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Prices to Devices: Price Responsive Devices and the Smart Grid

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1. Executive Summary

The Smart Grid promises to improve the quality, resiliency, and integrity of the grid through the optimization of the existing energy delivery infrastructure and integration of new renewable generation sources. A primary element of the Smart Grid is the enhanced communications capabilities that enable consumers to better manage their electricity consumption and costs via new smart appliances and devices located at the customer's premises. These are commonly referred to as Home Area Network (HAN) devices.

As Smart Grid communications systems open new opportunities for consumer participation, a variety of HAN stakeholders are defining the format and types of messages and signals that will facilitate energy awareness and empower consumers. Most important are the data signals that provide price information. Numerous studies have confirmed that consumers prefer energy information quantified in monetary terms rather than electrical terms like kilowatt-hours. However, while a *nominal* price signal of $0.13 per kilowatt hour (kWh) is useful for consumers, additional information is required to enable new price responsive devices that modify their behavior automatically in response to higher or lower prices. Price responsive devices are important because they offer their owners convenient and user-friendly management of energy use in a future where the retail price of electricity will more closely reflect the actual economic cost as it varies throughout the day. Price responsive devices require slightly different price signals than nominal price signals; they require *relative price signals* that use metrics such as high, medium, and low to convey the context of the nominal price and drive action.

This white paper will inform HAN stakeholders of Southern California Edison's HAN research and development work in concert with HAN device suppliers to develop price responsive devices. The intent of this paper is to:

- Define the types of price signals (e.g., nominal and relative);
- Review the methods for determining relative price signals;

- Highlight the regulatory and policy requirements for establishing a national market for HAN devices;
- Discuss the technical and behavioral implications of providing price signals; and
- Inform ongoing Smart Grid policy and standards discussions in the United States at the federal and state levels.

Based on SCE's work with a variety of industry partners, SCE makes the following recommendations:

- Relative price signals benefit HAN devices capable of price responsiveness;
- Relative price signals enable national and international markets for price responsive HAN devices and can accommodate the wide variety of retail electricity rate structures;
- Price signals must be authenticated due to the control-like effects they have on price responsive HAN devices;
- Relative price signals should be simple and clear so they are actionable by cost-constrained HAN devices and understandable by consumers; and
- Default time-differentiated rates are needed in order to create a sustainable market for price responsive HAN devices like smart appliances.

2. Background

Southern California Edison (SCE) and number of utilities and service providers are deploying Home Area Networks (HAN) to empower their customers to make more informed energy decisions. The use of consumer devices will help them to access a variety of information from their utility and/or electric service provider. A recent survey by The Brattle Group shows that consumers with energy displays conserve an average of 4.3 percent on their energy use.[1] Other research shows consumers do not readily understand kilowatt-hours and strongly prefer price information (e.g., $/hr).[2]

Since 2008, SCE has actively collaborated with manufacturers of programmable communicating thermostats (PCTs), in-premise displays, energy management systems (EMSes), plug-in electric vehicles, smart appliances, and other emerging technologies and applications to validate and demonstrate standards-based methods for communicating price information using the Smart Energy Profile (SEP).[3] Price signals enable HAN applications to inform consumers about electricity pricing and could allow them to automatically adjust their energy use to conserve during high price periods or when a bill is projected to be higher than a budgeted amount defined by the customer.

Communicating pricing information is viewed as a critical component to enabling a successful HAN. However, price information can take several different forms and has a variety of contexts and uses. Some in the field support a concept called *prices-to-devices*, wherein HAN devices are provided with a retail price for electricity, sometimes as frequently as every hour or fifteen minutes (i.e., hourly or so-called “real-time pricing”). As HAN technology evolves, a number of stakeholders have proposed requirements, rules, mandates, and/or guidelines on the types of information protocols HAN providers should follow. Some of the entities promulgating standards include various state utility commissions, the National Institutes of Standards and Technology (NIST), the Association of Home Appliance Manufacturers (AHAM), and OpenSG (part of the International Electrotechnical Commission).

