications, and discusses Virginia's efforts to develop a smarter grid. The authors provide recommendations to promote smart grid development that provides net benefits to rate payers and supports Virginia's clean energy goals.

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ENERGY TRANSITION INITIATIVE
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The Energy Transition Initiative (ETI) at the University of Virginia is dedicated to helping policy makers and other stakeholders navigate the challenges that come with shifting Virginia's energy systems away from fossil fuels and towards renewables and other zero-carbon sources. The ETI brings together experts from the Weldon Cooper Center, Virginia Solar Initiative, Virginia Clean Energy Project, and other units at the University of Virginia to research clean energy and sustainability practices; develop and maintain tools to help localities understand the process, costs, and benefits of adopting cleaner energy technologies; and engage directly with policymakers, energy providers, entrepreneurs, consumers, and other interested stakeholders to smooth the transition to a sustainable energy economy.

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EXECUTIVE SUMMARY

The electric power sector is in the midst of a major transformation. Renewables now account for the majority of new generating capacity and cost reductions in wind and solar energy as well as battery storage continue to outpace expectations (EIA, 2020). Encouraged by these trends, a growing number of states, including Virginia, have passed legislation intended to accelerate the transition to clean energy sources. The Virginia Clean Economy Act (VCEA) requires the state's investor-owned utilities to rapidly increase the percentage of electricity sales derived from wind and solar, with the ultimate goal of achieving a 100% carbon neutral power supply by 2050.

Advances in communication and information technologies are also affecting the structure and operation of the electric grid, allowing utilities to efficiently integrate a much more diverse mix of electricity generating, storage and demand management technologies. *The smart grid* is the umbrella term for the intelligent, communication-enabled devices and associated information systems that enable this integration. A U.S. Department of Energy (DOE) assessment of the state of the country's electric system infrastructure summarized the impetus and objectives for smart grid development as follows.

> "A revolution in information and communication technology is changing the nature of the power system. The smart grid is designed to monitor, protect, and automatically optimize the operation of its interconnected elements, including central and distributed generation; transmission and distribution systems; commercial and industrial users; buildings; energy storage; electric vehicles; and thermostats, appliances, and consumer devices (DOE, 2015)."

The Virginia General Assembly recognized the importance of modernizing the state's electric grid when it passed the Grid Transformation and Security Act (GTSA) in 2018. Despite that legislative authorization, a comprehensive plan for smart electric grid development in Virginia has yet to emerge. This report is intended as a resource for policymakers and other stakeholders involved in Virginia's transition to a smarter, cleaner electric grid. It explores how smart grid capabilities can enable integration of clean energy resources, energy storage, and demand management technologies and summarizes the literature on the costs and benefits of smart grid applications. The report also reviews Virginia's recent efforts to develop a smarter grid, including grid modernization plans and petitions submitted by Dominion Energy's subsidiary, Virginia Electric and Power Company, and decisions of the Virginia State Corporations Commission (SCC) related to those filings. The final section outlines initiatives and guidelines to promote development of a smart grid that will provide net benefits for ratepayers and support achievement of Virginia's clean energy goals.

Recommended actions include:

1. Develop a shared vision of the services and benefits a smart grid should deliver
    - Initiate a process of broad stakeholder engagement that is coordinated by a neutral party and engages Virginia's investor-owned and cooperative utilities as well as representatives from ratepayer, environmental, and business interests as well as representation from relevant state government agencies.
    - Consider amending the GTSA to require stakeholder engagement in smart grid planning and implementation and set a deadline for delivery of a grid transformation plan to the Governor and General Assembly.
2. Implement a phased, adaptive strategy for smart grid development.
    - Initiate the first phase of a statewide smart metering implementation program.
    - Conduct an integrated set of pilot projects designed to evaluate costs and benefits of smart metering implementation, including evaluation of time-of-use rates and other dynamic, grid responsive rate structures implemented in combination with behind-the-meter smart technologies for different customer classes.
    - Expand smart charging pilot programs for electric vehicles to include residential, commercial and public charging stations as well as a range of applications of vehicle to grid charging technologies.
    - Implement demonstration projects for virtual power plants (VPP's), distributed energy resource management systems (DERMS) and smart micro-grids.
    - Utilize smart metering, dynamic pricing, smart charging, and VPP/DERMS pilot program results to refine plans for broader implementation of smart grid technologies and systems.
3. Align utility compensation for smart grid investments with measurable outcomes.
    - Develop and implement performance incentive mechanisms for utility smart grid investments that link compensation to ratepayer and broader public benefits.

- Ensure broad stakeholder engagement in developing performance metrics, incentives and processes for measuring and evaluating outcomes.
- Condition smart grid investments on transparent program evaluation including public access to the underlying program evaluation data.

4. Ensure public access to smart grid data and encourage innovation.
    - Ensure rigorous, transparent evaluation of pilot program results with full access to anonymized program data by independent researchers and other stakeholders.
    - Require Virginia's utilities to provide customers with online access to detailed smart meter data for their accounts and public access to anonymized smart meter data, subject to data aggregation guidelines that protect customer privacy.
    - Design and implement rate structures, information and communication systems, and grid management strategies to encourage third-party innovation and aggregation of energy services from smart, behind the meter systems.

As the transformation of Virginia's electric power system accelerates, smart grid technologies will be needed to maintain grid reliability, efficiently integrate new technologies, and cost-effectively balance supply and demand. Uncertainty regarding smart grid costs and benefits can be managed by implementing a phased development process guided by stakeholder involvement and outcomes-based performance incentives. That process should proceed with a sense of urgency to ensure Virginia is prepared to efficiently manage a more complex and decentralized electric power system.

1 Introduction

The electric power sector in the U.S. is in the midst of a sweeping transformation. Costs of wind and solar energy have declined rapidly and these clean but intermittent sources of power now account for the majority of investment in new generating capacity (EIA, 2020). Investment in distributed and community solar is also increasing as households and businesses seek to contribute to clean energy goals and gain some control over their energy bills (Mackenzie and SEIA, 2020). Advances in energy storage and demand management technologies are enabling utilities to more cost-effectively integrate high levels of utility scale and distributed renewables (Edmunds and Laboratory, 2017). Encouraged by these trends, a growing number of states, including Virginia, have passed legislation to accelerate the transition to clean energy sources of electric generation. The Virginia Clean Economy Act, which was passed during the 2020 General Assembly and signed into law by Governor Northam, requires Virginia's utilities to be 100% carbon free by 2050.

Navigating the transition to a clean energy future at reasonable cost, while reliably meeting the demand for electricity at all times of the day and in all seasons, will require increasingly sophisticated integration of centralized generation, distributed generation, storage and load management. *The smart grid* is the umbrella term for the intelligent, communication-enabled devices and associated information systems that enable this integration. A U.S. Department of Energy (DOE) assessment of the state of the country's electric system infrastructure summarized the impetus and objectives for smart grid development as follows.

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The Virginia General Assembly recognized the importance of modernizing the state's electric grid when it passed the Grid Transformation and Security Act in 2018. Despite that legislative mandate, a comprehensive plan for developing and fully leveraging the capabilities of a modernized electric grid in Virginia has yet to emerge.

This report serves as a resource for policymakers and other stakeholders involved in

Virginia's transition to a smarter, cleaner electric grid. It discusses current and emerging applications of smart grid capabilities, summarizes research and case studies that have evaluated the costs and benefits of those applications, and explores how smart grid capabilities can enable synergistic integration of clean energy resources, energy storage, and demand management technologies in an increasingly electrified energy system. The report also reviews Virginia's recent efforts to develop a smarter grid, including grid modernization plans and petitions submitted by Dominion Energy's subsidiary, Virginia Electric and Power Company (hereinafter referred to simply as Dominion), and decisions of the Virginia State Corporations Commission (SCC) related to those filings. The final section outlines recommendations to accelerate development and effective utilization of smart grid capabilities in support of Virginia's clean energy transition.

2 Smart Grids: Their Uses, Costs, and Benefits

The term *smart grid* generally incorporates four elements:

- Communication-enabled equipment and devices,
- Enhanced systems for data management and analysis,
- New operations management capabilities, and
- Dynamic rate structures that reflect system-wide conditions.

This broad definition of what constitutes a smart grid is reflected in Title XIII of the U.S. Energy Independence and Security (EISA) of 2007.

SEC. 1301. STATEMENT OF POLICY ON MODERNIZATION OF ELECTRICITY GRID. It is the policy of the United States to support the modernization of the Nation's electricity transmission and distribution system to maintain a reliable and secure electricity infrastructure that can meet future demand growth and to achieve each of the following, which together characterize a Smart Grid:

(1) Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid.

(2) Dynamic optimization of grid operations and resources, with full cyber-security.

(3) Deployment and integration of distributed resources and generation, including renewable resources.

(4) Development and incorporation of demand response, demand-side resources, and energy-efficiency resources.

