Price Normalization for Price-Responsive Devices—Algorithms and Issues

Chellury Ram Sastry
Battelle
sastryc@battelle.org

William Cox
Cox Software Architects
wtcox@coxsoftwarearchitects.com

Toby Considine
TC9 Incorporated
toby.considine@gmail.com

Keywords: Simple Levels, Price Communication, Collaborative Energy, OASIS Energy Interoperation, OASIS EMIX, ZigBee SEP2

Abstract

One of the key Demand Response applications involves the use of smart appliances and devices within a facility (residential or small commercial buildings) that can be programmed and automated to respond to DR signals (that could be either pricing signals or other energy curtailment signals) arriving from a utility, wholesale market, or a 3rd party energy service provider. Several technical, business, and policy challenges need to be overcome before such DR applications become ubiquitous and gain widespread consumer acceptance.

In this paper we concentrate on the abstraction of dynamic prices to "Simple Levels", and propose metrics for quality of mappings. We also address general issues with mapping including volatility, seasonal variation, and effective use of Levels where price (hence cost) is abstracted away.

Several significant issues arise in performing price normalization.

1. The general range of prices changes over time—from summer to winter, from year to year.
2. The mapping between price ranges and QoS provided to consumers from various smart devices. Furthermore, these mappings need to consistent across different price providers, software, and/or curtailment requesters.
3. The normalization must express information needed to properly respond to actual price information, and must show differentiation across time

While considering descriptive statistics from one year-long sample of simple level mapping, we examine various issues that need to be considered in evaluating price normalization algorithms, and examine several classes of algorithms, including moving averages, statistical analysis of history, and hybrid approaches. We apply them to sample historical price streams where wholesale prices are used as proxies for retail prices and scarcity, and compare to actual approaches used in pilot projects.

Our purpose is to create a framework for analyzing and discussing the quality of response and the quality of mapping of complex time series of prices to simple levels.

1. INTRODUCTION

The problem of abstracting what we call Simple Levels (or *Normalized Prices*) from real-time price streams seems simple on the surface. The goal is to give a simplification of prices to Energy Managers (EMs) and devices, presuming that their goal of cost-effective energy use and energy conservation is well-served by the simplification.

In effect, the Simple Levels are thought to be a "good enough" abstraction of actual price behavior to improve energy efficiency.

In this paper we examine these assumptions, describe and analyze the problem, and propose metrics for evaluating quality of algorithms that abstract Simple Levels from real-time price streams.

We also discuss prediction and forward- and backward-looking approaches.

Our purpose is to create a framework for analyzing and discussing the quality of response and the quality of mapping of complex time series of prices to simple levels.

2. THE ASSUMPTIONS

There are several explicit and implicit assumptions around Simple Level abstractions. For example, the Smart Energy Profile 2 work requires that a facility system be "[p]rovided a simple, relative price signal (e.g., low, medium, high, critical)" [SEP-MRD] but also wants cost information for the present and historical periods.[1]

We assume that Simple Levels run from 1 to MaxLevels, a parameter that may vary across deployments. SEP2 [SEP2-AS], for example, presumes four levels, but is designed to express more; OASIS Energy Interoperation [EnergyInterop] Simple Levels are parameterized for any number. ISOs and other sources that deliver Simple Level information have chosen varying numbers of levels, including 3, 4, 9, and 11 (e.g. [OpenADR1], [SEP2], [Knudsen]

Ivan O'Neill writes, "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." [O'Neill]

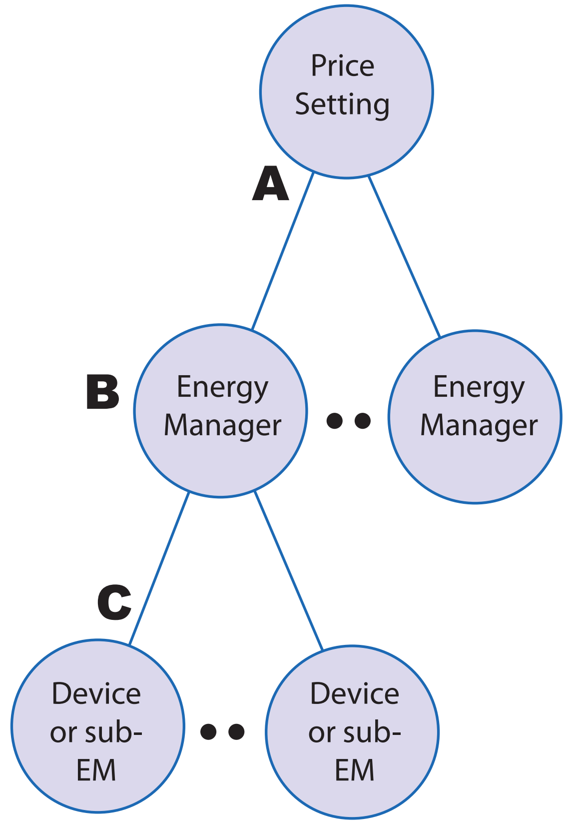

FIGURE 1 WHERE TO DETERMINE SIMPLE LEVELS?

