New Applications of Electronic Commerce Technology To Energy, Buildings, and Capital Management

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Abstract

We discuss application of electronic commerce technologies to building and energy management. Our examples focus on home systems, but the techniques apply virtually unchanged to commercial and industrial environments.

Traditional power grid / home interactions involve low-level control interactions and direct communication with the target devices. Widely used eCommerce interactions can provide control that is at least as fine-grained while enabling the homeowner to maintain primary control of his own domicile. Ecommerce interactions are technology agnostic and general purpose; the same signal can interact with multiple site-based systems, resulting in greater scalability and interoperability.

Service-based systems provide natural end-points for economic signals. Agents can encapsulate domain knowledge of each system while providing a well-defined common service interface for interaction. Agents can also be aware of other systems in the house, offering additional opportunities for optimization. Most importantly, agents can be aware of the owner, the owner’s schedule, and the owner’s wishes. Systems that preserve and enhance homeowner autonomy will see greater long-term acceptance

Economic signals place responsibility for delivered performance on the local system, they align performance with responsibility. Because they enhance interoperability, they increase competition and expand innovation. Because economic signals make costs and opportunities transparent, they encourage site-based investment in new systems.

Our approach is fully consistent with the GridWise Interoperability Principles [25] and leverages broadly used business definition, management, and monitoring technologies, while allowing the same set of services to be used in many environments.

We can accelerate the movement to dynamic pricing and effective use of energy by not reinventing functionally similar standards.

1. INTRODUCTION

We apply electronic commerce (eCommerce) technologies to energy management, using economic interactions as a means to better shaping of both demand and for tailoring consumer-side activities to maximize economic benefit from energy suppliers to consumers.

Markets are the best means for effective management of resources, exploiting the elasticity of demand for energy by passing through pricing information, which in turn is correlated to cost information. The interactions defined here allow us to reduce infrastructure use, and hence reducing or delaying required capital inputs for improving transport and distribution infrastructure.

Markets have developed for demand curtailment commitments [1] and demand response [2], today primarily in the industrial and commercial energy markets. Limiting and shaping demand by pricing has demonstrated value both for infrastructure use and distribution. Monetization of demand curtailment suggests that the limitation and shaping of demand we describe here is valuable, and may be sufficient to purchase controller and information technology enhancements while saving energy costs for the consumer [3].

When we say *consumer* we mean the user of the energy purchased and then delivered through distribution systems; our examples and solutions focus on home use, but can easily be extended to commercial and industrial use.

Building and industrial controls are broadly used, so these solutions may be more easily implemented in the non-residential space.

Finally, by creating a rationale for more intelligent and responsive user agents (effectively at the consumer side), the effects of a reduction on consumption can also be monetized, increasing value of intelligence in building control.

2. PLUG-IN HYBRID CHARGING USE CASE

2.1. Description

We start with a simple use case. Consider a home with two high-wattage appliances, an air conditioner and a battery or plug-in hybrid car.

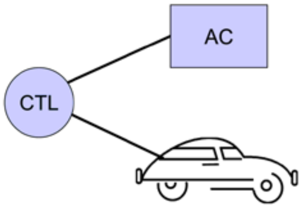

Figure 1

The controller in Figure 1 should be viewed as a service provider, not a particular piece of hardware. The functions may be located in an enhanced electric meter, at a distribution center, in the house, in the car charging station, at the air conditioner or external to the physical premises on the Internet (requiring some hardware assist close to the appliance).

The service provided is to manage energy purchase and consumption. In this simple example this devolves to distribution. Inputs will include pricing information in later elaborations; outputs include control signals to the car charging station and the air conditioner.

Note that pricing information will require (except in the simplest case) synchronized time as an input, to react to time-related changes in pricing.

2.2. Energy Management Issues

The worst-case scenario for this use case is as follows:

On a hot, peak energy use day, the consumer drives home at 5:30pm, plugs in the car, and turns on the air conditioning.

In single-price environments, the consumer will incur no additional energy cost, but there are substantial hidden costs:

1) The consumer risks the loss of use of the home environment if the energy demand leads to brown outs, black outs, or trips the main circuit breaker.
2) The energy provider risks higher peak generation costs.
3) The distribution utility risks peak loads that can interrupt or curtail use via brown outs or blackouts, which in turn affect other customers.

For similar usage issues, e.g., interruptible electric hot water heating rates, system control can limit overloading the grid but will affect the customer's use of hot water.

This sledgehammer-like approach is similar to cutoff functions in Automated Metering Infrastructures—protect the grid, but reduce customer benefits to zero. Special care must be taken to sequence turning on customers' power; otherwise spikes and surges in demand can take the system back down.