3. Nominal and Relative Information

Before discussing price signals, it is helpful to illustrate the differences between nominal and relative information using a familiar example. Motorists in many parts of the United States are familiar with highway information signs that are routinely updated during high traffic periods with estimated travel times to various destinations [Figure 1]. Note that while this nominal information has value to drivers, unless an individual drives this route frequently, one would not know if the 23-minute travel time to San Francisco airport (SFO) was a shorter, average, or longer travel time for that particular time of day; therefore, the driver would not know whether to choose an alternate route or to continue with the planned route. The motorist simply knows how long the rest of the drive should take and the impact it could have on his or her plans.

Figure 1 – Example of Nominal Travel Time Information (Photo: John Huseby/Caltrans)

The missing element for a driver unfamiliar with the area is context. Only with context do nominal signals transform into relative signals capable of driving action and useful in decision-making. Continuing the traffic analogy, Southern California has an extensive network of highway sensors. Various service providers aggregate this information and synthesize the thousands of readings into relative information useful to consumers. SigAlert.com is one such service provider. It applies relative signals (i.e., colors) to nominal traffic readings to provide users with the ability to put their route options in context [Figure 2].

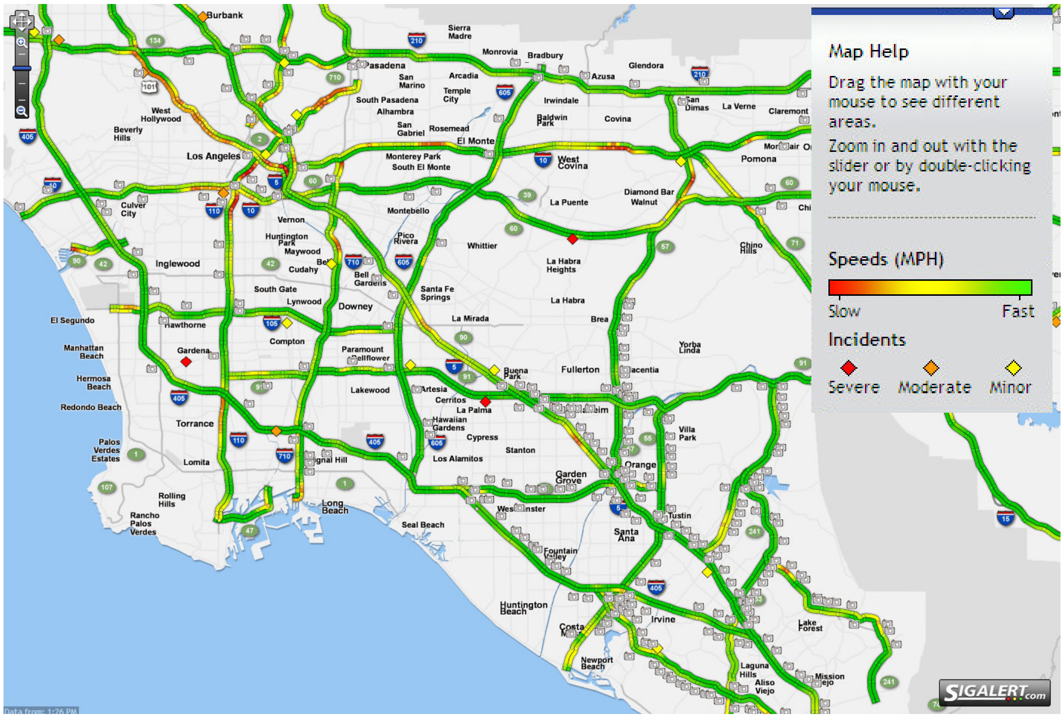

Figure 2 – Example of Relative Travel Time Information (Photo: SigAlert.com)

Color coding provides quick, at-a-glance guidance with its red, orange, yellow, and green color scheme, each of which corresponds to an average speed reading. In this way, drivers are empowered to choose the quickest route and modify their driving behavior, which has the aggregate effect of easing traffic congestion. SCE proposes using similar methods to advise the Smart Grid stakeholder community on ways to facilitate the creation of a national market of HAN devices capable of price responsiveness.