In the following sub-sections we list and briefly describe some commonly held assumptions.

2.1. Simple Levels Reflect Cost

The most that is reflected in Simple Levels is relative price (or cost). While it's critical to have monotonically increasing prices in parallel with increasing Simple Levels, the steps are not defined in the abstraction. So Simple Levels reflect relative cost as higher or lower, but not how much higher or lower.

2.2. Computing Levels take Significant Resources

It is implicitly assumed that Simple Level computation takes significant computing and/or memory resources. For example, "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." [O'Neill]

The implication is that it is more efficient or cost-effective for something other than the device or the residential EM to compute relative prices.

[1] [SEP-AS] has a parameterized numPriceLevels but appears to typically use perhaps four levels. (p.104)

2.3. EMs want an abstraction of Price

This assumption is connected to the computing resource assumption. If the computation can be done in one place (near the price-setting point) then it's more efficient for the large numbers of EMs and the larger number of devices getting price information.

2.4. Price Responsiveness is "Good Enough" with Simple Levels

This is implicit in the referenced work and others that presume that Simple Levels are all that's required. We'll discuss this in more detail below; suffice it to say that this requires experimental evaluation, not simple assertion.

2.5. The Same Set of Levels Work for All

In effect, one size fits all is the approach. Assuming that price responsiveness is "good enough" together with assuming significant resources for computing levels, the presumption is that the possibly varying needs of the consumers of Simple Levels don't matter.

2.6. Four Levels Suffice

Most implementers of price-responsive residential devices seem to be using three or four levels. [O'Neill] implies that "three or four" relative price levels suffice to achieve consumption reduction and load shifting.

3. THE MODEL

We define the Cut Points (or inflection points) for a normalization algorithm for [Simple] Levels as follows. We use the terminology in [O'Neill], where the nominal price conveys actual price information and the relative price corresponds to Levels.

The input is Price, which varies over time. We map an input Price(t) into Levels, which are numbered from 1 to MaxLevels (a parameter that is constant for a given deployment).

There are therefore (MaxLevels – 1) Cut Points that separate the levels. Figure 2 shows a structure with four Levels and three Cut Points. Recall that four levels are typically presumed to suffice.

We identify Price_i, the Price mapped to Level_i. The relationships are:

$$\text{Price} \leq \text{Price}_1 \quad \text{for } L = 1$$

$$\text{Price}_{i-1} \leq \text{Price} \leq \text{Price}_i \quad \text{for } L = i$$

$$\text{Price}_{\text{MaxLevels}-1} \leq \text{Price} \quad \text{for } L = \text{MaxLevels}$$

We call these Price_i ($i = 1..\text{MaxLevels} - 1$) numbers Cut Points. See Figure 2.

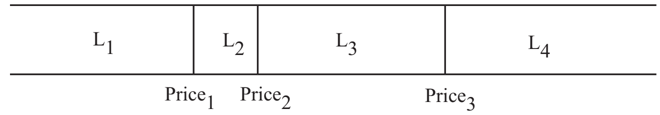

FIGURE 2 CUT POINTS AND [SIMPLE] LEVELS

Of course, Cut Points that work during a time of high prices (say summer in New York) will not work well during a time of low prices (say winter in New York, or almost any time in Tennessee), so the Cut Points and therefore the Levels change over time as well as geographic location. Clearly adaptation of time and general price ranges is very important or there is no differentiation with values either nearly all 1 or 4 in our example.

The nature of the necessary change over time and prevailing prices, and the quality of abstraction that gives rise to energy and cost efficiency, is the main topic of this paper and future related work.

4. THE PROBLEM

We focus on two things:

1. The extent of similarity to actual prices, therefore actual costs
2. A figure of merit that will allow us to compare the quality of adaptive algorithms to determine Cut Points

This will lead to a framework to analyze price-to-level mapping algorithms.

It's clear that to determine cost for a time interval we need to know the usage during the interval and the (average) price during the period. Since this information is not necessarily conveyed in simple models delivering Levels (e.g.. [SEP2] and [O'Neill]), we suggest that both the Nominal and Relative price be conveyed.

