Technical and Economic Concepts Related To The Smart Grid –

A Guide For Consumers

SmartGrid
consumer
collaborative

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FOREWORD

About This Document

This guide was commissioned as a companion piece to “Smart Grid Economic and Environmental Benefits,” a related report from the Smart Grid Consumer Collaborative (SGCC). This guide has been designed to help people unfamiliar with the electric distribution utility industry to understand the technical and economic fundamentals behind the concepts presented in that report. Many consumers will find this guide valuable as a stand-alone piece. The related report is not required reading for this document; however, the report may make more sense for many readers once the concepts presented in this guide are understood.

About the Smart Grid Consumer Collaborative

SGCC is a consumer-focused nonprofit organization formed to promote an understanding of the benefits of modernized electrical systems among all stakeholders in the United States. Membership is open to all consumer and environmental advocates, technology vendors, research scientists, and electric utilities for sharing research, best practices, and collaborative efforts of the group. Learn more at smartgridcc.org.

About the Wired Group

This document was prepared for the SGCC by the Wired Group, a consultancy helping clients to unleash the latent value in distribution utility businesses. Learn more at wiredgroup.net.

Acknowledgements

The SGCC would like to thank the many companies and organizations that helped formulate insights from the research reviewed and provided feedback on the content, themes, and layout of this document. Only by continuing to collaborate on consumer issues will we be able to fully realize the promise of Smart Grid. If you are not a member, we invite you to join us as we continue to listen, collaborate, and educate going forward.

October 8, 2013

Patty Durand, Executive Director
Smart Grid Consumer Collaborative

1. INTRODUCTION

Most people have only a cursory understanding of how electricity arrives at their homes and businesses. They understand that electricity is delivered via wires in their neighborhoods but don't recognize the size, scope, and complexity of the effort required to do so in a reliable and cost-effective manner.

Distribution utilities go to great effort to ensure electricity is delivered reliably and efficiently. They have managed the laws of physics so well over the last century that consumers rarely give electric delivery a second thought. However, stakeholder interest in the distribution utility business is increasing. Consumers and businesses are demanding more flexibility and ever-greater reliability from their electric grids, environmental advocates are demanding utility distribution services that support reductions in environmental impact, and businesses and low-income consumer advocates continue to prioritize low costs above all else. The different stakeholders maintain competing interests that utilities, regulators, and governing boards strive to reconcile.

Smart Grid capabilities are available to reduce environmental impact and increase flexibility, reliability, and customer choice. They can also reduce operating costs and "lost" electricity, as indicated in the SGCC's companion report, "Smart Grid Economic and Environmental Benefits." However, Smart Grid capabilities can be costly to implement. Increasingly, stakeholders will be asked for their input on the kind of distribution grid they want, how much they are willing to spend on it, and the trade-offs they would prioritize.

As stakeholders endeavor to answer these questions collectively and strike a balance between their competing interests, they are increasingly motivated to gain a better understanding of the technical and economic concepts central to modern electric distribution utility operations and business models. This document attempts to help nontechnical readers better understand these concepts so that they can gain new perspectives and better place their specific objectives into a broad and well-rounded context.

The components of this document have been selected for presentation as a result of their relevance to the Smart Grid investments that many utilities have made or are considering. The components are ordered to match that of the SGCC's companion report, "Smart Grid Economic and Environmental Benefits." However, there is no prerequisite to read that work to obtain value from this document. The Smart Grid–related concepts presented here include:

- The Basics of Traditional Ratemaking
- How Integrated Volt/VAr Control Works to Benefit Customers
- Time-Varying Rate Primer
- Technical Challenges of Significant Amounts of Customer-Sited Generation

2. THE BASICS OF TRADITIONAL RATEMAKING

The SGCC's "Smart Grid Economic and Environmental Benefits" report discusses the conservation benefits and operating and maintenance expense benefits of some capabilities. In this section we help readers understand the traditional ratemaking process, the incentives it offers to utilities, and how these incentives are not always in alignment with some Smart Grid benefits. We offer three potential opportunities to address the issues traditional ratemaking presents to the maximization of Smart Grid benefits for customers.

How Traditional Ratemaking Works

The goal of traditional ratemaking is to enable utilities to cover their costs. In the case of investor-owned utilities, the goal is to enable recovery of costs plus earn enough profit to attract capital for grid investment. Investor-owned utilities typically present their case for an increase in rates to state regulators in a proceeding called a "rate case." Municipal and cooperative utilities present their cases for rate increases to their governing boards. Although a vast oversimplification, a rate case generally addresses two questions:

- What are the utility's costs?
- Given anticipated sales volumes, what rates must be charged to cover those costs?