(5) Deployment of “smart” technologies (real-time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices) for metering, communications concerning grid operations and status, and distribution automation.

(6) Integration of “smart” appliances and consumer devices.

(7) Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles.

(8) Provision to consumers of timely information and control options.

(9) Development of standards for communication and inter-operability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid.

(10) Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services.

Applications of smart grid systems can be separated into two general categories with respect to ease of implementation and quantification of costs and benefits:

- “Utility facing” applications that directly reduce utility operating costs or enhance grid function and reliability (e.g. by enabling remote meter reading, more rapid detection and response to power outages, or integrated operation of utility owned generation and storage technologies).
- “Customer facing” applications that provide customers with more detailed information on energy use, permit more complex rate structures, and enable utilities and their customers to more efficiently integrate and manage behind-the-meter smart systems and devices.

The direct operational cost savings of utility facing applications resulting from automated meter reading, remote customer connection/disconnection, and power outage detection can be reliably realized, are relatively easy to estimate and measure, and are routinely reflected in benefit-cost analyses of smart grid investments. Other benefits of utility facing applications, such as the value to customers of minimizing the frequency or duration of power outages, are more difficult to quantify in monetary terms and, not surprisingly, are rarely reflected in smart grid benefit-cost estimates.

Benefits from customer facing smart grid applications include more efficient energy use, enhanced demand response, and increased customer satisfaction. Empirical studies of investments in smart meters have shown that simply providing customers with more frequent and detailed energy use information is viewed as beneficial by most customers and results in modest reductions in energy use (Flego et al., 2018, Moretti et al., 2017, Torriti, 2020). But the benefits of information alone represent only a fraction of the potential benefits of customer facing smart grid applications. The literature on time of use rates and demand response programs provides some indication of the benefits of more integrated smart grid applications that combine detailed energy use information, time varying rates and behind-the-meter technologies. Greater reliance on intermittent renewables for utility scale power generation, together with continued customer adoption of distributed energy systems, electric vehicles, and smart devices of all kinds, can be expected to increase the potential for and benefits of demand response over time. For this reason, backward looking empirical studies must be supplemented with forward looking modeling to properly estimate the potential benefits of customer facing smart grid applications.

The difficulties involved in quantifying the full set of benefits of smart grid investments create significant challenges for regulatory review and oversight. This is particularly true for smart meters and associated information systems that are foundational elements for a wide range of utility and customer facing smart grid applications. Our review of smart grid technologies focuses on both utility and customer owned smart systems as well as control systems, rate structures, and market mechanisms that can unlock the benefits of smart grid investments. The policy recommendations we develop from that review include options for managing uncertainty regarding costs and benefits.

3 Smart Grid Technologies and Applications

Advanced Metering Infrastructure

Advanced Metering Infrastructure (AMI) is the technical term for smart meters and associated communication and information systems. AMI enables "customer energy management and demand response via both information and rate programs; utility operational advantages such as outage detection and management, remote meter reading, and remote customer (dis)connections; smart charging of plug-in electric vehicles; and integration of distributed generation resources" (Faruqui, Mitarotonda, et al., 2011). Smart meters reside quite literally at the boundary of utility and customer facing smart grid assets and applications. Investments in AMI can directly reduce utility operating costs for meter reading and outage detection, but to realize the more extensive and diverse benefits of customer facing smart grid applications, AMI must be combined with dynamic pricing systems, customer communication, and behind the meter smart systems and devices. Even in states and countries where the transition to smart metering systems is more advanced, coordinated customer facing applications are still in early stages of implementation. Consequently, post-implementation assessments of smart grid investments are generally limited to utility facing applications or include only a small subset of potential customer facing applications (Torriti, 2020, DOE, 2016).

Benefit-cost assessments of smart metering investment have sought to work around these empirical data limitations by synthesizing information from pilot projects, case studies, and modeling analyses. One of the more rigorous smart metering program assessments was conducted by the Department of Business, Energy and Industrial Strategy (DBEIS) as part of an interim review of the UK's nationwide smart meter implementation program (DBEIS, 2019). The DBEIS analysis included empirical results for the first six years of the program as well as projected future costs and benefits over the next fifteen years. The analysis estimated the UK's smart metering program would result in total net benefits of more than £6 billion ($7.7 billion) over the 2013-2034 appraisal period. Benefits quantified in the analysis included operational costs savings from automated meter reading, service connection/disconnection, and outage detection; reduced cost from energy theft and bad debts; consumer time and energy savings resulting from more detailed and immediate data on energy use; financial benefits to consumers of demand response; and the avoided cost of carbon emissions. The study report emphasized that;

> "... there remain significant future benefits that are not quantified within the analysis and we would expect the annual benefit to increase in size beyond the appraisal period as we head toward 2050. Without widespread deployment of smart meters, it becomes significantly more challenging to meet the (UK's) target of net zero emissions by 2050. For example, the CCC estimates that without a flexible energy system, which smart meters are a key part of unlocking, the costs of delivering net zero emissions by 2050 could be up to £16bn per annum higher."

No comparably comprehensive study of smart metering costs and benefits has been completed for the U.S. This is due in part to the primary role of state versus federal regulation of electric grid investments in the U.S. One recent study provided a summary of smart grid benefit-cost estimates contained in regulatory filings of several utilities across the U.S. (Sergici, 2018). As shown in Table 1 below, smart grid regulatory filings by Ameren Illinois (Ameren), Commonwealth Edison Company (ComEd), Central Maine Power and Entergy Arkansas projected substantial net benefits from their proposed AMI investments. Scaling these estimates to Virginia's largest utility, Dominion Energy, based simply on relative customer base, suggests that total net benefits of AMI implementation across Dominion's 2.5 million customer accounts could range from $400 million to greater than $1.1 billion. A key question is whether the AMI benefits estimated by these utilities are in fact being realized.

Table 1: Summary of AMI Cost and Benefits Estimates from Utility Regulatory Filings

Utility	Investments	Years	Customers	Costs	Benefits	Estimated Net Benefits per Customer
Ameren Illinois	AMI and related uses, including RTP	2012-2019	1,200,000	$520 million	$1,442 million	$384
Commonwealth Edison, Illinois	AMI and related uses, including TOU rates and DR programs	2012-2019	4,000,000	$2,115 million	$4,221 million	$527
Central Maine Power	AMI and associated communications and information systems	2010-2012	600,000	$164 million	$107 million in operational savings, $338 million from demand management	$465 Incl. demand management
Entergy Arkansas	AMI, communications infrastructure, meter data management system, and outage support system	2017-2021	715,000	$270 million	$502 million	$324

Illinois was one of the first states to commit to state-wide investment in AMI technology. The state's two largest utilities, Ameren and ComEd launched their AMI implementation plans in 2012 following passage of the Illinois Energy Infrastructure Modernization Act (EIMA). To help ensure that ComEd's and Ameren's AMI investments resulted in benefits for their customers, the EIMA required the Illinois Commerce Commission (ICC) to develop a performance incentive mechanism that linked return on smart grid investments to program outcomes. The ICC consulted with utilities and other stakeholders to design this mechanism. In 2013, they set ten-year outcome goals, which include a 20% reduction in the frequency of power outages and a 15% reduction in their duration, a 50% reduction in unaccounted-for energy, and a 90% reduction in consumption by inactive meters.

The switch to smart meters throughout ComEd's and Ameren's service territories required more than six years to complete. Annual performance reports that the utilities must file with the ICC indicate that through 2019, both companies have been exceeding the targeted rate of improvement in the smart grid related performance metrics initially defined by the ICC. ComEd's 2019 performance report indicates that, by the sixth year of the program, the company had already achieved the 10 year targeted levels for all performance metrics (ComEd, 2020). These results indicate that smart grid investments in Illinois are generating measurable benefits, but the smart grid performance metrics that the ICC established are focused on only a subset of utility facing applications. The benefits and costs of customer facing applications of smart metering have not yet been comprehensively studied in Illinois. Nevertheless, several studies of initial applications of smart grid technology in Illinois (described below) indicate that the state's AMI investments are providing a foundation for long-term ratepayer benefits.

ComEd and the state of Illinois have been in the forefront in enabling access to detailed data on electricity use and experimenting with dynamic rate structures, both of which are made possible by investments in AMI. The Illinois Public Utilities Act (PUA) requires utilities operating within the state to "secure the privacy of the customer's personal information." The PUA also requires that upon request, utilities must make individual customer use data available to utility customers or their agents and make available to alternative retail electric suppliers as well as local government entities, generic information concerning usage, load curve or other general characteristics of customers by rate classification. The ICC have interpreted these provisions as allowing Illinois utilities to make anonymous data available to any interested third party, including energy service companies, academic researchers, and governmental organizations (ICC, 2014). Any data released must adhere to the "15/15 rule:" anonymous customer data must be clustered in groups of no fewer than fifteen accounts, each of which accounts for no more than fifteen percent of the group's total usage. ComEd has also implemented the Green Button open-data standard that enables customers on-line access to their own electricity use data.[1] As a result of ComEd's smart metering program these data are available in 15-minute intervals, Third parties are able to access similarly detailed but anonymous sets of customer data in accordance with the 15/15 rule.