4. Types of Price Signals

Both nominal and relative price signals are distinct from rate structures, which employ various strategies to accomplish perceived values of fairness or other policy goals. Price signals can be communicated regardless of the rate structure a consumer chooses. The Appendix provides examples of some rate structures and a more detailed discussion of how price signals can be used in conjunction with rate structures.

4.1 Nominal Price Signals

The nominal price signal is generally the actual retail economic price of electricity expressed in terms of currency ($0.13/kWh). Nominal prices vary widely across the United States depending on the electricity generation method and various rate structures determined by public utility or service commissions and oversight agencies.

4.2 Relative Price Signals

Relative price signals attempt to translate peak electric system conditions in a way that provides consumers with objective information on the economic scarcity of electricity specific to that geographic area or sub-system of the electric grid (e.g., ISO/RTO area, utility service territory, circuit, or substation).

In order to understand the relative price of a commodity, one needs to know the overall number of relative price levels in the scale and the currently active relative price level.

There are three general methods for obtaining relative price information:

- Manual programming
- Learning algorithms
- Trusted-source

4.2.1 Manual Programming

In this method, a device is programmed by a user with the information required to determine how relatively high or low the nominal price signals are that it could receive. This typically involves a comparatively sophisticated user interface with a calendar or some other scheduling mechanism for the user to program the device.

Manual methods have drawbacks as many devices like refrigerators do not typically have human-machine interfaces capable of supporting detailed user programming. It also requires additional effort by the consumer to become informed and adept at configuring his or her device. Consumer research on devices requiring detailed user programming like VCRs and early generations of programmable thermostats demonstrates that this can be a barrier to their widespread adoption and use.

Although service providers could program the rate structures into the devices, this is impractical for mass markets. Doing so requires configuring and managing millions of devices, puts bandwidth constraints on some communication systems, and imposes more costly memory storage capabilities on devices. The inherent difficulty and inconvenience of manual programming makes it unlikely to scale to a mass market.

4.2.2 Learning Algorithms

Over time, a device with a learning algorithm could build a historical model of nominal price signals received and derive its own definition of relativity on which to base its behavior. This has the advantage of being invisible to the consumer and flexible across a variety of national prices.

However, the technical requirements for designing appliances with adaptive logic to learn rate structures over time are likely to be unfeasible or unreliable when one considers the constrained platforms and cost implications of embedded devices common in a HAN like PCTs, pool pumps, and smart appliances. This would be compounded when rate structures and underlying prices change based on seasonal variations, as many rate structures do.

While learning algorithms may have successful applications in more sophisticated devices like energy management systems (EMSes), SCE does not believe learning algorithms are a viable option for mass market residential devices where up-front device costs drive purchasing decisions. Even with a sophisticated EMS, the devices it controls will be simple devices that require a relative price signal. In other words, the EMS proxies the price to the other HAN devices and becomes the trusted source described below.

4.2.3 Trusted Source

SCE believes the trusted source method is the most appropriate method of communicating relative price signals for the mass market adoption of HAN devices presently being developed to take advantage of the Smart Grid.

In the traffic analogy, users of the SigAlert traffic service trust it to accurately calculate the nominal speed readings (e.g., 30 mph) obtained from the sensor network and simplify it into an easily understood relative signal (e.g., yellow) for the driver. Under the trusted source method of communicating price signals, an entity would similarly transmit a relative price signal based on the active nominal price. To accomplish this, the trusted source defines a scale with a number of relative levels and provides the current active level. Table 1 provides an example of a 24-hour schedule for electricity with four relative tiers.

Time (24-hr)	Nominal Price	Active Relative Price Level	Total Number of Relative Price Levels
00.00 – 10.59	$0.11 / kWh	1	4
11.00 – 14.59	$0.25 / kWh	3	4
15.00 – 17.59	$0.40 / kWh	4	4
18.00 – 19.59	$0.19 / kWh	2	4
20.00 – 23.59	$0.11 / kWh	1	4

Table 1 – A 24-hour example of relative price levels

Note that higher relative levels signal peak electricity system conditions. With active relative price level and total number of price levels, a HAN device can easily and readily understand the higher cost of the current operating period and change its behavior. This has the advantage of working within the processing constraints of embedded consumer devices and across a wide range of electricity prices throughout the world.

