California's experiment shows the promise of dynamic pricing.

Demand Response and Advanced Metering

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CONGRESS HAS MADE DEMAND RESPONSE (DR) part of federal energy law. The Energy Policy Act passed last August says, "It is the policy of the United States to encourage States to coordinate, on a regional basis, State energy policies to provide reliable and affordable demand response services to the public." The act calls upon each electric utility to offer time-based rates to customers that reflect the time variation in the utility's supply costs and to help customers manage energy use and cost through advanced metering infrastructure (AMI). It also calls upon state commissions to conduct supporting investigations into time-based pricing rate schedules and other DR programs.

It is well known that the lack of DR was one of the contributing factors in the 2000–2001 California energy crisis. Subsequently, several states implemented a variety of DR programs, many of which used cash rebates to lower demand during peak periods and some of which exploited innovations in rate design to improve the efficiency of electricity pricing.

Most of the new pricing designs involve a dynamic element of "callability" that is superimposed on top of a time-of-use rate. In other words, customers are notified on a day-ahead or hour-ahead basis that prices will rise. Such pricing designs include critical-peak pricing, in which the higher prices are known ahead of time but their timing is uncertain, and real-time pricing designs, in which both the timing and price are uncertain.

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This article describes the results of the California DR experiment and how those results facilitate the development of business cases for advanced metering. Advanced meters measure not only the amount of electricity used during a month but the time of day during which electricity is used. That feature allows the price of electricity to vary by time.

THE EXPERIMENT

California's three investor-owned utilities and two regulatory commissions conducted a major pricing experiment involving some 2,500 customers over a two-year period. The experiment was designed to settle the question of whether price matters for residential and small commercial and industrial customers. Many observers were skeptical that small consumers would pay much attention to time-varying prices for electricity in a state where mortgage payments for many residents exceed $3,000 a month and monthly power bills average less than $100.

The experiment involved standard time-of-use rates and critical-peak-pricing rates, which were offered in two variants. One variant, CPP-F, informed customers about the highest rates on a day-ahead basis for a fixed-length peak period. Another variant, CPP-V, informed customers four hours before the event for a variable-length peak period. The CPP-V rate also featured enabling technologies in the form of smart thermostats that were price sensitive and were designed to automatically raise the air-conditioning temperature setting by two to four degrees when prices increased.

Customers were randomly selected from the state's population but had to affirm their participation in the experiment. For staying in the experiment, they were provided three types of appreciation payments, one upon completion of a survey and two after staying in the experiment for six and 12 months. They were assigned to one of several treatment groups featuring various levels of time-of-use and critical-peak-pricing rates. Other customers were assigned to control groups with standard rates. Customer enrollments began in April 2003 and the new rates went into effect in July 2003. The new rates continued through December 2004. Thus, the experiment featured several months of pre-treatment data and 18 months of experimental data.

The standard rates in California for residential customers consist of an increasing block structure with five tiers. The average rate for customers in the experiment was 13 cents per kWh. The time-varying rates were designed to leave average customers' annual power bill unchanged if they did not make any changes to their load profile and to lower their bill if they reduced peak loads. To avoid creating customer frustration, the rates featured significant peak–to–off-peak price differentials. Thus, if customers lowered their peak usage by 30 percent, they would save 10 percent on their monthly bill. On critical days, the average peak-period price equaled 59 cents/kWh and the off-peak price equaled 9 cents/kWh, yielding a ratio between peak and off-peak prices of 6.6 to 1. On normal days, the ratio between peak and off-peak prices was 2.4 to 1.

RESULTS The experiment revealed that customers did respond to time-varying prices. On average, residential customers reduced peak loads on critical days by 13.1 percent. The reduction was greater for customers in the warmer climate zones, and even larger for those with central air conditioning. Customers equipped with enabling technologies (automatic price-sensitive thermostats) delivered a response that was twice as high as those customers who did not have enabling technology.