The availability of detailed time varying electricity use data for all ComEd customers has enabled sophisticated analyses of the effects of alternative rate structures and electricity use patterns by customer type. An independent analysis of a real-time pricing program implemented by ComEd in 2016 indicated that 97% of residential ComEd customers who had smart meters installed at the time, would have saved money if they had been enrolled in the program (Zethmayr and Kolata, 2018). On average customers realized savings of more than 13% and households with smoother load curves realized savings of more than

[1] Customers of utilities that have implemented the Green Button open-data standard can securely download their own energy usage by clicking a "Green Button" on their electric utilities' website. See https://www.energy.gov/data/green-button for more information on the program.

30%. A subsequent study utilizing smart meter data from the summer of 2018, for about 2.5 million Illinois customers of ComEd and Ameren, found that residential customers with flatter electric load curves were more likely to reside in urban and lower-income areas, while high peak usage was more likely in higher income suburban areas (Zethmayr and Makhija, 2019). These authors concluded that smart meters combined with dynamic pricing that reflects the time varying costs of service delivery could have significant benefits for many lower income rate payers. The broader insight is that smart meters not only enable implementation of dynamic pricing, but also that the more detailed time series data that smart meters generate is extremely valuable in designing more equitable and efficient utility rate structures.

Demand Response and Load Smoothing

Demand response includes activities that reduce peak loads (shed), adjust the timing of electric loads from peak to off peak hours (shift), or modify the load curve (shape) to enable more efficient use of grid resources. Smart grid capabilities can significantly augment demand response by automatically reducing electricity use during times of peak demand based on customer defined preferences (load shedding), by making it easier for customers to use appliances or charge electric vehicles when electricity demand is low (load shifting and shaping), or by triggering discharge of behind-the-meter batteries during periods of peak demand and/or low renewables supply (load shaping). Shedding, shifting, and shaping customer loads and storage system operations to enable system-wide loads to more closely match generation from renewables reduces the need for expensive peak generating and storage capacity and associated grid infrastructure. As discussed more fully below, the demand response benefits of smart technologies can be significant. They are a critical element to the smart grid investment case.

A study conducted by the Brattle Group estimated that the U.S. has existing capacity for 59 GW of load flexibility and the potential to add an additional 139 GW of load flexibility by 2030 (Hledik, Faruqui, T. Lee, et al., 2019). This equates to 20% of the projected peak load of the U.S. in 2030. Hledik et al. estimated that realizing this load flexibility could save the U.S. $15 billion annually through avoided capacity and energy costs. According to the U.S. Energy Information Administration, retail electricity sales in Virginia are almost 3% of the U.S. total. If enhanced load flexibility in Virginia could yield savings proportionate to the nationwide savings estimated in the Brattle study, Virginia ratepayers could realize more than $400 million per year in savings. Other recent studies for electric grids in Australia

(Hungerford, Bruce, and MacGill, 2019), Israel (Baum et al., 2019) and South Korea (Jeon, Cho, and S. Lee, 2020) provide additional support for the conclusion that the potential benefits of smart grid enabled demand response are substantial.

As more devices are equipped with smart communication capabilities that can be programmed to operate on a flexible schedule or respond automatically to system pricing or other demand response signals, the magnitude and mix of opportunities for customers to participate in demand management will continue to increase. Smart devices can also be combined with information systems and AI to evaluate utility network supply and demand characteristics, anticipate real-time price changes and adjust customer electricity use and storage management to maximize customer value. There is a diverse and expanding list of companies providing aggregated storage and demand response services. This list includes large, diversified technology companies such as Siemens, GE, and Johnson Controls; energy management divisions of major power companies such as Enel X, NRG Energy and Engie Storage; and emerging technology companies such as Stem and Leap.

San Francisco-based company, Stem, uses artificial intelligence to automatically monitor customer energy use and control behind-the-meter energy storage systems, charging these systems when electricity is cheap and discharging them when electricity is expensive. Stem currently has over 600 active projects in California, Hawaii, Texas, and other areas where time-of-use electric rates have been implemented. Stem's busines model also includes energy storage aggregation services, that combine the response of smart storage devices across numerous customer sites, enabling even small businesses to participate in energy capacity markets and allowing utilities to obtain dispatchable power from distributed storage resources.

Leap claims its demand response exchange platform "allows every connected device to help balance the grid, and get paid for it."[2] In 2018, Leap was awarded contracts to provide Southern California Edison and Pacific Gas & Electric with a total of 90 megawatts of commercial-industrial load reduction capacity as part of California's Demand Response Auction market (St. John, 2018). Leap's customers provide "bidding curves" indicating when, how much and at what price they are willing to curtail load from equipment participating in the demand response platform. In parallel, Leap's platform converts pricing data from California's grid operator, CAISO, into "asks" for load reduction, which it communicates to every participating smart device. As participating devices respond with kilowatt-hour reduction offers, Leap matches and executes the trades in real time and verifies the reduction

[2] See https://leap.energy/

through smart meters, with those data also used to allocate the demand reductions to distribution utilities participating in the CAISO demand response system.

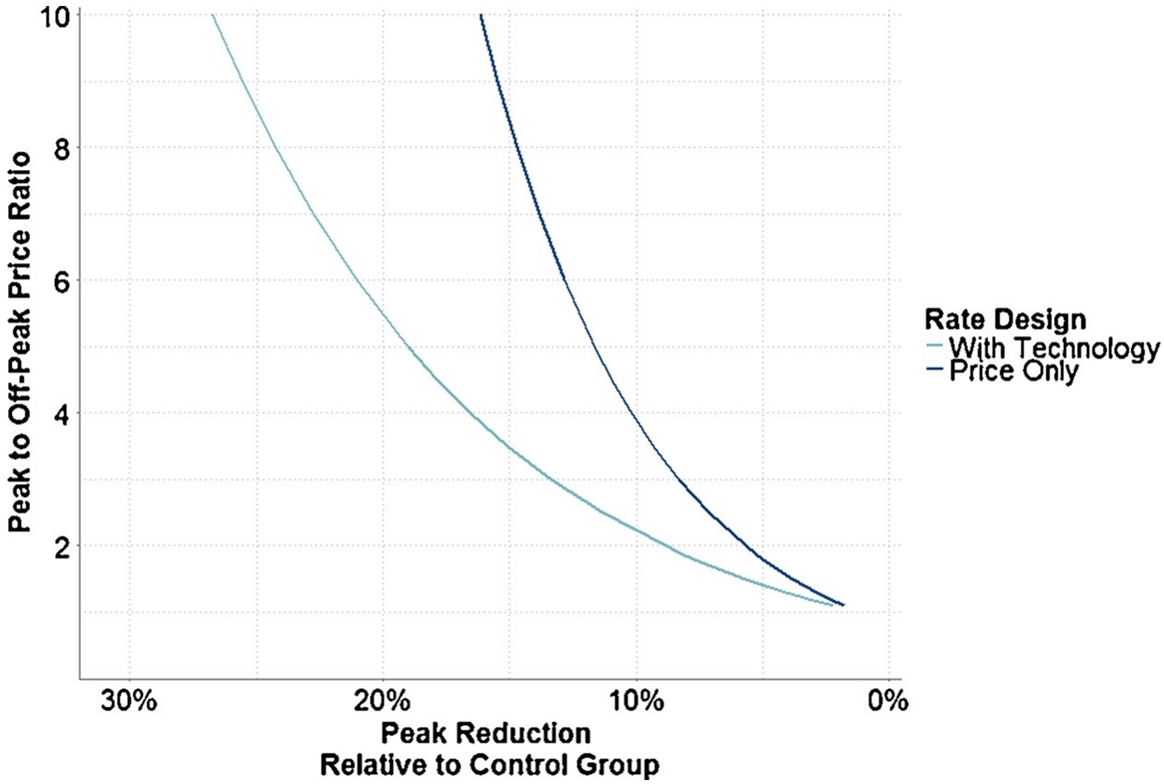
Dynamic Pricing

Dynamic pricing of electricity can take many forms including time-of-use (TOU) rates, peak demand surcharges (or rebates for peak demand reductions) and real-time prices (RTP). When dynamic pricing systems are in effect, customers have a clear financial incentive to use smart technologies that can automatically shed or shift loads and charge and discharge storage resources to minimize energy costs. In aggregate, these price-induced adjustments can significantly reduce peak loads, support system-wide response to supply shortages, and optimize use of system resources.