For the sake of simplicity, we ignore the revenue and cost of the electricity itself, and focus here on distribution grid costs and the revenues required to maintain and invest in it. (In most cases, the cost of the electric commodity itself is passed through to customers with no markup.) The mathematics behind the rate determination (with details omitted for clarity) look like this:

$$\text{Price per kWh} = \frac{\text{Anticipated utility costs}}{\text{Anticipated kWh sales volumes}}$$

Let's consider a municipal utility that is presenting a rate case to its governing board. The utility presents details indicating that its annual costs are \$100 million and that it expects to sell 2 billion kilowatt hours (kWh) annually. The utility is thus requesting a price per kWh of \$0.05:

$$\frac{\text{Anticipated utility costs}}{\text{Anticipated kWh sales volumes}} = \frac{\$100\text{ million}}{2\text{ billion kWh}} = \$0.05$$

The governing board approves the utility's request. Now let's see what happens to the utility under each of the following scenarios:

- The cost and sales volume forecasts were accurate
- The cost forecast was accurate, but the sales volume forecast was high
- The sales volume forecast was accurate, but the cost forecast was high

Cost and Sales Volume Forecasts Were Accurate

When the cost and sales volume forecasts used to request a rate increase turn out to be accurate, the utility is "made whole" (that is, it covers its costs). The utility is not overcompensated or undercompensated.

Revenue (2 billion kWh x $0.05/kWh)	$100 million
Less: Costs	$100 million
Overcompensation/Undercompensation	$ 0

The Cost Forecast Was Accurate, but the Sales Volume Was Less Than Forecast

When sales volumes are less than forecast – for any reason – the utility will not collect the revenues it needs to recover its costs. Let's assume actual sales volumes are 5 percent less than forecasted sales volumes. In this situation, the utility is undercompensated.

Revenue (1.9 billion kWh x $0.05/kWh)	$ 95 million
Less: Costs	$100 million
Undercompensation	$ –5 million

Conversely, if sales volumes are greater than forecast, the utility will collect more revenue than it needs to recover its costs. Sales volumes can vary from the forecast for a variety of reasons, such as an economic boom or bust, atypical weather, or energy efficiency programs. Some reasons sales volumes might be less than forecast are from Smart Grid capabilities, including time-varying rates and continuous application of Integrated Volt/VAr Control (also known as IVVC, which will be explained in more detail in section 3). The conservation value of these capabilities is described in the "Smart Grid Economic and Environmental Benefits" report available from the SGCC.

This simplified example indicates how utilities using traditional ratemaking methods are penalized when sales volumes drop, and why traditional ratemaking issues should be addressed if the conservation benefits of some Smart Grid capabilities are to be maximized.

The Sales Volume Forecast Was Accurate, but the Costs Were Less Than Forecast

When costs are less than forecast – for any reason – the utility will collect more revenue than it needs to cover costs. Let's assume actual costs turn out to be 4 percent lower than forecasted costs. In this situation the utility is overcompensated.

Revenue (2 billion kWh x $0.05/kWh)	$100 million
Less: Costs	$ 96 million
Overcompensation	$ 4 million

Conversely, if costs are greater than forecast, the utility will have spent more than it collects in revenues. Costs can be less than forecast for a variety of reasons, such as staff cuts or project postponements. Costs can also be less than forecast as a result of Smart Grid capabilities – via reductions in meter reading, outage restoration, and billing/collection/bad debt expenses, to name just a few.

This simplified example indicates how utilities are rewarded for reducing costs when using traditional ratemaking methods. After a subsequent rate case, the cost reduction benefits that the utility enjoyed before the rate case are transferred into customer benefits, in the form of lower rates.

Three Potential Solutions to Traditional Ratemaking Limiters of Smart Grid Benefits

There are at least three ways to help utilities overcome the limits that traditional ratemaking places on realizing Smart Grid benefits. These include:

- Reflecting anticipated sales volume reductions in forecasts used for ratemaking
- Providing economic rewards for utilities documenting maximum Smart Grid benefits
- Continuing dialog with stakeholders about how to improve ratemaking in instances of sales volume reductions

Reflect Anticipated Sales Volume Reductions in Forecasts Used for Ratemaking

Sales volume reductions from Smart Grid investments can be estimated. Continuing our example, assume a utility estimates sales volume reductions from Smart Grid capabilities at 5 percent of sales. When the utility reflects this change in its sales volume forecast, a different rate per kWh is determined:

$$\frac{\text{Anticipated utility costs}}{\text{Anticipated kWh sales volumes}} = \frac{\$100\text{ million}}{1.9\text{ billion kWh}} = \$0.053$$

Though the price for distribution services per kWh has increased ($0.053 versus $0.050), the price increase can be more than offset by customers using less electricity as a result of Smart Grid capabilities. Here's an example of how this works for a specific customer using 1,000 kWh per month, with a 5 percent volume reduction and a price for the electricity itself of $0.07 per kWh.