The trusted source could theoretically be any source the consumer trusts. In practice, it is likely to be the electric service provider, utility, regional transmission operator (RTO), independent system operator (ISO), or a trusted third party who obtains the data from one of the aforementioned sources. The definition of relative price levels must be done in a transparent manner and facilitated by regulatory agencies. Energy service providers under different regulatory regimes have different incentives when it comes to providing transparent information that could drive energy conservation or peak load shifting. Whatever the source of the signals, they must be transparent and free of perceptions of gaming by the source to the detriment of consumers. Failure to do so would erode public support for the Smart Grid.

5. Control-Like Effects on Device Behavior of Price Signals

In a connected world where consumer devices can be programmed to respond to price signals and automatically adjust their behavior, price signals assume control-like characteristics similar to demand response or load control signals. For example, electric utility customers enrolled in a time-of-use (TOU) rate plan, in which they pay varying prices for electricity used at different times, may preset their appliances to minimize usage during higher cost, on-peak periods and defer operation to lower cost, off-peak periods. A device's default response settings can be pre-programmed by the manufacturer for user convenience and to allow devices with unsophisticated user interfaces to have some response capability. For example, a refrigerator might disable its ice maker and suspend the defrost cycle during higher cost periods. In this way, price responsiveness serves as a softer form of demand response that avoids the prescriptive nature of direct load control and allows consumer preferences to drive consumption behavior. Consumers would be free to modify the factory default settings or override responses according to their preferences, but the default options provide convenient, out-of-box consumer benefits.

For further discussion of price response strategies and appliances, see the Association of Home Appliance Manufacturer's (AHAM) *Smart Grid White Paper* published December 2009, pages 8-9.

6. Requirements to Enable a National Plug-and-Play Market for HAN Devices Capable of Price Responsiveness

In order for consumer devices to easily respond to the variety of price signals and utility rate structures represented across the country, they must be able to determine how relatively expensive or inexpensive a nominal price is, in the range of possible prices for that consumer's rate plan (i.e., they need a method to determine the relative price). For example, a nominal price of $0.13/kWh is considered low for California, but high for Kansas.

AHAM has developed several requirements for enabling a reliable and consumer-friendly HAN that scales nationally or internationally:

- "Clear standards are required to describe dynamic pricing information across the United States. A fragmented system of tariff structures across the more than 3,000 utilities would present an impediment to the interstate commerce and use of consumer products.
- The pricing structure must allow manufacturers to build devices or appliances that are capable of managing this benefit and provide consumers with the proper incentives.
- The consumer must be able to easily set rules defining their preferences to govern their usage of electricity in the home."[4]

Relative price signals demonstrate their versatility when the out-of-the-box appliance is capable of responding to the variety of rate and price structures in the United States without customization or extensive configuration by the consumer. While it is unlikely that the wide variety of retail electricity rate structures will be standardized in the near term, relative price signals offer a readily available solution for communicating price signals that are not specific to a particular electricity rate structure.

7. Implications

Based on SCE's experience in developing HAN-enabled appliances and devices with partners, SCE believes there are important implications for device manufacturers, service providers, policy-makers, and regulatory organizations to consider when designing and implementing the Smart Grid.

7.1 Nominal Price Signals Are Not Enough

Informing consumers of their real-time cost of electricity (i.e., Price multiplied by Usage) requires nominal price signals to provide energy consumption information in monetary terms that consumers understand and use to manage their energy use. However, enabling convenient management of HAN devices and driving price responsiveness requires methods that inform the appliance or device of the relative price. The easiest and least complicated method to achieve this is by providing relative signals from a trusted source.