The relationship between price and energy use by rate period is displayed in Figure 1, which shows how energy use dur-

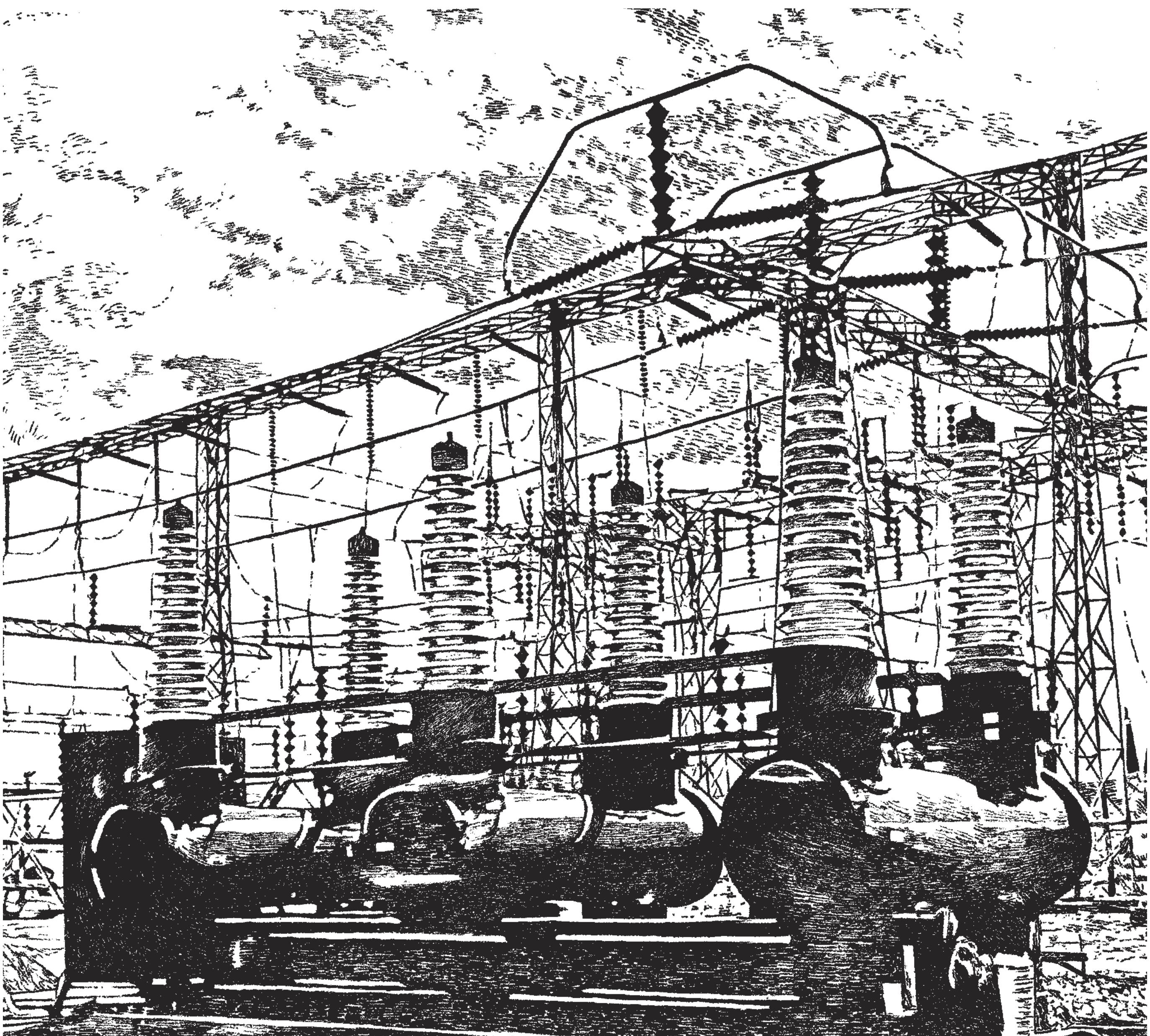

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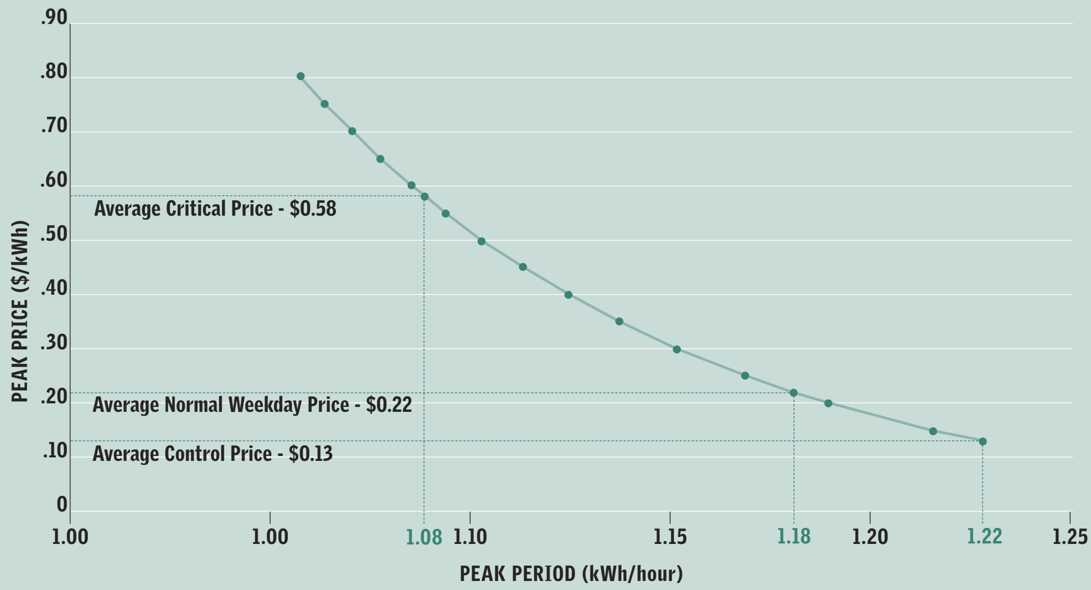
FIGURE 1

Energy Demand Under Variable Pricing

(California pilot program results)



ing the peak period varied with peak-period price, other things equal. A number of factors, such as weather, the saturation of air conditioning, or off-peak prices, are held constant along the curve. If any of them change, the curve will shift to the left or right, depending upon the nature of the change in the underlying factors.

The demand curve shows that at a price of 13 cents/kWh, which is the approximate price facing the control group and the price that treatment customers faced in the pre-treatment period, peak-period electricity use was 1.22 kWh/hour. At a price of 22 cents/kWh, corresponding to the average peak-period price on normal weekdays, demand fell to 1.18 kWh/hr.

One way of summarizing price responsiveness when price changes are large is the arc elasticity. Arc elasticity equals the percentage change in energy use relative to the average of the new and old values for both quantity (Q) and price (P), as depicted in the following equation:

$$\text{Arc Elasticity}=\{[(Q2-Q1)\div(Q2+Q1)]\div 2\}\div\{[(P2-P1)\div(P2+P1)]\div 2\}$$

In the example shown in Figure 1, a rise in the price from $0.13/kWh to $0.22/kWh (or 51.43 percent using the averaging approach in the formula) produced a drop in electricity use of 3.33 percent (from 1.22 kWh/hr to 1.18 kWh/hr), yielding an implicit arc own-price elasticity of demand of –0.065. When the price increased to 58 cents/kWh, corresponding to the average peak-period price on critical days, demand fell to 1.08 kWh/hr. Thus, a rise in the price of 126 percent from the initial average value of 13 cents/kWh produced a drop in electricity use of 12 percent, yielding an implicit arc own-price elasticity of demand of –0.096.