	Bill before volume reduction	Bill after volume reduction
Cost for Electricity	1,000 kWh x $0.070 = $70.00	950 kWh x $0.070 = $66.50
Cost for Distribution Services	1,000 kWh x $0.050 = $50.00	950 kWh x $0.053 = $50.35
Total Bill	**$120.00**	**$116.85**

Provide Economic Rewards for Utilities Documenting Maximum Smart Grid Benefits

From an economic perspective, many Smart Grid investments are no different than utility energy efficiency program investments. The utility invests money in energy efficiency programs, and customers benefit through reduced electricity usage and other global benefits (such as delayed or avoided construction of new generating plants). The same can be said of Smart Grid capabilities.

For years, many states have authorized investor-owned utilities to be rewarded for outstanding energy efficiency program performance through performance-based payment mechanisms. In summary, a state regulator will say to a utility: "We understand reductions in sales volumes from energy efficiency programs can harm your opportunity to cover your costs and/or earn a rate of return you require to raise capital. To compensate for these reductions, we will offer you an incentive if your energy efficiency programs perform well." It might be reasonable to consider similar performance-based payment mechanisms for Smart Grid capabilities that reduce sales volumes.

Continue Dialog about How to Improve Ratemaking in Instances of Sales Volume Reductions

Variations on traditional ratemaking processes are available that help utilities recover costs when faced with sales volume reductions. One of these is "decoupled" ratemaking. Regulators in 16 states use this approach in place of traditional ratemaking.[1] Decoupled ratemaking "decouples" a utility's revenues from sales volumes, making them indifferent to sales volume changes. It works like this: when sales volumes drop below forecasted levels, utilities are allowed to increase their rates without a rate case, thereby holding revenues constant. Further, when sales volumes increase above forecasted levels, utilities must decrease their rates, again holding revenues constant. In this way revenues do not vary with sales volume, and no overcompensation or undercompensation results.

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[1] National Resources Defense Council, "Gas and Electric Decoupling."

3. HOW INTEGRATED VOLT/VAR CONTROL WORKS TO BENEFIT CUSTOMERS

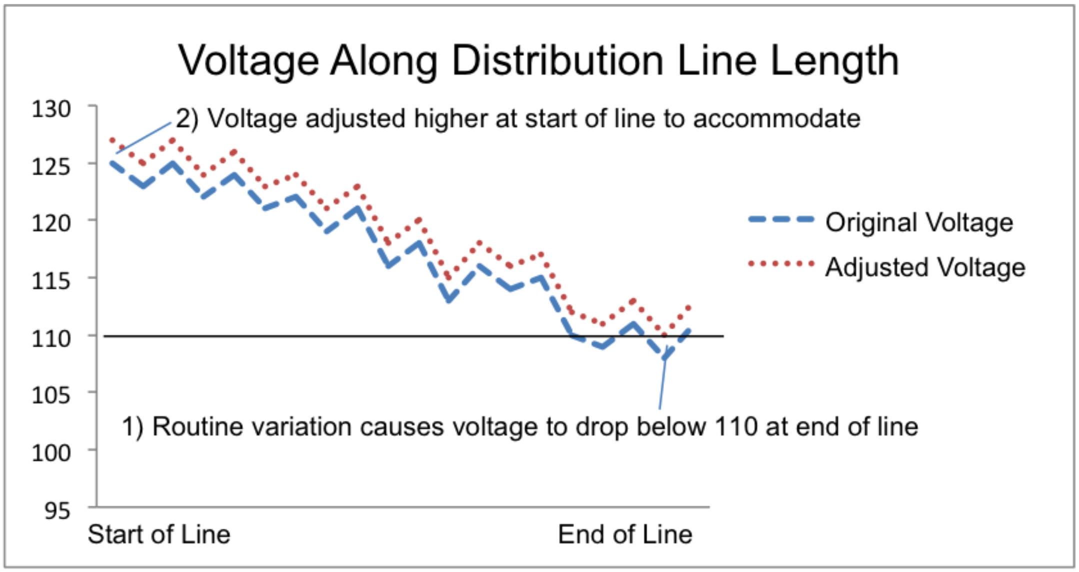
The SGCC's "Smart Grid Economic and Environmental Benefits" report indicates that Integrated Volt/VAr Control (IVVC) offers some of the greatest economic and environmental benefits of any Smart Grid capability. For those interested in the details of how IVVC can offer such large benefits, we describe how it works below. We'll begin with two technical electricity concepts: voltage and power factor (or VAr).