7.2 Price Signals Require Authentication

Because price signals will likely have control-like effects on the behavior of consumer devices, careful consideration should be given to the public broadcast of price signals. Unsecured price broadcasts in which devices do not have a trusted communications path to the price provider could lead to spoofing of price signals and nefarious or malicious behavior against consumers' HANs. The consumer backlash this could create would be a significant setback to achieving the nation's Smart Grid policy goals.

To prevent this, policy makers must require out-of-band registration and authentication of HAN devices with the price signal provider to ensure security and privacy when communicating price signals. HAN security has been thoroughly investigated and documented by a variety of Smart Grid industry groups like the OpenSG Users Group's AMI Security Task Force and NIST.

7.3 Keep It Simple: Devices Can Only Do So Much

For most residential users, the concept of *prices-to-devices* (i.e., nominal retail prices provided directly to devices) without a way to determine the relative price level is not particularly meaningful for achieving price responsiveness in devices. Consistent with the law of diminishing returns in other fields, there are limits to how much appliances can change their behavior in response to a relative price signal. Beyond three or four total relative price levels, additional relative price levels do not provide substantial consumption reduction or load shifting for most residential applications. Complexity increases uncertainty and consumer resistance to the changes enabled by the Smart Grid. Electric service providers and their oversight commissions should carefully consider the structure of the rates they design and consider how devices would interpret them.

7.4 Time-of-Use Delta Is Crucial to the Consumer Value Proposition

Beyond event-specific demand response programs, the value proposition of smart appliances and other devices depends on the underlying rate structures. The greater the difference between the on-peak and off-peak prices, the greater the value proposition to the consumer purchasing a price responsive smart appliance. The duration of the on-peak period also has a strong effect on the payback period of the upfront premium of the smart appliance.

Upfront rebate incentives also play a role, but ongoing operational incentives require TOU rates or other strategies (e.g., in the case of relative but no nominal price) that pay down the upfront cost of enabling communications in smart appliances.

7.5 Smart Grid-Compatible Devices Require Smart Grid-Compatible Policies and Rate Structures

Today’s rate structures are not, for the most part, Smart Grid-compatible. SCE is not the first to point out that time-differentiated rates are required to maximize the societal benefit of HANs and the Smart Grid. This is an important point for regulators and policy-makers who seek to encourage the adoption of price responsive HAN devices. In the absence of time-differentiated rates that apply to a critical mass of the population, it is unlikely consumers will see the value in paying the additional costs involved in making an appliance “smart.” Consumers buying smart appliances for the “green” factor will not sustain the market beyond the current generation of prototypes and field trials.[5]

8. Appendix

8.1 Rate Structure Examples

8.1.1 California's Tiered Schedule-D Rate Structure (Inclining Block Tariff)

California's Investor Owned Utilities – under the jurisdiction of the California Public Utilities Commission (CPUC) – have a tiered rate structure for the vast majority of residential customers as outlined in Table 2. The more one uses, the more one pays:

Tier	Delivery Charge	Generation	Nominal Total
Baseline	$0.04491	$0.07860	$0.12351
101% - 130% of Baseline	$0.06482	$0.07860	$0.14342
131% - 200% of Baseline	$0.16080	$0.07860	$0.23940
201% - 300% of Baseline	$0.19580	$0.07860	$0.27440
Over 300% of Baseline	$0.23080	$0.07860	$0.30940

Table 2 – Typical California IOU Residential Tiered Rate Structure (all prices per kWh)

California residential rates are structured to be higher for customers using greater amounts of electricity with the intent of changing energy consumption behaviors and driving conservation. The price one pays at the beginning of the billing period increases as consumption increases throughout the billing period. The baseline service calculation differs depending on which climate zone the customer's premises are located in and the season.

California's higher use rate customers shoulder a greater share of the cost of providing service because under Assembly Bill 1-X, post-2001 rates are frozen for the first two tiers (baseline and 101-130 percent of baseline). Increased generation costs, such as those experienced in 2006-2008, and electric system improvements and expansion have been funded by customers in tiers three through five.

California's rate structures present unique challenges for communicating prices to devices. Relative price signals via manual programming and learning algorithm methods are very complex because the nominal price changes are not based on time, but on usage and geographic climate zone baseline allocation. California's TOU rate option is even more complex because it overlays an on- and off-peak rate into the inclining tier structure shown in Table 2.