AMI BUSINESS CASE

By adapting these experimental findings to its mix of customers and climates, energy provider Pacific Gas and Electric developed a business case for implementing AMI in its service area. PG&E estimated that AMI would cost $2,265 million in present value of revenue requirements (PVRR) and result in operational benefits of $2,024 million in PVRR, leaving a gap of $241 million in PVRR to be covered by DR. About half of the AMI costs are associated with the installation of advanced meters and about half of the operational savings stem from avoided meter-reading costs.

To maximize customer acceptance, PG&E analyzed a "pure" critical-peak-pricing rate that would involve time-of-use pricing on 15 critical days in the summer and standard pricing on all other days of the year. Compared to the standard residential rate, the peak rate raised prices during the critical peak period by 60 cents/kWh and lowered them by 3 cents/kWh on all other hours. This yielded an average price of 73.1 cents/kWh during the critical peak period and of 10.1 cents/kWh during all other hours.

Based on market research, PG&E estimated that about a third of the customers with central air conditioning would adopt the rate, and perhaps a twentieth of all other residential customers. In the aggregate, this would amount to 15 percent of PG&E's residential customers. Under these assumptions, it predicted that DR would amount to 455 MW in the year 2011, when advanced meters and supporting infrastructure would be installed on all of the firm's 4 million electric customers. About 80 percent of the projected savings are associated with residential customers and the rest with small commercial and industrial customers.