Voltage

Electric voltage is analogous to water pressure. When water pressure (electric voltage) increases, more water (electric current) flows through a pipe (wire). Equipment running on electricity is designed by manufacturers to operate within a specific range of voltages. Most home appliances designed for use in North America, for example, are designed to operate within a voltage range of 110 to 120 volts. (In Europe, the range is 220 to 240 volts, which is why special adapters are required to use North American appliances in Europe.) High voltage can cause damage to appliances or cause them to operate inefficiently, whereas low voltage can cause appliances to work ineffectively or erratically.

One characteristic of voltage is that it drops as the length of a distribution line from the community substation increases. Utilities use various types of equipment to help keep voltage within the 110 to 120 volt range along the length of the distribution line, but doing so as customer loads change from season to season, day to day, and even hour to hour is a constant challenge. Utilities typically set the voltage higher at a community substation (the start of a distribution line) than they otherwise might to ensure the voltage delivered to customers at the end of the distribution line is comfortably above 110 volts (say, 115 volts). They do this to accommodate changing conditions that could otherwise cause occasional voltage drops below 110. Figure 1 illustrates the situation.

Figure 1. Adjustments for voltage violations at end of distribution line



Increasing voltage all along a distribution line to avoid voltage violations at the end is not the most efficient solution, as many electric loads (lighting, televisions, etc.) use more electricity at higher voltages than at lower voltages. Thus, customers served by higher voltages use slightly more energy, pay slightly higher bills, and generate slightly more carbon emissions than customers served at lower voltage levels. Note that the average of the adjusted voltage in Figure 1 is about 120.

Power Factor

Power factor is a measure of how useful electricity is. At a power factor of 1.0 (also called "unity"), 100 percent of the electricity available to a customer can be used to illuminate a light bulb or run a piece of equipment. Certain customer electrical equipment types can introduce power factor reductions into the distribution grid, making electricity less effective at serving all customer loads. In fact, some utilities measure customers' power factor impacts and levy a charge on such customers.

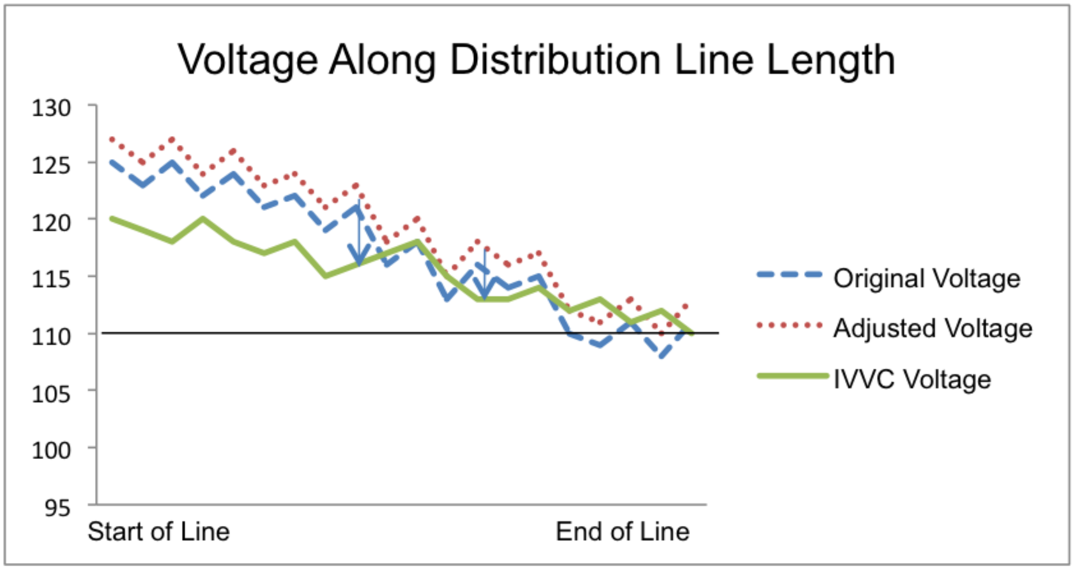
An analogy comparing power factor to the productivity of a manufacturing company may be helpful. The owners of such companies prefer for overhead costs (such as legal costs and accounting) to be as low as possible, making as great a proportion of the company's resources as possible available for productive activity (making steel or dishwashers, for example). The difference between unity (1.0) and measured power factor (for example, 0.95) in a utility's electricity can be considered undesirable overhead. The lower the measured power factor, the lower the productive portion of energy in the electricity a utility delivers. Customers understandably benefit when power factor is as close to 1.0 as possible, as they prefer the electricity they purchase to be as useful and productive as possible. Utilities strive to deliver electricity to customers with a power factor as close to 1.0 as possible, with 0.98 or 0.99 representing excellent performance.

Utilities have been correcting power factor for decades using devices called capacitor banks, or “cap banks” for short. Cap banks are placed around the grid where utilities need them to keep the power factor close to 1.0. However, power factor fluctuates from season to season, day to day, and even hour to hour as customers turn on and off equipment that impacts power factor. This variability makes power factor correction difficult. To compound the difficulty, power factor and voltage influence each other continuously in real time.