4.1. Approximation to Prices

In this section we discuss descriptive statistics from a one-year data set with real prices (Locational Marginal Prices) on 30-minute intervals. [Smith] The prices are in dollars per megaWatt-hour.

Figure 3 is a fragment of a price curve showing the actual prices as rectangles (they are constant within a time interval) and the way we graph the price curves.

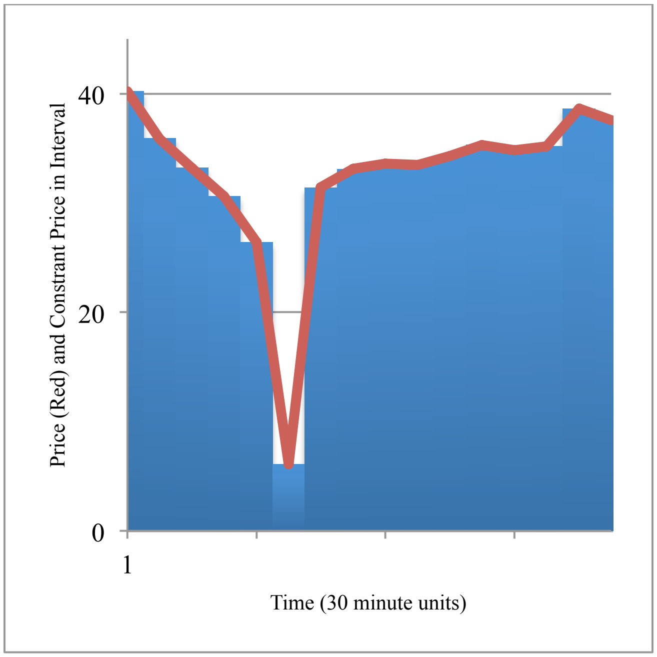

FIGURE 3 SELECTION FROM PRICE TIME SERIES SHOWING CURVE AND CONSTANT PRICES IN BLOCKS

We know from calculus that a set of rectangles can approximate a curve; Levels are a coarse approximation to a price curve. However in typical calculus approaches, the X-axis width of the intervals is the same but the Y-value or height is not constrained (and is usually equal to some value of the function in the interval). Here we observe that the number of Levels, MaxLevels, remains constant, but the Cut Points may vary over time, and that the interval widths may or may not be consistent. See

We focus on actions that may be taken, and therefore on actionable price information. (See e.g. [ServiceOrientedEnergy].) Would actions be different with complete knowledge of Price(t) rather than L(t)? And how complex is it to deal with Price(t), even with perfect future knowledge?[2]

Levels provide a coarse approximation; continuing with four Levels as in Figure 2, the difference between the price in L_1 and L_2 is at least ($Price_3$ – $Price_1$) and is unbounded. We may look for examples of incorrect actions with volatile prices.

Figure 4 shows full day in the same one-year data (Figure 3 shows the first eight hours of the same day). We show price in red with labels on the left, and Levels in purple with labels on the right. In this figure prices normalized to $Level_1$ range from 6 to 58; prices normalized in this sample to $Level_2$ range from 62 to 73, suggesting that the Cut Point $Price_1$ is approximately 60 and that $Price_2$ is greater than 73.

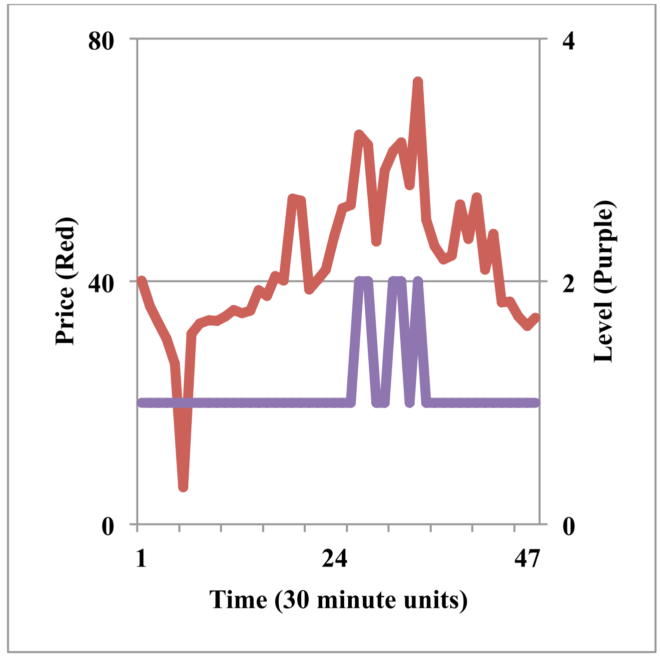

FIGURE 4 PRICE CURVE AND SIMPLE LEVELS—ONE DAY SAMPLE

In fact the graphed sample is not far from ordinary in the one-year data set the mean level is only 1.135, so the levels are nearly always 1. See Table 1.