An early study of the effectiveness of dynamic pricing evaluated Chicago's Energy-Smart Pricing Plan (Allcott, 2011). The plan included a sophisticated pricing mechanism that set the price of electricity for each hour of each day based on the wholesale price during the same hour of the previous day. The manner in which participants were informed of prices was simple: the program provided consumers with small lights that would change color depending on the current price of electricity. It was found that the plan caused residential customers to decrease electricity consumption during peak hours, without changing consumption during off-peak hours. A 10% increase in the price of electricity at peak periods resulted in a 1% reduction in peak demand by residential customers.

The Chicago Energy-Smart program relied on manual adjustments by consumers and was not implemented in combination with smart thermostats or smart appliances. More recent studies have examined the combined effects of dynamic pricing and smart technologies. A 2017 Brattle Group study analyzed the results of 334 time-varying electricity "pricing treatments" in nine countries (Faruqui, Sergici, and Warner, 2017). Pricing treatments in the experiments included simple TOU rates, a variety of peak period pricing arrangements, and real-time pricing that reflects system supply and demand at intervals of as little as fifteen minutes. Some of the pricing experiments were offered with enabling technologies such as smart thermostats, while others relied on manual adjustments by consumers. A meta-analysis of more than 300 experiments was performed to estimate what the authors refer to as the "arc of price responsiveness," with and without enabling technologies. As shown in Figure 1, customers on average reduced demand by approximately 5% in response to a 2 to 1 peak-to-off-peak price ratio and by approximately 10% at a price ratio of 4 to 1. If peak/off-peak price differentials are combined with enabling technologies, the peak demand reduction of a 2 to 1 price ratio increases to 9%, while the average demand reduction of a 4 to 1 price ratio increases to 16%. Additional increases in the peak-to-off-peak price ratio result in proportionally smaller peak demand reductions, but the increased demand response of combining time varying prices with smart enabling technologies is observed at all price ratios.

Figure 1: Peak Demand Reduction as a Function of Peak/Off-peak Price Ratios



Source: Arcturus 2.0: A meta-analysis of time-varying rates for electricity (Faruqui, Sergici, and Warner, 2017)

Another Brattle Group study summarizes current TOU rates and trends in the U.S. (Hledik, Faruqui, and Warner, 2017). The survey found that 14% of all utilities and 58% of U.S. investor-owned utilities offered TOU rates, but only 3% of customers were enrolled on average. The low participation rates in many programs were attributed to a lack of marketing and customer communication; voluntary opt-in program structures, and long peak-pricing periods, often up to 12 hours, that make the programs inconvenient for many customers. A more recent update of the survey suggests that customer participation in TOU and other dynamic rate plans is likely to increase as more utilities require customers to opt out of TOU rate plans if they do not wish to participate (Faruqui, Hledik, and Sergici, 2019). More recent programs tend to have shorter peak pricing periods, generally six hours or less. The survey also found that solar PV adoption is causing some utilities to rethink TOU rate designs in order to incentivize customers to shift loads to mid-day hours when there is excess solar PV output and reduce loads during late evening hours when PV output declines.

The literature on TOU rates highlights several key features that increase enrollment and retention and enable ratepayers to respond effectively: customer education and communication, sufficiently strong price differentials, relatively short duration of times during which peak prices are in effect, and access to enabling technologies (Faruqui, Hledik, and Sergici, 2019, Sherwood et al., 2016). Smart systems that include smart meters, thermostats, appliances and energy storage systems allow for more precise and automated opportunities for households and businesses to react to time-varying rates. The converse is also true. Dynamic pricing unlocks the potential of smart meters and smart behind the meter systems and devices augmenting customer demand response. The analysis of ComEd's real-time pricing program discussed previously, also indicates that smart meters enable more rigorous and detailed evaluation of the benefits of dynamic pricing systems, which allows for further refinements in the design of dynamic pricing programs (Zethmayr and Kolata, 2018).

Smart Charging of Electric Vehicles

Electric vehicles (EV's) are a growing source of electricity demand that can provide substantial benefits as part of a cleaner, smarter electric grid. Electric vehicle owners have significant flexibility on when to charge their vehicles. If properly managed with smart systems and dynamic pricing, EV's could become a major source of demand response, improving grid capacity utilization, while also reducing transportation related emissions of CO2 and other pollutants. These benefits only increase as electric generating capacity continues to shift toward clean energy sources.

The potential to shift the timing of electric vehicle charging is illustrated by the Electric Nations EV pilot project in the UK. The project, conducted by the electricity distribution network operator Western Power Distribution, gave smart chargers to 673 EV-owning participants. Following a period of "free reign," participants were enrolled in several trials to see how effective smart charging systems combined with pricing incentives would be in shifting the timing of vehicle charging (Technology, 2019). An important result of the Electric Nations project is that charging flexibility was high across all of the trials conducted.

The project used a simple metric to quantify flexibility.

$$\text{Flexibility} = (1 - \frac{\text{charge time}}{\text{plug-in time}}) * 100\%$$

A flexibility score of 10% indicates the vehicle was charging for 90% of the time it was plugged in, whereas a flexibility of 80% indicates the vehicle was only charging for 20% of the time it was plugged in. The higher the flexibility, the more a vehicle's charging time can be adjusted. In the study, 75% of all charging events had flexibility over 44%, and half of all charging events had flexibility over 76%. Program managers for the study concluded that shifting the timing of vehicle charging is unlikely to cause much inconvenience to the majority of drivers and incentives can be effective in achieving shifts in charging patterns (Technology, 2019).

Results of the third trial in the Electric Nations project demonstrated the inherent flexibility of EV charging and the responsiveness of EV owners to price incentives. Each participant received a shopping voucher reward balance of £10 at the start of the trial. If they charged during peak hours, their balance would decrease by 13 pence for each unit of electricity used. If they charged overnight, they would earn 5 pence for each unit used. Participants were provided with a smart charger app that allowed them to choose to charge their vehicle right away or charge during off-peak hours. Participants could change this decision at any time. After nine weeks, the average participant had more than doubled their reward balance.

Unidirectional smart charging systems capable of scheduling the timing of EV charging are referred to as *V1G charging systems*. These systems, if implemented in combination with dynamic pricing, can smooth load curves and reduce or avoid the need for new grid capacity to support increased EV penetration. Smart bidirectional vehicle-to-grid (V2G) or vehicle to home, business, etc. (V2X) charging technology that enables electricity to flow to and from the vehicle, based on criteria defined by EV owners, offer the potential for even greater economic and environmental benefits. With smart V2G or V2X charging, EV's provide the grid, directly or indirectly, with flexible loads as well as distributed storage capacity. This dual capability magnifies the demand response of EV's and will become increasingly valuable as the electric grid becomes more reliant on intermittent renewable energy sources. V2G-enabled EV's can discharge electricity to the grid when output from renewables is relatively low compared to demand, and recharge at times when low-cost renewable generation is high. Technology assessments and modeling studies indicate that use of smart V2G technology could result in substantial decreases in peak loads, marginal electricity costs, and CO2 emissions for electric grids with high levels of renewables and EV penetration (Han, Oh, and Son, 2018, Andersen et al., 2019, Jeon, Cho, and S. Lee, 2020). Since EV owners are paying the cost of purchasing and maintaining their vehicles, the grid benefits of smart V2G-enabled EV's can be obtained at comparatively little cost to ratepayers (Coignard et al., 2018).

The benefits of V2G charging systems have been demonstrated in a number of pilot projects. One project involving Nissan, the northern European transmission system operator TenneT, and the EV technology company Mobility House, successfully used V2G technology to reduce curtailment of renewable energy generation in Germany caused by transmission system constraints between northern and southern Germany (House, 2020). The demonstration project utilized Mobility House's ChargePilot V2G charging system to charge Nissan Leaf EV's in northern Germany with electricity from wind farms in the region that would otherwise have been curtailed. In southern Germany, V2G enabled Nissan EV's to feed electricity back into the grid at periods of peak demand, reducing the utilization of coal and gas fired generating sources. The V2G smart charging system generated grid cost savings and CO2 emission reductions without compromising the mobility and charging requirements of EV owners participating in the project. Mobility House recently entered in a partnership with EVBox, a subsidiary of global energy company Engie, to develop and commercialize V2G charging systems. Under this program, EVBox, which reportedly has installed over 125,000 EV charging systems in over 70 countries, will provide V2G-enabled smart charger hardware while Mobility House will provide the software to interface with the grid and control the V2G systems based on owner input (EVBox, 2020, Grundy, 2020).

San Diego based Nuvve is another emerging company seeking to commercialize V2G charging. Nuvve has conducted pilot projects of its V2G charging systems in Europe, the U.S. and Japan, and in 2019, launched a joint venture with EDF Energy to provide V2G charging and management services for EV fleets owned by businesses and governments. The joint venture, which expands an ongoing V2G collaboration between the companies in the UK, is part of EDF's plans to become a leader in the electric mobility market (EDF, 2018). EDF has described V2G charging technology as "a winner three times over: economical for the customer, low carbon for the planet and excellent for the grid" (EDF, 2019).