Integrated Volt/VAr Control

Integrated Volt/VAr Control (or IVVC) is a Smart Grid capability that can deliver significant efficiency benefits to customers. It allows a utility to continuously optimize voltage and power factor all along a distribution line. As described above, improving power factor reduces undesirable overhead in the electricity customers purchase. The closer power factor is to unity (1.0), the less electricity a customer must buy for a given amount of utility. IVVC reduces the variability in voltage along a distribution line and the rate at which voltage drops along the length of a line. This enables the voltage to be lowered along the entire length of a distribution line, as shown in Figure 2; note that the average of the IVVC voltage in Figure 2 is about 115, versus 120 for the original voltage.

Figure 2. Impact of IVVC on average distribution line voltage



The 4 percent reduction in average voltage – from 120 to 115 – along a distribution line may not seem like much, but most research indicates electric usage drops between 0.5 percent and 0.9 percent for each 1 percent reduction in voltage. Using a conservative estimate of 0.75 percent, the 4 percent voltage reduction translates to a 3 percent electricity usage reduction for every customer served by a distribution line with IVVC.

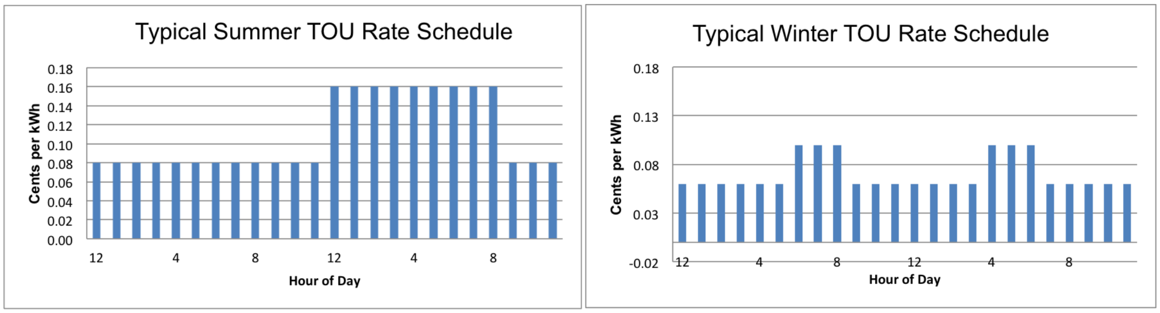
4. TIME-VARYING RATE PRIMER

The SGCC's "Smart Grid Economic and Environmental Benefits" report identifies several benefit drivers, challenges, and opportunities for increasing the benefits of time-varying rates, including customer participation rates, participant usage shifting, and structural winners and losers. Below we describe the most common types of time-varying rate designs and the pros and cons of each design. We also include a more detailed discussion of some of the challenges and opportunities of time-varying rates.

Time-Of-Use Rates

Time-of-use (TOU) rates are the simplest form of time-varying rates. Two time periods – peak and off-peak – are defined and priced differently. Some utilities add a third time period (mid-peak), and most utilities vary the prices for winter and summer.

Figure 3. Typical summer and winter time-of-use rate schedule

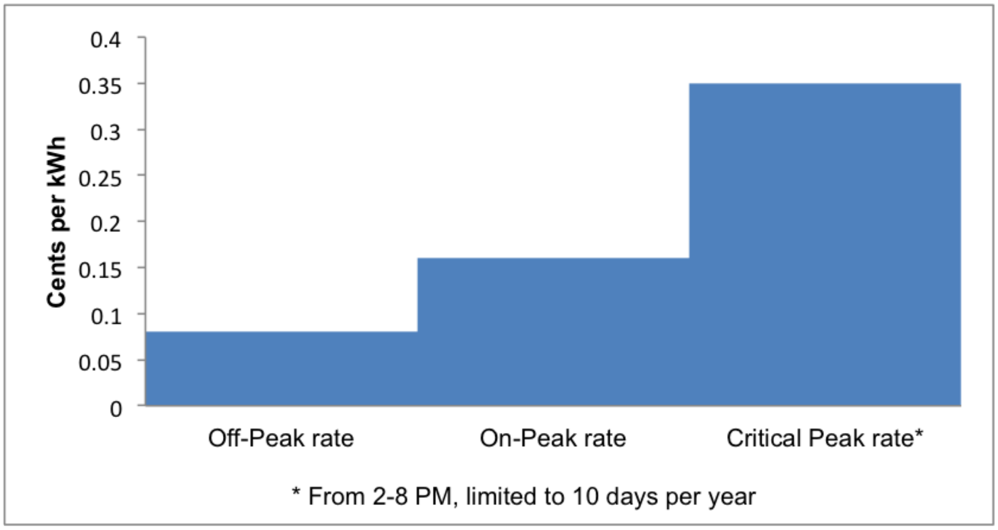


Though TOU rates are simple to understand, customers participating in them have demonstrated less load-shifting behavior than when using other types of time-varying rates. As described in the "'Revenue Neutral' Rate Design" section below, some TOU participants are natural winners because they normally use less energy during peak periods. These participants' bills are likely to drop a bit with no change in behavior. This can cause problems for a utility as revenues drop with no corresponding drop in costs from changed behavior.