8.1.2 Time-of-Use Rate Structure

TOU rates vary throughout the day at known intervals and provide a nominal price signal that typically reflects some measure of underlying wholesale market conditions. In most TOU schemes only the nominal price for that TOU interval is communicated to the device as illustrated in Table 3.

Time (24-hr)	Interval (not typically communicated to the device today)	Price (per kWh)
00.00 – 10.59	Off-peak	$0.13
11.00 – 13.59	Mid-peak	$0.20
14.00 – 19.00	On-peak	$0.30
19.00 – 23.59	Off-peak	$0.13

Table 3 – Time-of-Use Rate Structure Example

While many utilities offer a TOU rate, customer apprehension and lack of awareness are barriers to widespread adoption.

See Appendix Section 8.2 for additional discussion on how TOU and relative price signals can be effectively communicated to price responsive devices.

8.1.3 Real-Time or Hourly Price Rate Structure

Real-time price rates attempt to more closely align the retail price an electricity consumer pays with the actual wholesale price of electricity. The assumption is that exposing consumers to the actual spot price leads to greater conservation of electricity during peak times by modifying behaviors so more energy is consumed off-peak.

Generally, the rate price is not updated in real-time, instead it is communicated on a day-ahead basis with prices provided at least hourly - possibly every 15-minutes. Historically, RTP rates are only applied to sophisticated commercial and industrial consumers capable of investing in the people and technologies to minimize their cost of electricity input to production.

Time (24-hr)	Nominal Price (per kWh)
00.00 – 00.59	$0.0134
01.00 – 01.59	$0.0301
…	…
10.00 – 10.59	$0.0928
11.00 – 11.59	$0.2059
…	…
14.00 – 14.59	$0.3523
15.00 – 15.59	$0.4219
16.00 – 16.59	$0.2264
…	…
21.00 – 21.59	$0.0876
22.00 – 22.59	$0.0410
23.00 – 23.59	$0.0223

Table 4 – Real-Time Price Rate Structure Example

8.2 Rate Structure Examples Matched with Relative Price Signals

8.2.1 Time-of-Use Rates with Relative Price Signals

TOU price signals imply that a nominal price for a given time period reflects relative system price conditions; however, enabling an effective national marketplace for smart devices and appliances requires utilizing an explicit relative price signal. HAN communication standards must be developed with this requirement in mind. Table 5 shows an example of the data attributes required.

Time (24-hr)	Interval (not communicated to devices)	Nominal Price (per kWh)	Active Relative Price Level	Total Number of Relative Price Levels
00.00 – 10.59	Off-peak	$0.13	1	3
11.00 – 13.59	Mid-peak	$0.20	2	3
14.00 – 19.00	On-peak	$0.30	3	3
19.00 – 23.59	Off-peak	$0.13	1	3

Table 5 – Time-of-Use Rate Structure with Relative Price Signals

8.2.2 Real-time Price Rate with Relative Price Signals

Relative price signals can include real-time price structures as well. The price signal provider chooses a relatively small number of relative price tiers to map the hourly variations in nominal price. This can be based on established rules or definitions agreed upon by the appropriate stakeholders and regulatory bodies. An example is shown in Table 6:

Time (24-hr)	Nominal Price (per kWh)	Active Relative Price Level	Total Number of Relative Price Levels
00.00 – 00.59	$0.0134	1	4
01.00 – 01.59	$0.0301	1	4
…	…	…	…
10.00 – 10.59	$0.0928	2	4
11.00 – 11.59	$0.2059	3	4
…	…	…	…
14.00 – 14.59	$0.3523	4	4
15.00 – 15.59	$0.4219	4	4
16.00 – 16.59	$0.2264	3	4
…	…	…	…
21.00 – 21.59	$0.0876	2	4
22.00 – 22.59	$0.0410	1	4
23.00 – 23.59	$0.0223	1	4

Table 6 – Hourly Real-Time Price Structure with Relative Price Signals (abridged)

9. References

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