Fermata Energy is a Virginia-based company preparing to commercialize V2G hardware, software and operational management systems. Fermata has conducted two V2G pilot projects in Danville, Virginia in collaboration with the municipal government and local businesses. The projects demonstrated that Nissan EV's combined with Fermata's smart V2G charging technology can provide valuable grid services and enable EV owners to reduce energy costs and minimize capacity charges (Morris, 2019). Fermata and Nissan are also collaborating on a pilot project to reduce energy costs at Nissan's North American headquarters in Franklin, Tennessee and its design center in San Diego, California. The pilot will continuously monitor electric loads at the facilities and manage charging and discharging of Nissan Leaf batteries to minimize charging costs and provide power to the facilities during more expensive high-demand periods (Nissan, 2018). In the first quarter of 2020, Fermata received a $2.5 million investment from TEPCO Ventures, the technology investment arm of Tokyo Electric Power Holdings (Ventures, 2020) and obtained certification under the North American safety standard UL 9471 for its 15 KW V2G charging system. Fermata's CEO has indicated the company is working with several U.S. utilities on the commercial launch of its V2G charging technology and management system, focusing initially on businesses and other organizations operating fleets of EV's.

Forging stronger links between the development of a clean electric grid and electrification of transportation can provide significant economic, climate change mitigation, and air quality benefits (Blonsky et al., 2019, Malmgren, 2016). Smart grid capabilities and smart charging technology provide the means for creating that linkage. At present, not all EV's are equipped to interact with V2G charging systems. In the U.S., EV's produced by Nissan, Mitsubishi, and other manufacturers following the CHAdeMO charging standard are factory enabled for V2G charging. As discussed in more detail in the recommendations, the Commonwealth or Virginia could accelerate the development and integration of V2G enabled charging systems and vehicles within the state by supporting additional demonstration and pilot projects and preferentially supporting V2G charging systems as the technology becomes widely available.

Optimizing Distributed Grid Technologies

As the electric grid transitions to a more complex and distributed network of generating sources and storage devices, large, centralized power stations are being supplemented, and in some cases replaced , by hundreds of utility-scale renewable generation and storage facilities and tens of thousands of rooftop and community PV systems spread throughout a utility service area (Klump, 2020, Stoker and Colthorpe, 2020). Utility-scale and distributed renewables are increasingly being paired with on-site and aggregated energy storage and demand management systems to create virtual power plants (VPP's) (Burger, 2019).

The decentralization of generation is set to accelerate as continued innovation and cost reductions for renewables, storage, and demand management technologies interact with increasingly ambitious clean energy goals. Smart grid technologies, such as smart inverters and distributed energy resources management systems, will be critical for efficient, reliable operation of an electricity supply based on widely distributed, smaller scale generation.

Smart inverters have emerged as a valuable technology for managing both utility-scale and distributed solar generation. Inverters transform the electricity generated by a PV array from direct current to alternating current and control the flow of electricity from the PV system to the grid. Standard inverters have relatively simple signal processing capabilities and are designed to shut down power flow from the PV system after sensing grid disturbances, such as a grid power outage or voltage or frequency fluctuations. Smart inverters are designed with more complex grid communication and sensing capabilities, allowing the inverter to go into standby mode when a grid disturbance is detected, and to resume normal operation once the disturbance is resolved. Distributed renewables equipped with smart inverters are also capable of continuing to power behind-the-meter equipment and appliances even after a power outage on the grid. Hybrid smart inverters are designed to function with co-located battery systems to optimize PV system operation as well as storage recharge and discharge in response to utility rate structures (Misbrener, 2018). PV systems equipped with smart inverters can also perform additional grid-supportive functions including voltage regulation and rapid frequency response that reduces the need for inertial resources in the power grid (Denholm et al., 2020).

A key capability of smart inverters is that they allow networks of distributed energy resources (DERs) and energy storage systems, including V2G-enabled EVs, to be collectively managed as VPPs. An emerging category of software, known as distributed energy resources management systems (DERMS), takes the VPP concept even further, by enabling utilities to manage distributed energy resources, energy storage systems, demand management devices, smart EV charging devices, voltage regulators and other smart distributed technologies as an integrated system. A number of utilities in the U.S., Europe, and Japan, including Portland General Electric in Oregon (Enbala, 2019), Southwestern Electric in Louisiana (Pickerel, 2020), Tucson Electric and APS in Arizona (Orkney, 2019, Pyper, 2016), Austin Energy in Texas (Spector, 2017), and UKPN in the UK (Menonna and Holden, 2020) have implemented DERMS for distributed generation, storage and demand management systems.

Several states, most notably California and Hawaii, have begun to require the use of smart inverters as a requirement for grid interconnection, and have developed timelines for expanded use of smart inverter functionality. Industry-wide codes and standards (e.g., IEEE 1547 and UL 1741) are also being updated to guide continued development of smart inverters and improve interoperability of DER's and electric power systems (Lydic, 2018). While smart inverters and other smart grid systems can deliver significant benefits for both consumers and grid operators, they also create some additional security risks. Smart grid technologies expand the number of communication-enabled grid access points – what cyber-security analysts call the "attack surface." If properly designed and implemented, smart grid and distributed systems can also increase grid resilience to cyber intrusions by providing early warning of grid abnormalities and allowing distributed systems and microgrids to continue to operate in the event of grid outages. Enhancing cybersecurity safeguards for smart grid systems is the focus of ongoing technology development efforts by vendors, government laboratories and standard setting organizations (Kwon, Yoo, and Shon, 2020, Marron et al., 2019, NIST, 2019).

4 A Brief History of Smart Grid Development in Virginia

Virginia's Grid Transformation and Security Act (GTSA), also known as Senate Bill 966, passed on March 9, 2018. The Act defines an electric distribution grid transformation project quite broadly to include any project

> "associated with electric distribution infrastructure, including related data analytics equipment, that is designed to accommodate or facilitate the integration of utility-owned or customer-owned renewable electric generation resources with the utility's electric distribution grid or to otherwise enhance electric distribution grid reliability, electric distribution grid security, customer service, or energy efficiency and conservation, including advanced metering infrastructure; intelligent grid devices for real time system and asset information; automated control systems for electric distribution circuits and substations; communications networks for service meters; intelligent grid devices and other distribution equipment; distribution system hardening projects for circuits, other than the conversion of overhead tap lines to underground service, and substations designed to reduce service outages or service restoration times; physical security measures at key distribution substations; cyber security measures; energy storage systems

> and microgrids that support circuit-level grid stability, power quality, reliability, or resiliency or provide temporary backup energy supply; electrical facilities and infrastructure necessary to support electric vehicle charging systems; LED street light conversions; and new customer information platforms designed to provide improved customer access, greater service options, and expanded access to energy usage information."

Although the GTSA declares that "electric distribution grid transformation projects are in the public interest," it also requires that the SCC, in ruling on distribution grid transformation project petitions, "shall consider whether the utility's plan for such projects, and the projected costs associated therewith, are reasonable and prudent."

Dominion's Smart Grid Transformation Plan

On July 24, 2018, Dominion submitted a petition to the SCC for Phase I of its Grid Transformation Plan, which outlined seven categories of proposed investment. On January 17, 2019, the SCC approved two proposed investments in Dominions' Phase I Plan – physical & cyber security and telecommunications infrastructure – and rejected five other elements - advanced metering infrastructure, a customer information platform (CIP), grid reliability & resiliency, predictive analytics, and emerging technology. Dominion submitted a revised plan on September 30, 2019. On March 26 2020, the SCC issued a ruling that approved four of the six categories of investment in Dominion's revised grid transformation plan. The approved investments included an improved customer information platform (CIP), additional physical and cyber security measures, and a Smart Charging Infrastructure Pilot Program, which would offer rebates to install smart chargers at EV charging sites and allow Dominion to own four smart charging stations to study EV charging issues and opportunities. Elements of Dominion's revised plan that were not approved, included system-wide installation of smart meters and associated communication system improvements, which together accounted for the majority of Dominion's proposed grid transformation investments. Table 2 below summarizes each of Dominion's grid transformation proposals to the SCC as of May 2020 and SCC's response to each.

Elements of Dominion's grid transformation plan that the SCC has repeatedly rejected include system-wide AMI installation, distribution system technology upgrades to provide "self-healing" grid capabilities, and a distributed energy resources management system.