Critical Peak Price Rates

Critical Peak Price (CPP) rates are an enhanced version of TOU rates. In addition to assigning higher prices during defined periods, CPP rates enable a utility to declare a limited number of days annually (generally 10 or so) on which rates are set dramatically higher for certain predefined hours (such as 2 p.m. to 8 p.m.). This is done to better reflect the dramatically higher costs of electricity on critical peak days. These dates are not set in advance but vary with conditions (generally the weather). Participating customers are notified of such days approximately one day in advance via text message, e-mail, or automated phone call.

Figure 4. Typical Critical Peak Price rate structure



CPP participants demonstrate greater load-shifting behavior than TOU rate participants,[2] but there are still natural winners for which to account in rate design. Although CPP rates are designed to be revenue neutral, customers seem to focus on the dramatically higher rates for the few hours rather than the slightly lower rates for thousands of other hours annually. Convincing customers to voluntarily participate in CPP rates, therefore, can be more difficult.

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[2] Faruqui, Ahmad, and Jenny Palmer, *The Discovery of Price Responsiveness – A Survey of Experiments Involving Dynamic Pricing of Electricity,* March 12, 2012: 4.

Peak-Time Rebate Rates

Peak-Time Rebate (PTR) rates were developed in response to the difficulty in getting customers to embrace CPP rates. They are also useful in cases where time-varying rates have been ordered by a regulator to be the default rates (also called opt out rates, as a customer must take action to avoid them), with the potential adverse satisfaction impact such an order portends.

PTR rates are similar to CPP rates in that certain “critical peak” days are declared one day in advance. However, rather than requiring participants to pay a dramatically higher rate on those days, participants receive a bill credit reflecting the change in behavior the participant demonstrates. Baseline usage levels are created for each individual customer, and the reduction in each participant’s actual usage on critical peak days relative to his or her baseline determines rebate size. If a customer chooses not to conserve on a critical peak day, there is no reward, but neither is there a penalty (unlike CPP rates, in which failure to conserve on a critical peak day can cause customers’ bills to increase).

The research indicates that rate-shifting behavior under PTR may be greater than that of TOU rates, but it is likely not as great as that of CPP rate participants.[3] There also appears to be a significant measurement issue, with many customers paid rebates they did not deserve, and other customers unpaid for rebates they did deserve.[4] These discrepancies can be mitigated by examining behavior response over all declared peak days, but delayed rebate payment is not as effective a feedback mechanism as immediate bill credit.

Opportunities to Increase Time-Varying Rate Benefits

There are several opportunities to increase the benefits of time-varying rates in practice. Perhaps the greatest opportunity is to increase customer participation in such rates. This will require a change in public perceptions about time-varying rates, a tall order to be sure. Because time-varying rates change how customers pay for their electricity, there is customer satisfaction risk in attempting to increase time-varying rate participation, and it is understandable that neither regulators nor utilities are very interested in taking on this risk. A related opportunity is ensuring that utilities can recover their costs in the face of sales volume reductions from large-scale participation in time-varying rates. We examine these opportunities individually.

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[3] Faruqui and Palmer, *The Discovery of Price Responsiveness – A Survey of Experiments Involving Dynamic Pricing of Electricity:* 4.

[4] George, Stephen S. “Peak Time Rebates: The Promise vs. the Reality.” Presentation to the National Town Meeting on Demand Response and Smart Grid, June 28, 2012.

Public Perception

Public perception of time-varying rates is generally incorrect and unfavorable. Some of these perceptions include the following.