3. IMPROVEMENTS AND SOLUTIONS

3.1. Step One—More Intelligence

3.1.1. Changes to the Model

Consider the addition of limited intelligence based on time-of-day usage patterns (and perhaps a delay function for car charging). Figure 2 shows an Agent into which we separate (metaphorically) the intelligence.

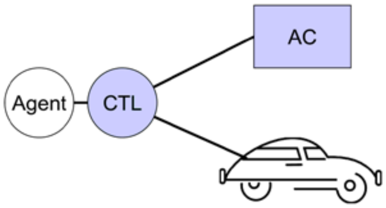

Figure 2

For example, pre-cooling before occupancy or charging the car at night will move some demand from peak times with a higher risk of interruption to lower use times with a lower risk of interruption.

In today's flat-price markets, there is no customer benefit beyond risk mitigation, but costs to energy providers are reduced through limiting operating and capital costs for peak generating capacity. In addition, avoiding failures in the distribution network reduces costs of distribution and generation.

3.1.2. Discussion

The monetization of demand curtailment markets may provide opportunity for aggregators of home consumers in addition to demand curtailment markets for present business and industrial consumers.

In existing pilots [3] whole house level demand curtailment has been at no explicit charge to the customer, who also typically saves a modest amount on electrical rates, reflecting in turn the value to energy providers and distributors.

3.2. Step Two—Pricing Information

We now allow price information to be obtained by the controller.

3.2.1. Changes to the Model

In Figure 3 we have added agents to the air conditioner and the car, with lines connecting all controllers to emphasize that they communicate (indeed, they may be deployed to the same hardware). The controller now has access to query-response interaction (or a pushed download) for obtaining present and future pricing information.

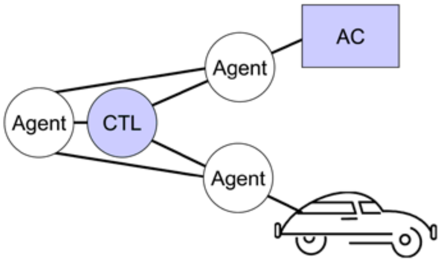

Figure 3

Obviously, full two-way interactions allow for better information; typical low-bandwidth connections through AMI or power lines to the customer make broadcast of all prices problematic.

3.2.2. Discussion

Because this model uses prices rather than control, all decision making moves to the consumer. When the consumer faces unique events (tighter budget, weekend guests) the consumer is able to modulate the response. This model is likely to provide more long term satisfaction with load curtailment on a house by house basis, and thus more potential curtailment to the grid overall.

3.2.3. Which Kind of Pricing

There are a number of variations of static and dynamic pricing; we follow the terminology of [4] and [5].

Static Pricing

1) Flat-rate pricing (FR)
2) Summer/winter pricing, or Seasonal Rates (SR)
3) Time-of-use pricing (TOU)
4) Critical Peak Pricing (CPP)

The common feature is that pricing varies in some manner that is known in advance. With SR and TOD pricing, the information is known far in advance, and could be programmed into the controller. With CPP, expected peak days are still known in advance, but with less notice, making manual programming more difficult.

Dynamic Pricing

1) Real-time Pricing (RTP)
2) Price-ahead (P-A)

In RTP the controller obtains pricing information by means of a query to the supplier or distribution, a data stream pushed to the agents, or other means, possibly fairly close to the time of use. Price-Ahead (our term) describes systems where a future price vector (say for the next eight hours) is available, allowing a look ahead at future rates.

From our perspective, once the pricing information is in the agent, the algorithms are similar—determine whether an electrical use can be deferred or pulled up to a lower-cost period, and do so. The difference is overall responsiveness to both expected and unexpected events (e.g., peak usage and failures).

Future Pricing

We anticipate forward markets for energy; such markets have broad benefits [6]. Forward markets already exist in various forms for commercial and industrial customers. The customer's agents can make a bid or solicit quotations in a futures market. This blends seamlessly into the P-A scenario where the forward pricing limit is determined by the market rather than directly by the energy supplier. The Olympic Peninsula Project [4] did not use future pricing.

3.2.4. Analysis

From our perspective, the various pricing models differ little in the agent algorithms; they differ principally in the effects (latency and gross effect) on consumption and the extent of load shaping they support.

Finer-grained and more dynamic pricing affords benefits in system and grid resilience to unexpected changes in load, demand, or peak capacities (e.g. a generator, or a transmission line failing) as well as increased flexibility in demand shaping (see e.g. [7]). In particular, there's no need to wait for tariff changes to affect pricing.