Level	*Count*	*%*
1	15489	91.1
2	1002	5.9
3	214	1.3
4	288	1.7

TABLE 1 FREQUENCY OF LEVELS ONE THROUGH FOUR IN ONE YEAR OF 30 MINUTE PRICES (N=16993)

Over the entire series the mean price was 50.1 and the price range was from zero to over 540.

Clearly when over 90 per cent of the prices communicated are the lowest level there is little differentiation to be exploited by an energy manager.

4.2. Volatility of Electricity Markets

Volatility has long been of interest in the economics of market design. There is recent work on models of volatility for electricity markets (see [Roozbehani] and [Sapio] for a foundation). We are interested in volatility, in part because the quality of simple level mapping is partly determined by volatility in the underlying price stream.

[Roozbehani] defines and measures volatility as excursions around a moving average. This seems particularly

[2] The latter question will be addressed in a future paper.

appropriate, as the algorithms we discuss all involve moving averages of some sort.

[Hirst] noted that wholesale prices tend to be volatile; price volatility is used to justify price-responsive demand by separating risk mitigation from commodity pricing.

Zareipour analyzes price volatility across wholesale markets in North America. (See [Zareipour] Chapter 5, and [Zareipour2007].)

We assert that higher volatility suggests relatively worse performance for Simple Level mappings.

Typical Time of Use contracts or tariffs, or slightly variable as with Block & Tier contracts or tariffs, may appear volatile but the Cut Points should be those of the contract.

The sample we discuss used 30 minute LMP wholesale clearing prices without forward information; volatility in that sample will be examined in a future paper.

4.3. Consumer / Device Use Cases

We have shown elsewhere [EI-SEP] that Cut Points will vary from customer to customer and from area to area. Moreover, simple levels convey only a rough approximation of costs, which is critical information in making energy choices.

The Cut Points selected might be selected for each consumer or device (or perhaps class of same), and that the optimal set of Cut Points will vary over particular device behavior.

Further work is needed in this area, as the quality of response and energy efficiency also depends on device behaviors. To address this, we define a simple model of device behavior below.

4.4. Asymmetry

The prevailing price over some period establishes the expected basis for deciding whether electricity is inexpensive, expensive, or "normal." While a consistent change in price (say one cent per kWh) is the same cost differential whether the prevailing price is high or low, the literature suggests that there is greater volatility at higher prices.

A 50 per cent difference in price will have greater benefit or cost at higher prices; this asymmetry may be important in designing mapping algorithms.

Mapping algorithms, to have beneficial economic effect, must respond to changes in the prevailing price—all high or all low Levels may masquerade significant costs.

We suggest that algorithms reflect both longer-term and shorter-term price levels and volatility to address the masquerading issue.

4.5. Quality Metrics

While we work under the assumption that relative price determination is at higher architectural levels (A or B in Figure 1), the figure of merit for a particular dynamic mapping needs to compare results from use of Levels compared to an "equally intelligent" algorithm using actual prices.

We propose that difference in cost of electricity for a given mapping algorithm compared to when optimal choices are made with full knowledge of prices.

Note further that devices programmed to take four levels as input cannot effectively use more levels or full price variation. Accordingly we consider the choice of when to perform specific actions.

5. DISCUSSION

Selecting Simple Levels appropriate to a given time for a given device seems relatively simple over short time periods. The problem becomes far more complex with multiple devices or classes of devices, and over time. We explore some of the issues in the following sections.

5.1. Price Streams

We call time sequences of price information *price streams*. The metaphor is a set of time intervals, flowing from the future, through the present, and into the past. A price is attached to each interval; forward or future prices are projections, and may or may not be able to have transactions executed at those prices.

One example from PNNL in Section 6.1 is specified to possibly use forward prices; another project being undertaken by members of the SGIP Business and Policy Domain Expert Working Group, actually uses forward prices [BPDEWG], though they use projections and not transactable prices, i.e., you cannot necessarily purchase at the forward price quoted.[3]

5.2. Model Behavior

For an accurate reflection of benefit from price-sensitive devices one approach is to have a model of device[4] behavior. That behavior is quite complex on its own, and efficient behavior is part of the value provided by device and management systems in a competitive market.

---

[3] You cannot transact at the prices used in the Vineyard or Olympic Peninsula projects either, as these are based on wholesale prices to provide trends on retail prices.