Perception	Reality
Time-varying rates are simply a ploy for utilities to make more money.	Utilities and regulators ensure new rate designs are “revenue neutral”; that is, the utility collects the same amount of revenue in total from the customer base irrespective of which rates they choose (all else being equal). In reality, most utilities lose money on time-varying rates due to reductions in energy use by participants.
Time-varying rates are part of a government plot/an assault on my individual/customer rights.	There are no laws requiring utilities to charge their customers a flat rate per unit of use, or requiring utilities to insulate customers from cost fluctuations related to time of day or day of year.
Time-varying rates involve a lot of effort and inconvenience for a small economic reward.	Rewards are a function of rate designs. Customers from many utilities report significant savings from use shifting, which can be made easier with enabling technologies such as energy displays or programmable or remotely controlled thermostats.
Time-varying rates are unfair to people with health issues who must maintain the temperature of their living spaces within a narrow range.	Few utilities or regulators mandate specific rates. In almost all cases these customers can simply request a different rate from their utilities.
Low-income customers have fewer/smaller loads to control and therefore can’t save money on time-varying rates.	Research indicates low-income customers are actually more likely to save money with time-varying rates than other customers due to increased price sensitivity.[5]
Time-varying rates will cause many customers’ electric bills to rise.	The bills of a minority of customers who fail to shift usage may go up, but many more customers appreciate the opportunity to reduce their bills.

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[5] Wood, Lisa, and Ahmad Faruqui, “Dynamic Pricing and Low-Income Customers: Correcting Misconceptions about Load-Management Programs,” *Public Utilities Fortnightly* (November 2010): 60–64.

However inaccurate, these widely held perceptions make regulators and utilities hesitant to advocate for time-varying rates. Regulators could order utilities to make time-varying rates the “default” rate on which each customer is placed unless he or she specifically instructs otherwise. These “opt out” programs (as a customer must take action to opt out of the default rate) would lead to dramatically higher participation.

Utilities, and retail electric providers in restructured states, could unilaterally and aggressively promote time-varying rates for customers to select on a voluntary basis. However, few utilities wish to take on the risk to customer satisfaction with these programs, called “opt in” programs (as a customer must take action to select them). And finally, there is no reward (and in many cases there is outright disincentive) for utilities to take customer satisfaction risk to increase time-varying rate participation.

Lack of Utility Incentives/Presence of Utility Disincentives

Many utilities have no incentive to change the negative perceptions among consumers about time-varying rates. Expecting utilities to take significant customer satisfaction risks with no opportunity for gain would be illogical. In fact, most utilities’ sales volumes fall as time-varying rate participation rises, creating a significant disincentive under traditional ratemaking processes. See the earlier section on “Traditional Ratemaking” for more information.

“Revenue Neutral” Rate Design

Most utility regulators and governing boards require the various rate options a utility may wish to introduce to be designed as “revenue neutral”; that is, utilities will collect the same overall revenue no matter which rate options their customers choose, all else being equal. Although this concept sounds logical in principle, it introduces some challenging issues when it comes to time-varying rate designs, including the issue of rate “cherry picking.”

Although time-varying rates can be designed to be revenue neutral for customers on average, some customers will turn out to be better off, some worse off, and some about the same, assuming no change in usage behavior or shift in usage to off-peak price periods. If you are a customer in the “better off” group, you are more likely to choose the optional rate than a customer in the “worse off” group, again assuming no change in use. Furthermore, as a member of the “better off” group, you would save money even if your usage behavior did not change (making you a “free rider”). An example will help readers better understand these concepts.

Consider a time-varying rate incorporating a higher peak-period price between the hours of 2 p.m. and 8 p.m. on weekdays. A customer who is typically out of the house during those hours due to his or her occupation would be more likely to participate in the time-varying rate. As described above, changes in usage behavior among those participating in time-varying rates (switching and/or reduction) are critical to reducing costs to the benefit of all customers. If only those customers who benefit from the new rate participate in it and do not change usage behaviors, utility revenues will drop with no corresponding reductions in utility costs.

To address this potential limitation, a utility could:

- make a time-varying rate the default rate, encouraging participation by both "worse off" and "better off" customers in relatively equal proportions;[6]
- make the price difference between peak and off-peak periods moderate at first and grow the difference over time (to reduce the number of "worse off" customers who opt out);[7]
- offer only a Peak-Time Rebate version as its time-varying rate. (Peak-Time Rebates are earned based on behavior changes, but measurement issues loom large.)[8]

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[6] Khoury, D., and L. Tan, "The DRA's Responses to the Residential Rate Design OIR Questions." Report in response to Administrative Law Judge ruling in California PUC docket R.12-06-013. May 29, 2013: 38.

[7] Ibid.

[8] George, Stephen S. "Peak Time Rebates: The Promise vs. the Reality." Presentation to the National Town Meeting on Demand Response and Smart Grid, June 28, 2012.

5. TECHNICAL CHALLENGES OF SIGNIFICANT AMOUNTS OF CUSTOMER-SITED GENERATION

The SGCC's "Smart Grid Economic and Environmental Benefits" report indicates that significant amounts of customer-sited generation present reliability and efficiency challenges to the distribution grid. As customer-sited generation levels are currently insufficiently high to study reliability and efficiency challenges at scale, we present descriptions of the technical challenges utility engineers are beginning to confront as the level of customer-sited generation increases. From there we describe the types of capabilities in which investments can be made to manage the technical customer-sited generation challenges to avoid the reliability and efficiency impairment associated with customer-sited generation.