3.3. Step Three—More Information

We now add additional information inputs to the agents, such as actual and predicted information, for example

1) Weather

2) Occupancy
3) Usage

This will permit the agents to make energy efficient decisions with lessened effect on the customer's use of the premises and the car.

3.3.1. Changes to the Model

In Figure 4 we have added simple Web services access to the agents for obtaining additional information. We show these (one way and two way) information flows going to the leftmost agent, as we've presumed communication between them. Recall that the agents may be deployed within a single computer system, making communication easier, or distributed across a building or neighborhood.

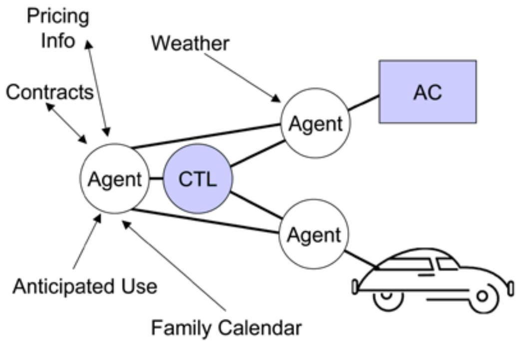

Figure 4

3.3.2. Discussion

In heated buildings, external temperature sensors—outdoor reset controls—have been used for decades to reduce heating costs and improve comfort [8].

In commercial buildings, occupancy information is typically available with a combination of time-of-day programs and active occupancy sensors, which may connect to building management system or (e.g.) to individual light switches. Many commercial buildings include some capacity for estimating need for a room and appropriately pre-cooling or pre-heating before use.

We extend the meaning of *anticipated usage* by including access to some form of calendar or other anticipated use information. For example, if the customer is on an extended trip, the need for cooling is reduced. If the customer has family visiting, or an event to go to tonight, it may be more important to charge the car now rather than wait until the early morning.

Incidentally, the mechanism for interruptible electric hot water does not adapt to changing short-term usage: your hot water supply is just as interruptible when you have a house full of guests as when the house is empty.

3.3.3. Analysis

This model may further reduce energy consumption, but the principal goal is to add flexibility to adapt to the occupants' needs. By allowing automatic overrides, consumption can be adjusted to adapt to the occupants' needs. The goal is not additional energy savings, but to use pricing (more toward the RTP end of the spectrum) to limit costs while ensuring a minimum or desired level of comfort and utility.

4. REALISM OF THE MODELS

Everything described in this paper can be implemented today. The engineering of solutions needs to consider varying capital, deployment, and maintenance costs.

The functional needs of the controller include the ability to turn on and turn off the air conditional and car charging station; work such as the PNNL Appliance Controller demonstration project [9] as well as home automation and building automation technologies that perform those function with control signals from a computer.

The agent could be built from a single-board computer, or run on a household computer, or be part of a home automation system, or be an integration of distributed functions in device controllers. The agents could be implemented by the distribution utility or by a home controller manufacturer. Aggregators of demand curtailment may be a source of funding.

Information in electronic calendars is readily available, although not always in an immediately useful form. The iCalendar specification [10] is a case in point, supported by many home and commercial computing environments.

Communications deployment is an issue, not because it's difficult, but system designs and costs vary considerably. Ideally, one could use an existing Internet connection, and some AMIs permit low-bandwidth data transmission. Reasonable disconnected operation is critical [4][25].

Monitoring and measuring sensors are readily available.

We address security requirements and existing solutions in the next section.

5. ECOMMERCE TECHNOLOGIES

The eCommerce standards and techniques we described have mostly been broadly used for years. We can accelerate the movement to dynamic pricing and improved use by not reinventing functionally similar standards.

5.1. Service-Oriented Architecture

We have taken a Service-Oriented Architecture (SOA) [11] approach, although we didn't mention it in advance. SOA is broadly used in eCommerce and enterprise software, and has benefits for modeling and implementing software solutions. See, for example, [12] for application of Semantic SOA to building services and emergency management.

5.2. Contracts and Purchases

The most obvious use of eCommerce technologies is the interaction to buy and sell energy. Agency and negotiation, though primitive, are well suited to these kinds of pricing and purchasing. Our examples are from broadly deployed eCommerce Web services defined by OASIS [13].

Can you trust the pricing on which you're relying? XML Digital Signature (XML DSIG) [14] can help, but it is likely better to use a reliable messaging standard that used digital signatures to both assure delivery and validate the source. EbXML Message Service (ebXML MS) [15] is such a technology, broadly used and interoperable. Other techniques are mentioned below.