[4] We use the term *device*; the term *consumer* is also used. These refer to an actor that is trying to make economical choices for timing and amount of energy. A typical goal is minimum cost for a certain amount of work done.

For example, a device may have multiple time segments where it uses energy, multiple opportunities to pause within its execution sequence, and differing power needs at different times.

Rather than attempt to address those complexities, we define a simple device and show how it can behave, that is what actions might be inferred from a price stream. This paper does not address the complexities of device behavior, but complex behavior can be composed from these simple blocks.

For simplicity we use the dataset of Figure 4[5] and further restrict to the first interval with Level 1. See Figure 5 below.

Out model device operates for one unit of time, and consumes one unit of energy during that unit. In our example the time unit is 30 minutes; the energy consumption and price is flat across each time interval.

To avoid scaling in the discussion we will use the prices as described, although few devices consume 1 MWh of energy in 30 minutes.

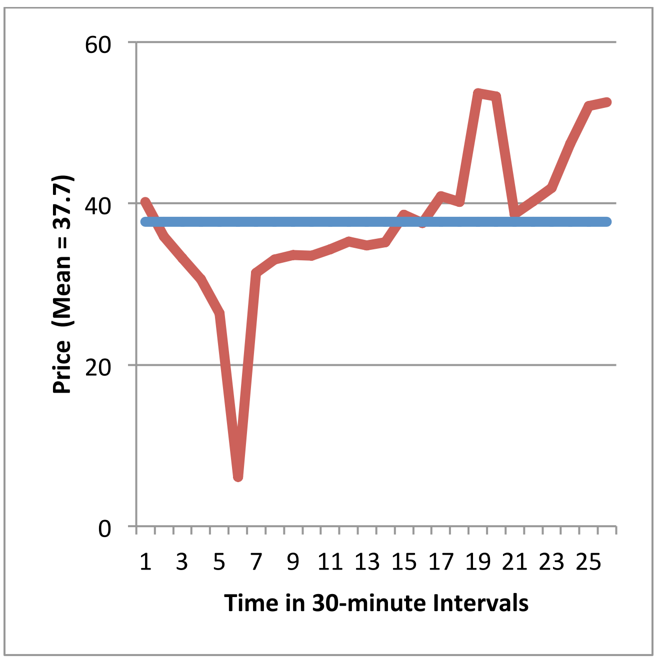

FIGURE 5 FIRST LEVEL 1 SEGMENT OF FIGURE 4 (MEAN IN BLUE)

As we see in Figure 5 the mean price is 37.7, the minimum 6.1, and maximum 53.7, so the maximum price error (the maximum benefit or loss with a wrong choice) is

$$\text{MaxPriceError} = | P_{MAX} – P_{MIN} |$$

[5] Future work will address extensive samples over long periods.

Similarly, the expected price error is

$$\text{ExpectedPriceError} = \text{Maximum of } \{ | P_{MAX} – P_{MEAN} |, | P_{MEAN} – P_{MIN} | \}$$

The formula only describes the maximum possible error based on excursion from the mean; while overly simplistic, this illustrates the concept of price error.

If our device starts at some random point in the graph, the energy price at that time can be better or worse by MaxPriceError, and expected to differ by ExpectedPriceError.

With such a broad range in Level 1, a device manager may believe that the price is the same, so behavior can be the same. The determination of the mean cannot be done *a priori* as the future is not know; it can only be estimated from the history and projections of the future unless transactable prices are supplied. Summing over the range

This can expand to include probable gain or loss as well as maximum error; the key point is that the device manager is told that the price as conveyed by Level is the same, so the manager may conclude that any time is as good as any other with respect to cost.

6. EXAMPLES

In this section we describe two example algorithms for price normalization. We close with observations on the quality required for price responsive devices and

6.1. PNNL Price Normalization

Pacific Northwest National Laboratory (PNNL) undertook a pilot project in the Olympic Peninsula region of the Pacific Northwest to study the use of transactive control for demand response in what is called the Olympic Peninsula Project [OlympicPP]. We describe the price normalization scheme that was used. A variant of this scheme is currently being implemented in the Battelle AEP smart grid demonstration project in Ohio.

Given a time window of size N, let p_i, i = 1, 2 , …, N denote nominal prices over that window. Let μ denote the mean, and let σ denote the standard deviation of the pi . Then normalize each p_i to p_{ni} as follows

$$p_{ni} = (pi - \mu) / \sigma$$

While the demonstration project does not explicitly talk about 'levels', members of the PNNL project suggested that the normalized prices, not the nominal prices be utilized to map to levels.