Technical Challenges Utility Engineers Are Beginning to Confront

As the proportion of customer-sited generation rises relative to distribution grid capacity, utility engineers are beginning to wrestle with impacts to reliability and efficiency. The technical challenges include:[9]

- Upstream protective devices (circuit breakers) can trip, causing outages
- Increased variation in voltage and harmonics can degrade power quality
- Increased variation in load and phase volatility can reduce grid efficiency

We will examine each of these and associated Smart Grid solutions individually.

Upstream Protective Devices (Circuit Breakers) Can Trip, Causing Outages

The electrical panel in your home or car includes a variety of breaker sizes (or, if your home is old enough, a variety of fuse sizes). Circuit breaker and fuse sizes are indicated by numbers in amps (such as 10, 15, or 20). The higher the number, the greater the disturbance the circuit breaker or fuse can accommodate before it trips. When a circuit breaker or fuse trips, it disconnects the wires beyond it (for example, wires to electrical outlets, clothes dryer, or air conditioner) from the system to protect the wires and equipment above it (for example, those out of your home and on to the distribution grid).

Note that on your electrical panel, different-sized circuit breakers are used for different equipment. A series of wall outlets might be protected by a 10-amp circuit breaker, while a bigger load (such as a clothes dryer or air conditioner) might be protected by a 40-amp circuit breaker. If a 10-amp circuit breaker were to be used on a clothes dryer, it would unnecessarily trip all the time; if a 100-amp circuit breaker were used on a clothes dryer it might not trip when it should, creating a dangerous situation. Circuit breaker sizing is like the story of Goldilocks and the three bears; one does not want them undersized or oversized, but just right.

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[9] Electric Power Research Institute. *Integrating Smart Distributed Energy Resources with Distribution Management Systems* (white paper), September 2012: 4–8.

Fuses and circuit breakers on the distribution grid serve the exact same function but on a much larger scale. Like the fuses and circuit breakers in your home, those on the distribution grid are sized appropriately to normal conditions. Large amounts of customer-sited generation on a distribution line could send electricity "backward" toward the substation. (Distribution grids have been designed to distribute electricity in one direction only. They have not been designed to accommodate two-way electrical flow.) Sending electricity backward through a circuit breaker or fuse is likely to be perceived by the device as a fault, causing it to trip and disconnecting the grid below it as a protective measure. Customers below the tripped device would experience an outage. Smarter grid designs, smarter protective devices, and automated systems are required if grid reliability is to be maintained as customer-sited generation grows.

Increased Variation in Voltage and Harmonics Can Degrade Power Quality

Many types of customer-sited generation introduce voltage, power factor, and harmonic frequency variability into the distribution grid. The "set it and forget it" approach to grid equipment settings practiced by utilities with traditional distribution grids will not likely be able to maintain high power quality on portions of the grid where customer-sited generation levels are high. As was discussed in the section on Integrated Volt/VAr Control (IVVC), high voltage and low power factor on the distribution grid can cause customers to use more energy than they might otherwise. IVVC can help manage some of the power quality challenges introduced by high levels of customer-sited generation – 24 hours a day, 365 days a year.

Increased Variation in Phase and Load Volatility Can Reduce Grid Efficiency

For a variety of reasons, central stations are configured to generate electricity in three phases. For optimum grid efficiency, these phases must be maintained equidistant from one another (measured in milliseconds) as they travel down distribution lines. Though phase balancing is a continuous concern, it is generally addressed periodically when problems arise. Smart Grid distribution automation devices provide an opportunity to continuously monitor phase balance in real time. Software applications can be written that interpret phase balance data and automatically adjust field equipment to reestablish phase balance 24 hours a day, 365 days a year. This advance could be particularly important as levels of customer-sited generation on the system increase, bringing with it potentially harmful effects on phase balance and grid efficiency.

Like phase balancing, load balancing is a continuous concern that is only addressed periodically. It involves identifying optimum distribution line configurations so that no one distribution line becomes overloaded during times of peak demand. Load balancing is an optimization problem, similar to a transportation system planner designing bus routes. Electricity can be distributed to homes and businesses along many optional paths (distribution lines). The challenge is to choose the paths offering the greatest value (in the case of electricity, reliability and efficiency) despite multiple asset and operations constraints.

As with bus route redesign, once optimum load balance has been established it is not generally reexamined until inefficiencies and reliability deteriorate to the point at which rebalancing becomes necessary. Load balancing software applications offer the possibility to rebalance continuously as the loads on the distribution grid change in real time. These applications could be extremely helpful as increases in customer-sited generation increase the variability of loads on the grid hour by hour and even minute to minute.

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