VALUE The final step in this analysis is properly valuing the

DR. The California Public Utilities Commission had provided an estimate of $85/kW-yr, representing the avoided cost of a peaking generation unit. PG&E elected to use a more conservative estimate of $52/kW-yr, which is the figure that results once the income stream associated with the peaking unit is netted out. The latter figure yielded a value of $270 million in PVRR, which was estimated by taking a present value of the annual stream of DR impacts. Additional savings of $68 million in PVRR were expected in reduced transmission and distribution capacity costs, yielding total savings of $338 million in PVRR. This is more than sufficient to cover the operational gap of $241 million in PVRR. Based on this analysis, PG&E has requested authority from the California Public Utilities Commission to begin AMI deployment in 2006.

San Diego Gas and Electric has sought similar authority, based on its analysis of the options. In its initial filing, it took an opt-out approach to offering dynamic pricing options. Assuming that 80 percent of the customers would stay with the dynamic pricing option, it found AMI deployment to be cost-effective. The third utility, Southern California Edison, has concluded that more work needs to be done in developing a better meter, to avoid a situation in which it is locked in to an obsolete technology. Therefore, the firm has requested funds to develop an Advanced Integrated Meter to improve the cost-effectiveness of AMI for its ratepayers.

All three utilities are relying on customer response results from the experiment and adapting them to their service area conditions. The differences in their AMI deployment strategy thus stem not from how they are modeling DR but from how they are modeling the operational benefits of AMI on their system.

HOW DOES DR CREATE VALUE?

DR provides benefits by reducing the need for peak capacity and improving system reliability. The main benefit from DR is peak demand reduction. Because many power plants that serve peak demand have very low utilization factors, on the order of only 100 hours out of the year (or one or two percent of the total hours in the year), avoiding the cost of building a new peaking capacity can result in significant savings.

Because generating units suffer mechanical breakdowns and because peak demand is inherently uncertain, electric power systems must have a "reserve margin"—more capacity than needed on peak in order to accommodate unit outages. Typically, electric power systems have a 12–15 percent reserve margin to ensure reliability. As a result, every megawatt of peak consumption reduced by DR results in the savings of not just one megawatt of avoided peak capacity costs, but also the avoided reserve margin. So, if the target reserve margin is 15 percent, a megawatt of avoided peak consumption results in 1.15 megawatts of avoided peak capacity investment.

Another benefit from DR is increasing the price elasticity of electricity. Clearly, sending better price signals to consumers through dynamic pricing programs can increase the price elasticity of demand. To the degree that price elasticity is increased, there is the benefit of decreasing the degree to which market power can be exercised, which is often a major concern.

CONCLUSION

DR creates value when it encourages electricity consumers to reduce load at peak times by either curtailing energy-using activities or shifting them to off-peak times. Load that is reduced during times when the power system has encountered critical conditions (in the form of higher prices on wholesale markets or in the form of stress from supply insufficiency) will carry greater value than load that is reduced during normal times.

The pricing experiment in California has shown that well-designed dynamic pricing programs can have a significant impact on critical peak loads, even for residential and small commercial and industrial customers. California's three independently owned utilities are using the experimental results to develop business cases for AMI. R

READINGS

- "Demise of PSE's TOU Program Imparts Lessons," by Ahmad Faruqui and Stephen S. George. *Electric Light & Power,* Jan. 2003.
- *Electricity Pricing in Transition,* edited by Ahmad Faruqui and Kelly Eakin. Boston, Mass.: Kluwer Academic Publishers, 2002.
- "Getting Out of the Dark," by Ahmad Faruqui, Hung-po Chao, Vic Niemeyer, Jeremy Platt, and Karl Stahlkopf. *Regulation,* Vol. 24, No. 3 (Fall 2001).
- "Preventing Electrical Shocks: What Ontario—and Other Provinces—Should Learn about Smart Metering," Commentary 210, by Ahmad Faruqui and Stephen S. George. Toronto, Ontario: C. D. Howe Institute, April 2005.
- "Quantifying Customer Response to Dynamic Pricing," by Ahmad Faruqui and Stephen S. George. *Electricity Journal,* May 2005.