Table 2: Summary of Dominion Grid Transformation Petitions and SCC Responses

Dominion Submission Date	Submission Description	Proposed Investments	SCC Response Date	Approved Budget	Stated Rationale for SCC Decision	Estimated Costs Dominion (SCC)	Estimated Benefits Dominion
July 24, 2018	First submission of Dominion's plan to address the GTSA ("Phase I")	Physical & Cyber Security	January 17, 2019	$154.5 million	Elements "well-conceived, well-supported and cost-effective"	3 Years: $917.8 million ($1,500 million) 10 Years: $5,511.4 million ($5,986 million)	Not Fully Calculated
		Telecommunications Infrastructure					
		Advanced Metering Infrastructure	January 17, 2019	$0	Lack of detail, not cost-effective, will lead to economic loss for customers		
		Customer Information Platform					
		Grid Reliability & Resiliency					
		Predictive Analytics					
		Emerging Technology					
October 3, 2018	Residential demand-response programs	Appliance Recycling	May 2, 2019	Five-Year Spending Cap: $225.8 million	Programs passed at least three of four cost-benefit tests as mandated by the 2018 Virginia General Assembly.	Five-Year Spending Cap: $225.8 million (Not Found)	Not Found
		Home Energy Assessment					
		Smart Thermostat Management (DR)					
		Smart Thermostat Management (EE)					
		Efficient Products Marketplace					
		Customer Engagement					
	Non-residential demand-response programs	Heating and Cooling Efficiency					
		Lighting Systems & Controls					
		Window Film					
		Office Program					
		Small Manufacturing					
September 30, 2019	Second submission of Dominion's plan to address the GTSA ("Phase IB")	Customer Information Platform	March 26, 2020	$212 million "and additional related costs"	Costs to customers were "adequately justified by the overall benefits to [them]."	3 Years: $593.5 million ($837.8 million) Total PV Cost: $2,703.6 million ($6,685 million)	Total PV Benefits: $3,026.1 million
		Grid Improvements					
		Physical & Cyber Security					
		Smart Charging Infrastructure Pilot Program					
		Advanced Metering Infrastructure	March 26, 2020	$0	Costs to customers "were not justified by the overall benefits to [them]."		
		Telecommunications					
April 14, 2020	Dominion requests reconsideration of rejected Phase IB investments	Advanced Metering Infrastructure	April 27, 2020	$0	AMI: Insufficient time-of-use rate design proposal All: Potential benefits "too speculative and uncertain"	3 Years: Not Found ($545.3 million + transformer costs)	Not Found
		Grid Improvements: Self-Healing					
		Proactive Service Transformer Replacement					

- AMI - Dominion proposed deploying "digital smart meters and their supporting network infrastructure" throughout its service area. The plan would entail the installation of more than two million smart meters over a six-year period. In its initial ruling, the SCC rejected the AMI proposal on the basis that "Dominion has not submitted a comprehensive plan to maximize the potential of AMI." The SCC's initial ruling also indicated that "a future (AMI) proposal must include a plan for time-varying rates."
- Self-healing grid - Dominion had proposed deploying digital intelligent grid devices such as line sensors and digital relays, automated control systems and related communication systems to automatically isolate outages, reroute power flows, and restore power quickly with minimal intervention from system operators. The SCC found these proposed investments to be "expensive and sweeping," and targeted customers who did not need improved service.
- DERMS - The SCC found these investments to be premature given current DER penetration in Dominion's service area and also lacked sufficient cost estimates.

In its April 2020 petition, Dominion requested reconsideration for investments in AMI, self-healing grid improvements, and proactive service transformer replacement that had previously been rejected. On April 27, 2020, the SCC again rejected all of these proposed investments. In its filing, Dominion claimed they had "presented a concrete, definitive plan to implement system-wide advanced rate options that leverage AMI to all customers, including a TOU rate," that they had shown there would be significant benefits that they would provide to their customers through AMI, and that rejecting the AMI investments was "contrary to the legislative goals and mandates set by the General Assembly in 2018, 2019, and 2020." The SCC claimed the proposed AMI benefits were not based on anything Dominion planned, "but on broad averages from experiences in other states," and were thus "speculative and uncertain." As discussed below, the SCC found that significantly more experimentation would be required before TOU rates could beneficially be implemented to all Dominion customers. With regard to its proposed self-healing grid investments, Dominion claimed they would target customers who would gain more benefits and prove the value of a self-healing grid, and that rejecting the investments was "contrary to legislative goals and mandates." The SCC argued the investments were too expensive, and that Dominion's was seeking to target as many customers as possible without reference to recipients' service reliability.

Dominion TOU Rates Pilot Program

On December 23, 2019, Dominion proposed a time-of-use rate experiment. The experiment would be revenue neutral, voluntary, and initially available to only a limited number of residential customers with AMI. The experiment would include on-, off-, and super off-peak time periods, based on historical loads throughout the seasons. Dominion proposed including 10,000 customer accounts. To be eligible, the customer must have AMI at their property, must not be participating in several other energy programs, and have systems with a capacity less than or equal to 10kW. Dominion's stated goals for the experiment were "(i) to provide customers a positive customer experience and an opportunity to reduce consumption and save on their electric bills; (ii) to efficiently manage customer engagement, while balancing customer value and prudent expenditures; and (iii) to introduce modern customer engagement techniques and incorporate lessons learned." Dominion proposed hiring a third party to evaluate the experiment, including management evaluation, which will measure participation, preferences, satisfaction, behavior, feedback, and demographic information; a bill impact analysis that will determine whether participants saved money; and a load impact analysis that will determine how participants changed their loads. The experiment would start on January 1, 2021. On February 14, 2020, Dominion further proposed including a "Solar Incentive Program" in their experiment that would provide an optional $500 rebate to customers who installed a new solar/net metering installation. The information benefits of this addition to the program seem to be limited, since it does not appear to require the use of smart inverters or provide additional incentives for smart solar plus storage systems that could enable more significant customer responses to time varying rate structures.

The SCC approved the experiment, including the Solar Incentive Program, on May 20, 2020. The SCC found the experiment to be "necessary in order to acquire information which is or may be in furtherance of the public interest." While Dominion had claimed the experiment would "lay the groundwork for a systemwide rollout of TOU rates," the SCC was more cautious, indicating that the experiment would "serve only as an initial step toward the potential development of a systemwide rate design for TOU rates," and significantly more information would be necessary before a larger rollout. The SCC required that Dominion put all pricing information in its marketing material and online, and also file an annual report on the experiment.

5 A Smart Grid that Benefits Virginia: Recommendations

The SCC's hesitation in approving core elements of Dominion's smart grid investment petitions is understandable, as Dominion has yet to present a detailed plan for how they will use these costly investments to benefit their customers. Nevertheless, smart technologies and systems will be needed to cost-effectively balance electricity supply and demand as Virginia transitions to a more complex, decarbonized electric grid . The challenge will be to invest in smart grid technologies at a pace that will support the decarbonization mandates and other objectives of the VCEA, while developing the regulatory frameworks, rate structures, and energy market ecosystem to deliver increasing value from smart grid technologies. To achieve those objectives, we believe it will be necessary to accelerate investment in smart grid technologies beyond what the SCC has currently approved. The initial phases of smart grid implementation process should be explicitly designed to rapidly generate customer and application specific insights that can inform subsequent phases of smart grid planning and investment. Stakeholder engagement, rigorous, transparent program evaluation, and public access to data will be critical throughout what will likely be a decade long process of smart grid design and implementation.

Four steps can be taken to ensure smart grid development supports Virginia's clean energy transition and provides net benefits for ratepayers.

1. Develop a shared vision of what a smart grid should deliver
2. Design and implement a phased, adaptive strategy for smart grid development
3. Align utility compensation for smart grid investments with measurable outcomes
4. Ensure public access to smart grid data and encourage third-party innovation

1. Develop a shared vision of Virginia's future electric grid

Building a smart grid is not an end in itself. It is a means of achieving other goals that include a clean, reliable, low-cost electric power supply, an improved customer experience, and continued innovation that benefits ratepayers. A smart grid can be developed with an emphasis on centralized control of utility scale assets or it can be designed to flexibly incorporate distributed technologies and to encourage third party investment and innovation that enables utility customers to optimize their energy use. These goals and approaches are not mutually exclusive, but the mix and sequencing of technologies to be deployed and how these technologies are used will differ depending on the broad vision and outcomes being pursued.

Articulating the goals to be pursued in a smart grid development program and reaching an agreement on their relative priorities is a critical first step in building and maintaining consensus for a decade long process. It is true that Dominion conducted several stakeholder engagement sessions in preparation for its grid transformation investment petition to the SCC. Nevertheless, a broader process of stakeholder engagement, commissioned by the SCC and managed by a neutral third party will be needed to ensure that a wide range of options have been debated and some degree of consensus has been reached.

It is our view that smart grid technologies should be deployed with the goal of creating a dynamic, innovative, and customer-focused electricity marketplace. Decarbonization of electric generation, together with expanded electrification of the economy, has taken center stage in efforts to halt global warming. Investment in clean energy, energy storage, and electrified transport are expanding rapidly. Households and businesses are seeking to support the transition to a clean economy and gaining greater control over their energy costs by investing in distributed energy resources and smart systems. Third party innovators are enabling utility customers to optimally manage their electric loads and to participate in electricity markets as suppliers of energy services. Even within a regulated and vertically integrated electric utility system, such as currently exists in Virginia, the electric grid should be designed and managed as a platform for transmitting energy and information to and from customers, with third-party innovators actively encouraged to expand the energy management services available to all classes of ratepayers. We suspect many stakeholders in Virginia share this vision for the future electric grid. But that remains to be determined through a process of stakeholder engagement.