The window size N is arbitrary, and may include past as well as projected or actual future prices. Furthermore, the mean μ can be computed as a weighted average, i.e., giving more weight to most recent prices when compared with those at the far end of the window length.

The Olympic Peninsula Project used a time window of 24 hours for market price (see [OlympicPP] page 2.6), which seems rather short but nonetheless provided benefits.

While seemingly simple, this normalization scheme has some profound features in it, suggesting benefits to both consumers and utilities

Consumer benefits include

- There is a consistent notion of levels irrespective of the actual nominal prices when dealing with normalized prices, simplifying device and individual response
- It offers opportunities to save money even when prices are modest over a given window length, irrespective of the actual price volatility

Utility and system operator benefits include

- The window length N, and whether to consider past prices or future prices or a combination of both, can be tuned to elicit a desired consumer response, depending on the utility goals: reduce peak load, reduce fuel cost, decrease load in the event of forecasted storm to increase reliability etc.

Note that the economic effect of this apparent application of mechanism theory [MechanismTheory] is not addressed in [OlympicPP]. Prices need to be grounded in real markets, not by fiat—only real prices from markets can effectively balance supply and demand.

6.2. Vineyard Project Price Normalization

General Electric (GE), in partnership with Grid Solutions and others have undertaken a pilot project on Martha's Vineyard in Southern Massachusetts to examine the benefits of real-time pricing. [VineyardDOE] [VineyardGE] The data set we examined was produced by some variation of the method summarized here. [VineyardData]. The description and figure are from [GridSolutions].

In the Vineyard Power Management System (VPMS), the price is broadcast from ISO-NE, which is the Regional Transmission Organization serving New England. and which regulates the distribution of power throughout New England, as managing the regional wholesale electricity marketplace. The broadcast is the market-determined Real-Time Locational Marginal Price (LMP, or simply "price") for the relevant region, measured in dollars per megawatt hour, transmitted every five minutes.

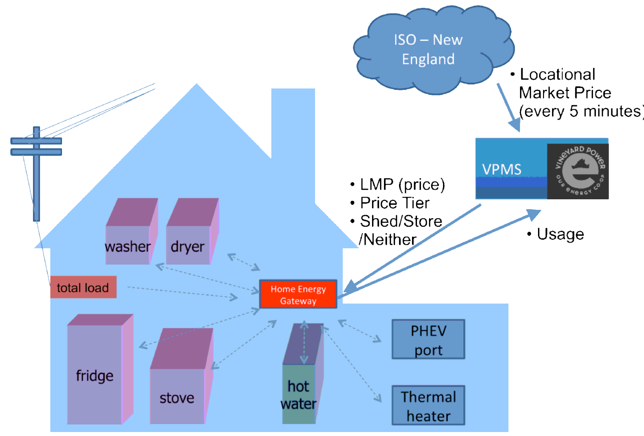

FIGURE 6 VINEYARD PROJECT OVERVIEW [GRIDSOLUTIONS]

The VPMS then computes a Simple Level[6] based on whether the price it just received is historically high or low compared to recent prices and which way the price is trending (higher, lower, or neutral). The price and the price tier are then both sent to the Home Energy Managers in members' homes, displaying the price as dollars per kilowatt-hour. The price levels are recalculated hourly by the VPMS based on the price stream for the last 30 days.

The Home Energy Manager transmits the price tier to the connected appliances and the appliances react to the tier level to reduce energy demand whenever the price tier is high.

The Vineyard Project uses an algorithm that considers prices over the past 30 days, which seems rather long in contrast to the Olympic Peninsula Project, but under further analysis seems to be more effective on the trend of prices over weeks rather than hours.

The Vineyard project thus seems to optimize the determination of overall price level rather than seeking to take economic advantage of shorter-term variation as in the Olympic Peninsula Project.

6.3. Analysis

Both of the projects we've reviewed including moving averages though with different approaches; the Olympic Peninsula set of parameters allows for great flexibility.

There is a clear advantage to knowledge of future prices, even if those prices are not transactable. Likewise, there is a requirement for knowing the current price (if only for display).

This project was inspired by appliance designers comments that the levels provided seemed to always be 1 or 4; the extensive sample from the Vineyard project shows that

[6] The Project calls it a *Price Level*.

behavior, though it would be more accurate to say the level is nearly always 1.

In the continuing absence of retail markets, it seems likely that wholesale market clearing prices will continue to be used as a proxy measurement of scarcity and of how retail prices would vary.

The missing factor seems to be that the algorithms used reflect the general trend of prices well (over weeks or months), but do a less effective job of reflecting shorter-term variation.

Longer-term smoothing (to determine whether a price is globally higher or lower than typical) would seem to be effective but for the well-known volatility of wholesale prices. Similarly, short-term smoothing in effect tries to determine whether a price is locally higher or lower than typical).

Supplying nominal prices and both short-term and long-term price trend information would seem to benefit the economic actions of simple devices, with or without future knowledge.

7. SUMMARY AND CONCLUSIONS

Our goal is to create more effective ways to abstract actionable information from volatile prices.

We have defined a model to describe the quality of a method for mapping prices to Simple Levels, and discussed some of the challenges.

Some assumptions (implicit or explicit) made in designing residential systems seem to have little foundation in fact. Definition of figure(s) of merit has promise in creating a means for evaluating the efficacy of level mapping algorithms.

Future work will focus on volatility measures, scale and scope of combining general and recent prices, and further refinement of algorithms and their parameters using our analytic approach, including our framework for analyzing and discussing the quality of response and the quality of mapping of complex time series of prices to simple levels.

References

[BnPDEWG] Smart Grid Interoperability Panel Business and Policy Domain Expert Working Group, http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/BnP.

[CIM] *IEC 61968: Common Information Model (CIM) and Messaging Interfaces for Distribution Management*, and *61970: CIM for Wires Models.* http://iec.ch/

[CultureOfArchitecture] Cox, William. *Mind the Opportunities—Towards a Smart Grid Culture of Architecture,* Grid-Interop 2008 Presentation. http://coxsoftwarearchitects.com/Resources/Grid-Interop2008/Cox%20Opportunities%20Grid-Interop%202008.pdf

[EMIX] OASIS Committee Specification Draft 04, *Energy Market Information Exchange 1.0*, September 2010. http://docs.oasis-open.org/emix/emix/v1.0/csd04/emix-v1.0-csd04.html approved November 2011 as Committee Specification 1.0.

[EnergyInteroperation] OASIS Committee Specification Draft 03, *Energy Interoperation 1.0*, November 2010. Contained in ZIP archive at http://www.oasis-open.org/committees/document.php?document_id=44364&wg_abbrev=energyinterop Direct link to PDF specification http://www.oasis-open.org/committees/document.php?document_id=44407&wg_abbrev=energyinterop

[Framework] NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0. http://nist.gov/smartgrid/upload/FinalSGDoc2010019-corr010411-2.pdf

[GridSolutions] Extract from white paper, *Consumer Description of Price Tier Calculation v06*, personal communication.

[GWAC] GridWise Architecture Council, *GridWise® Interoperability Context-Setting Framework (v1.1)*, March 2008. http://www.gridwiseac.org/pdfs/interopframework_v1_1.pdf

[Hirst] Hirst, Eric, *The Financial and Physical Insurance Benefits of Price-Responsive Demand*, The Electricity Journal 15(4), 66-73, May, 2002.

[MechanismTheory] Nobel Prize in Economics, 2007. See http://en.wikipedia.org/wiki/Mechanism_design

[OlympicPP] D. J. Hammerstrom, et al, "Pacific Northwest GridWise™ Testbed Demonstration Projects, Part I. Olympic Peninsula Project," PNNL-17167, October 2007, http://www.pnl.gov/main/publications/external/technical_reports/PNNL-17167.pdf

[PAP03] *NIST/SGIP Priority Action Plan 03: Develop Common Specification for Price and Product Definition.* http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/PAP03PriceProduct

[PAP04] *NIST/SGIP Priority Action Plan 04: Develop Common Schedule Mechanism for Energy Transactions*. http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/PAP04Schedules

[PAP09] *NIST/SGIP Priority Action Plan 09: Standard DR and DER Signals*. http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/PAP09DRDER

[Roozbehani] Mardavij Roozbehani et al, *Volatility of Power Grids under Real-Time Pricing*, arXiv Pre-Print, arXiv:1106.1401, 2011. Linked at http://arxiv.org/abs/1106.1401. Linked with discussion from http://knowledgeproblem.com/2011/08/08/worried-about-too-much-demand-elasticity-in-electric-power-markets/

[SEP-MRD] ZigBee + HomePlug Smart Energy Profile 2 Marketing Requirements Document, 1.0, March 11, 2009.

[SEP-AS] ZigBee + HomePlug Smart Energy Profile 2, Application Specification, Version 0.7 Third Release, 12 July 2011.

[ServiceOrientedEnergy] William Cox and Toby Considine, *Price Communication, Product Definition, and Service-Oriented Energy*, Grid-Interop 2009.

[VineyardData] Charles Smith, General Electric, private communication.