Recommendation: Virginia should initiate a formal process to engage Virginia stakeholders in crafting a vision of a future smart, modernized electric grid, including the services and benefits it should deliver. Amending the GTSA to require stakeholder engagement and setting a schedule for delivery of a grid transformation plan and periodic updates would help to ensure that a grid transformation planning process yields timely and meaningful results.

Minnesota's e21 process and Rhode Island's Power Sector Transformation Initiative provide instructive examples of stakeholder engagement and consensus building in support of smart grid development (DPUB and OER, 2017, GPI and CEE, 2016).

Developing a shared vision for grid transformation in Virginia will take time. That vision will also need to be periodically reviewed and revised as technology, energy system economics and public priorities continue to evolve. We recommend proceeding in parallel with broader stakeholder engagement and the initial steps of a phased smart grid investment plan. Lessons learned from experimentation, pilot projects and phased implementation can beneficially inform stakeholder discussions and improve smart grid design and operational management.

2. Design and implement a phased and integrated plan for smart grid technology investment, application development, and customer benefit assessment

The SCC should use its authority under the GTSA and the Virginia Clean Economy Act (VCEA) to require the state's investor-owned utilities to develop a portfolio of smart grid pilot projects and a staged smart grid investment program. These efforts should seek to evaluate the benefits of implementing multiple utility- and customer-facing smart grid technologies in combination with dynamic pricing systems and advanced tools for efficient integration of distributed technologies. Planned investments should be linked to measurable outcomes that are associated with ratepayer benefits and support public policy goals. As smart grid development proceeds from pilot projects to broader implementation, the SCC should define performance targets and tie compensation to independently verifiable outcomes. We describe below key elements of a smart grid development program that can beneficially proceed in parallel with a stakeholder engagement process.

Advanced Metering Infrastructure Smart meter implementation has emerged as the most significant area of disagreement between Dominion and the SCC regarding grid modernization plans. AMI is a core element of a smart grid and Dominion is correct in asserting that without "deployment of AMI technology across the service territory, the Company cannot transform the distribution grid." As discussed above, AMI implementation, when undertaken in concert with dynamic pricing and other enabling smart technologies, can provide significant net benefits. The key question is how to pace and structure AMI implementation in Virginia.

Dominion's proposed AMI investment plan envisions installation of more than two million smart meters over a six-year period. Dominion's broader grid transformation proposal as well as the experiences of other states and countries with AMI implementation, suggest that development of smart metering applications will be a lengthier, ongoing process. Combining smart meters with dynamic pricing systems and other technologies and programs that leverage the full potential of AMI technology will require significant experimentation . It is also true that the level of generation from renewables as well as the penetration of DER and other behind the meter demand response technologies in Virginia are still relatively low and do not yet require full deployment of smart grid technologies. Nevertheless, due to market trends and the requirements of the VCEA penetration of renewables and distributed technologies will increase steadily over the next decade. This creates the opportunity for a carefully designed phased approach to smart metering installation that includes a portfolio of experiments with dynamic rate structures and other applications to unlock the customer facing benefits of these technologies. This phased approach will avoid premature investment while still generating valuable information to guide subsequent phases of program design and application development.

Recommendation: The initial pilot phase of Dominion's AMI program should be implemented according to a rigorous design that will generate robust, actionable insights for different customer classes, under various conditions:

- Smart meters should be installed at a small percentage of residential, commercial, and industrial accounts. Each customer class should be partitioned into several experimental groups to enable evaluation of the effects of smart metering, both alone, and in combination with other programs and technologies, including dynamic pricing, smart devices (e.g. smart thermostats, appliances, DER's, and storage systems), and energy monitoring and information systems.
- Interim and final pilot program assessments should be designed to evaluate changes in energy use, load profiles, monthly bills, and customer satisfaction for each customer class and experimental group before and after program implementation.

Planning for the next phase of AMI implementation could begin based on an interim assessment of Phase 1 results, with adjustments made as additional data become available.

Dynamic Pricing and Demand Response As noted, there is substantial evidence that demand response can significantly reduce system capacity requirements and operating costs. These benefits become more pronounced as the share of electric generation from intermittent renewables increases (Hledik, Faruqui, T. Lee, et al., 2019, Jenkins, 2020, Jeon, Cho, and S. Lee, 2020). When implemented in combination with dynamic rate structures and behind-the-meter smart systems and devices, AMI can significantly augment customer demand response and generate system-wide cost savings.

Recommendation: To help realize potential benefits of smart grid infrastructure, dynamic rate structures and smart behind-the meter technologies, we recommend that SCC and Virginia's utilities implement a coordinated program of dynamic pricing and demand response experiments and pilot programs that encompass different classes of customers as well as a range of pricing structures implemented in combination with complementary behind the meter smart systems and technologies.

The Commonwealth should arrange for research on the following topics as part of a Phase 1 smart grid implementation:

- Expand participation in Dominion's time-of-use (TOU) pilot program to include parallel dynamic pricing experiments for commercial and industrial customers.
- Experiment with different peak/off-peak price ratios and duration of peak pricing periods to understand demand response and cost implications for different customer segments.
- Initiate similar dynamic pricing experiments with APCO and Old Dominion.
- Provide customers participating in dynamic pricing experiments with different combinations of smart technologies, real-time energy monitoring and reporting, and other capabilities, while maintaining control groups that receive no complementary technologies.
- Include customers who have installed distributed solar and/or storage systems in dynamic pricing experiments and pilot programs

Smart Charging for Electric Vehicles A significant increase in the stock of electric vehicles in Virginia can be expected as battery and EV prices continue to decline, auto companies launch new EV models, and clean energy and decarbonization initiatives are extended to include the transportation sector. Smart charging technology and dynamic electricity pricing are the principal mechanisms for realizing positive synergies between an electric grid increasingly powered by clean but intermittent renewables and the electrification of transportation. Time-varying rate structures combined with V1G smart chargers can draw upon the inherent flexibility in EV charging to shift load curves for vehicle charging to periods of low system-wide electricity demand or high renewables supply. The savings from reduced generating capacity, grid infrastructure requirements and a lower cost generation mix can be substantial (Jeon, Cho, and S. Lee, 2020). As the share of intermittent renewables increases, V2G equipped EV's and charging systems offer even greater potential to reduce customer and system-wide costs and help utilities balance supply and demand.

Dominion's Smart Charging Infrastructure Pilot Program, approved by the SCC in March 2020, focuses on development of charging stations for multifamily residences, workplaces, and transit stations. The SCC also approved Dominion's electric school bus pilot program that will use V2G technology. These pilot programs will yield valuable insights but they are limited in scope.

Recommendation: To increase the insights obtained from pilot projects and accelerate realization of the substantial benefits smart charging EV's can provide, we recommend that Virginia:

- Expand V1G and V2G smart charging pilot programs to include single family residential customers.
- Undertake additional pilot programs to evaluate V2G charging systems for light duty vehicle fleets (e.g. utilities, government agencies, taxi and delivery services, etc.).
- Implement smart charging pilot programs in combination with smart metering and dynamic rate structures.
- Ensure rigorous, transparent evaluation of pilot program results with full access to anonymized program data by independent researchers and other stakeholders.

The broader public benefits of an electrified transportation system justify involvement of other agencies of state government in developing a smart EV charging system in Virginia. The Commonwealth has already allocated $14 million of funding from its share of the Volkswagen Environmental Mitigation Trust (VEMT) to support development of public EV charging stations over the next several years. An additional $14 million will be used to replace diesel public transit buses with all-electric buses.

Virginia's Beneficiary Mitigation Plan (BMP) limits use of funds from the VEMT for light duty electric vehicle infrastructure to the $14 million that has already been allocated. The terms of the State Mitigation Trust allow Virginia to "revise its Plan to reflect shifting public or state priorities." Passage of the VCEA, with its commitment to a 100% clean energy grid by 2050, clearly signals a shift in public and state priorities. Given the synergies between a clean grid and smart, electrified transportation, a case can be made for using some portion of any remaining VEMT funds to accelerate adoption of EV's and implementation of smart charging systems.

Recommendation: In light of these considerations, we recommend the Commonwealth of Virginia take the following actions:

- Ensure that all VEMT funded charging stations at locations where vehicles are parked for long periods of time (e.g., multifamily residences, transit hubs, office complexes) are equipped with smart charging technology.
- Update the BMP to allow VEMT funding to be used for smart public charging stations, including V2G charging infrastructure.
- Evaluate providing additional incentives and public support to accelerate adoption of V2G enabled EV's and smart charging infrastructure in Virginia. These could include expanded legislative support for time-of-use and other dynamic rate structures, adoption of V2G charging technology for government vehicle fleets, and inclusion of V2G charging systems as eligible investments in the expansion of the Commonwealth's Commercial Property Assessed Clean Energy financing programs.