[O'Neill] O'Neill, Ivan, *Prices to Devices: Price Responsive Devices and the Smart Grid*, Southern California Edison, April, 2011, version cited is at http://asset.sce.com/Documents/Environment%20-%20Smart%20Grid/110414_PriceSignalsandPriceResponsiveDevices.pdf

[SEP2] ZigBee Alliance, HomePlug Powerline Alliance, *Smart Energy Profile 0.7*, Public Review Version 3, July 2011.

[VineyardDOE] *Vineyard/DOE Project Status Meeting*, July 13, 2011. http://www.smartgrid.gov/project/vineyard_energy_project_smart_grid_project

[VineyardGE] http://www.geappliances.com/home-energy-manager/marthas-vineyard-pilot/

[xcal] C. Daboo, M. Douglass, S. Lees, *xCal: The XML Format for iCalendar*, IETF RFC 6321, August 2011. http://tools.ietf.org/html/rfc6321

[Zareipour2006] Hadidreza Zareipour, *Price Forecasting and Optimal Operation of Wholesale Customers in a Competitive Electricity Market*, PhD Thesis, University of Waterloo, 2006.

[Zareipour2007] Hadidreza Zareipour et al, *Electricity Market Price Volatility: The case of Ontario*, Energy Policy (2007), doi:10.1016/ j.enpol.2007.04.006

Biography

Chellury Ram Sastry

Dr. Chellury Ram Sastry is currently a senior program manager and smart grid director with the Energy, Environment, and Material Sciences division at Battelle Memorial Institute, Columbus, OH (BCO). Prior to joining BCO, he was a senior engineer with the electricity infrastructure group in the energy and environment directorate at Pacific Northwest National Laboratory (PNNL), Richland, WA; and prior to that he was a project manager and senior research scientist with Siemens Corporate Research, Princeton, NJ.

His current focus includes providing R&D, business development, and technical marketing leadership to enhance BCO's grid system's portfolio in transmission/distribution modeling & simulation, smart grid data analytics, and advanced demand management to provide value-add services to residential and small commercial building customers. And particular areas of emphasis in this regard are the use of load for power system ancillary services including frequency regulation, and use of home energy management (HEM) to facilitate the penetration of distributed generation including PV. In the area of transmission modeling & simulation, he is leading BCO's efforts in the development of novel grid management tools based on load-flow approaches that yield accurate and reliable estimates of electrical state to thereby facilitate enhanced decision-making even when the power grid is operating under stressed conditions.

William Cox

William Cox is a leader in commercial and open source software definition, specification, design, and development.

He is active in the NIST Smart Grid Interoperability Panel and related activities. He contributed to the NIST conceptual model, architectural guidelines, and the NIST Framework 1.0.

Bill is co-chair of the OASIS Energy Interoperation and Energy Market Information Exchange Technical Committees, past Chair of the OASIS Technical Advisory Board, a member of the Smart Grid Architecture Committee, and of the WS-Calendar Technical Committee.

Bill has developed enterprise product architectures for Bell Labs, Unix System Labs, Novell, and BEA, and has done related standards work in OASIS, ebXML, the Java Community Process, Object Management Group, and the IEEE, typically working the boundaries between technology and business requirements.

He earned a Ph.D. and M.S. in Computer Sciences from the University of Wisconsin-Madison.

Toby Considine

Toby Considine is a recognized thought leader in applying IT to energy, physical security, and emergency response. He is a frequent conference speaker and provides advice to companies and consortia on new business models and integration strategies.

Toby has been integrating building systems and business processes for longer than he cares to confess. He has supported and managed interfaces to and between buildings, cogeneration plants, substations, chilled water plants, and steam and electrical distribution. This work led to Toby's focus on standards-based enterprise interaction with the engineered systems in buildings, and to his work in the Organization for the Advancement of Structured Information Standards (OASIS).

Toby is chair of the OASIS oBIX Technical Committee, a web services standard for interface between building systems and e-business, and of the OASIS WS-Calendar Technical Committee. He is editor of the OASIS Energy Interoperation and Energy Market Information Exchange (EMIX) Technical Committees and a former co-Chair of the OASIS Technical Advisory Board.

Toby has been leading national smart grid activities since delivering the plenary report on business and policy at the DOE GridWise Constitutional Convention in 2005. He is a member of the SGIP Smart Grid Architecture Committee, and is active in several of the NIST Smart Grid Domain Expert Workgroups.

Before coming to UNC, Mr. Considine developed enterprise systems for technology companies, apparel companies, manufacturing plants, architectural firms, and media companies old and new. Before that, Toby worked in pharmaceutical research following undergraduate work in developmental neuropharmacology at UNC.