Optimal Integration of Intermittent Renewables, Storage, and Distributed Technologies The VCEA requires that Dominion and APCO procure 3200 MW of solar and onshore wind by 2023 and an additional 4200 MW by 2030. By 2030, 41% of Dominion's and 30% of APCO's retail electric sales in Virginia must be derived from renewable sources. The VCEA also increases the cap on distributed, net metered solar to 6% of electric generation and requires installation of 3200 MW of storage capacity by 2035.

Recommendation: The rapid transformation of Virginia's electric grid should be accompanied by the implementation of smart grid systems designed to manage increasing grid complexity and integrate more distributed technologies. To achieve that result, we recommend the following actions:

- Consider legislation to include an explicit timeline and performance criteria for smart grid development .
- Adopt regulatory requirements for use of smart inverters on all new utility scale and distributed renewable and storage projects .
- Evaluate the demand response, load leveling and ancillary service benefits of combining smart meters, dynamic pricing and smart distributed solar and solar plus storage systems.
- Implement demonstration projects for VPP's, DERMS and smart micro-grids, with pilot program results used to develop plans for expanded implementation.
- Provide legislative and regulatory support for third-party participation in providing innovative technologies as well as aggregation and brokerage services for distributed behind-the-meter demand response, reserve capacity, and ancillary grid services.

3. Align incentives with outcomes and ensure transparent program evaluation

The difficulty that Dominion and the SCC have had in reaching a consensus on smart grid investments is due at least in part to misaligned incentives. In the traditional cost-of-service regulatory model, utility revenues are based on inputs rather than outcomes. This compensation model creates the need for regulators to determine that capital investments will be "used and useful" before granting approval (Alvarez and Stephens, 2018). For novel technologies, such as smart meters and associated communication and information systems that have multiple and still-evolving applications, a significant degree of pre-investment uncertainty about benefits is unavoidable. For these novel technologies, the traditional cost-of-service regulatory model creates a dilemma that is difficult to resolve: utilities stand to profit by installing capital equipment, while regulators are confronted with substantial costs and significant uncertainty regarding ratepayer benefits.

One means of creating greater alignment between returns realized by utilities on smart grid investments and benefits received by ratepayers, is through the use of performance incentive mechanisms (PIMs). Pre-approval uncertainty about the benefits of investments in smart grid technologies can be addressed by linking utility compensation for smart grid investments to measurable outcomes that are associated with ratepayer benefits. There is precedent for the use of this type of PIM in Virginia. The VCEA requires the SCC to implement a PIM that provides Dominion and Appalachian Power Company (APCO) additional returns on energy efficiency expenditures that results in energy savings in excess of targets defined in Virginia Code § 56-596.2 (VCEA, 2020, secs. 56-585.1 5c).

Recommendation: To accelerate smart grid development efforts in Virginia and ensure resulting investments yield net benefits for ratepayers, we recommend that the General Assembly, the SCC, and other state entities take the following actions:

- Study potential performance incentive measures for utility smart grid investments.
- Create a stakeholder engagement process to develop PIM's for utility and customer facing smart grid applications and outcomes.

A few examples illustrate how use of PIMs could provide stronger incentives to design and implement smart grid applications that benefit rate payers and support achievement of Virginia's clean energy goals.

- AMI - Compensation for investments in smart meters could be linked to utility operational cost savings, and to load smoothing and demand response by AMI enabled accounts. In addition to providing appropriate incentives, this structure would also set an efficient pace for AMI implementation by ensuring that dynamic pricing programs, incentives for use of complementary behind-the-meter technologies, and customer engagement activities are coordinated with smart meter installations.
- VPP's and DERMS –PIM's could be defined in terms of the supply and demand capacity being actively managed by the platform with minimum performance targets for demand response, load balancing and other outcomes. Initial pilot programs that compare system-wide effects of unmanaged distributed technologies and those being actively managed via smart VPP or DERM systems will be valuable in quantifying the effects of these systems and optimize broader implementation strategies.
- Grid monitoring and repair – Investment recovery and rate of return for investments in grid monitoring and self-healing grid technologies should be linked to improvements in standard industry metrics of outage frequency and duration, for the grid as a whole and for specific geographic areas and customer segments. As noted, PIM's based on improvements in reliability metrics have been successfully implemented in Illinois for smart grid investments by ComEd and Ameren.

Thorough and transparent program evaluation will be required in order to maintain support for a comprehensive smart grid development program that could take a decade to implement.

Recommendation: To ensure rigorous, data-driven performance evaluation, we recommend the SCC implement the following requirements and procedures.

- Explicitly define measurable program performance targets as part of smart grid planning and investment approval processes.
- Use third parties to assess smart grid investment and program performance.
- Include stakeholder engagement and customer experience surveys as part of the program performance process.
- Make smart grid performance assessments part of the public record.
- Condition smart grid investments on transparent program evaluation and public access to data.

4. Ensure public access to smart grid data and encourage open-source innovation

Virginia's investor-owned utilities are regulated monopolies, protected from competition by state law, and guaranteed a fair return on investment through the regulatory process. This regulated monopoly structure removes any basis for arguing that smart grid data and performance assessments should not be made publicly available due to competitive concerns. Issues related to customer privacy require more serious consideration, but as has been demonstrated in Illinois and other states, account specific data generated from smart meters can be anonymized and aggregated to allow public access while still protecting customer privacy.

The primary function of the electric grid is to transmit power, but it is also a communication network and data management system. The energy system transformation underway in Virginia, including implementation of smart grid technologies, will vastly increase the size and complexity of that data network, the volume of data it generates, and the importance of those data for efficient system operation.

Recommendation: We recommend adopting the following principles and standards for smart grid data access and management:

- Customers should have full, online access to detailed smart meter data for their accounts and should be permitted to authorize third party access to those data.
- Smart meter data should be publicly available and readily accessible, subject to data aggregation and other privacy protection guidelines.
- Customer owned smart systems and devices should be treated as behind-the-meter extensions of the smart grid, recognized as valuable energy supply, capacity, and demand response resources and encouraged through regulatory guidelines, efficient rate structure and pricing systems, including support for third-party technology innovators and aggregators.
- Rate structures, information and communication systems, and grid management strategies should allow and encourage participation of third-party innovators and aggregators of energy services from smart, behind the meter systems.
- Smart grid performance assessments should include criteria related to data access and management as well as third party innovation.

6 Conclusions

Virginia has embarked on a rapid transition to an electric grid powered by a high proportion of clean but intermittent sources of energy. That shift will be accompanied by increased investment in energy storage technologies, continued expansion of distributed solar energy systems, proliferation of smart appliances and devices, and increased use of electric vehicles. As the transformation of Virginia's electric power sector proceeds, smart grid technologies will be needed maintain grid reliability, cost-effectively balance supply and demand, and allow customers to fully benefit from new technologies.

To ensure Virginia is prepared to efficiently manage a more complex and decentralized electric power system, Virginia will need to move aggressively to take advantage of new smart grid technologies. Requiring stakeholder participation in smart grid planning and oversight will help ensure smart grid development proceeds with a focus on ratepayer and broader public benefits . Phased development, guided by performance metrics and incentives, can effectively address concerns about uncertain costs and benefits of smart grid investments. The SCC will need to play a proactive role in smart grid development by structuring the process, ensuring data access, promoting third party innovation, and implementing performance incentives and evaluation mechanisms. Changes are coming to Virginia's electric grid. A thoughtfully designed smart grid can help ensure those changes serve the public interest.

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The Energy Transition Initiative

The Energy Transition Initiative at the University of Virginia consists of a team of researchers at UVA's Weldon Cooper Center for Public Service exploring clean energy sourcing in response to new legislation mandating net carbon emission neutrality in Virginia by 2050. We advance these goals by researching clean energy and sustainability practices; by developing and maintaining tools to help localities understand the process, costs, and benefits of adopting cleaner energy technologies; and by engaging directly with policymakers, energy providers, entrepreneurs, consumers, and other interested stakeholders to smooth the transition to a sustainable energy economy.

The Weldon Cooper Center for Public Service

In every project we undertake and every community we serve, the Weldon Cooper Center draws on eighty years of experience and expertise from across the organization to support the needs of our clients and partners. Cooper Center professionals embrace mission- and impact-driven service to individuals, organizations, governmental bodies, and communities seeking to serve the public good. We conduct advanced and applied research in collaboration with clients so they may make a difference in governance and community life. We offer training programs and expert assistance to public leaders and skill development for political leaders who seek to work cooperatively with others. Our values of access, collaboration, commitment to community, and impact guide our work. We welcome partnerships and invite conversation about your goals and needs.

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