5.3. Beyond Pricing

Web services [16] or Representational State Transfer (REST) services [17] can be used to transmit information; in the eCommerce world Web services are preferred due to the response/acknowledgement.

Reliable messaging techniques, e.g. WS-ReliableMessaging [18], can be used to ensure delivery of messages.

Event delivery and management services, e.g., Web Services Notification [19], provides publish/subscribe events.

5.4. Distributed Security

The experience in distributed fine-grained security for eCommerce applies directly to our example situations. See, for example [20]. You want to ensure that only the right people, in the right roles, access your home, power grid, and other infrastructure.

Security standards such as WS-SecureConversation [21], when composed with WS-ReliableMessaging [18], satisfy critical requirements of notification of demand events or pricing signals with reliable delivery.

WS-Security [22] is a framework for secure interaction, and has been in broad use in the eCommerce space for several years. OASIS' Security Access Markup Language (SAML) [23] allows the creation of secure tokens that can be passed and validated to allow specific access, and eXtensible Access Control Markup Language (XACML) is used to define fine-grained access controls [24].

6. BENEFITS AND INTEROPERABILITY

In this section we briefly discuss how our approach relates to the GridWise Interoperability Principles [25], and the benefits of using the eCommerce approach.

6.1. GridWise Interoperability Principles

We use the statement of principles [25] rather than the more detailed GridWise Interoperability Framework [26].

Our proposals address the Business Principles and Information Technology Principles, permit satisfaction of the Usability Principles, and do not address the Regulatory and Governance Principles.

We satisfy B01 in that we address information exchange and boundary interfaces, consistent with SOA. Security and privacy concerns have been addressed with the portfolio of security standards we have listed.

Change is a fact of life in enterprise and eCommerce systems, which have long experience addressing B02.

The eCommerce techniques are used for many marketplace transactions, and are applicable to those envisioned in B03.

We do not directly address B04, as we have not examined costs/benefits and affects to the parties; this is part of an architectural and deployment plan.

Verification and auditability are addressed in eCommerce systems; this is an architectural and deployment requirement (B05).

Interoperability through service definitions addresses many of the integration issues in the principles; SOA is a best practice in enterprise software definition and deployment. (I01, I02). SOA addresses multi-company applications (I03), and typically uses Business Process, Business Data, and other modeling methods (I04).

Enterprise and eCommerce systems have substantial privacy and security requirements, many enforced by law, and have successfully evolved over time. (I07).

By definition, an eCommerce approach supports I08, and commercial implementations (often composed of open source components) have an excellent record of meeting performance, reliability, and scalability requirements (I09).

Finally, deployed enterprise and eCommerce systems have successfully dealt with multiple versions of specifications and technologies; care must be taken in both standards evolution and implementation to ensure consistent success.

6.2. Benefits of Using eCommerce Technology

By moving the definition of interfaces to the service level the eCommerce approach limits details of interaction that make brittle interfaces; the details of (say) a BACnet or LONmark interface when abstracted to a higher service level are not crucial to the service interactions. Of course, those interfaces and detailed monitoring are critical to properly managing building systems, but that level of detail does not need to be reflected in service definitions [12]. This gives flexibility to service definitions and greater ability to reuse and repurpose.

When engaged in economic interactions, only the price and characteristics of the service supplied are relevant—by ignoring other details, the interfaces are simplified and made more robust.

Decades of experience in enterprise systems (e.g. multi-tier database systems for managing business information) have shown great scalability as businesses have grown.

In addition, by adapting and reusing eCommerce interactions and security, we can accelerate the movement to dynamic pricing and effective use of energy by not reinventing functionally similar standards.

7. CONCLUSIONS

We have limited our examples to homes with two high-wattage appliances; this is clearly not realistic, but the behavior of the largest consumption appliances dominates those of lower demand appliances. Finer grained control has been explored (e.g. by [9]) but our simplification exposes the major effects.

The techniques used are essentially the same when applied to all consumers of RTP in residential, commercial, and industrial. Some extensions to the basic services may be useful for commercial and industrial consumers; see Future Work.

Future homes will have more large energy-using systems than today. Future homes will have a mix of energy technologies, including site-based generation and site-based storage. This transition will be mediated by a clear recognition of the costs and benefits; eCommerce interactions will make these benefits quantifiable. eCommerce style interactions inside the house may prove to be the most efficient means to integrate diverse systems within the house as they reduce the detail that needs to be understood by each party to the transaction.

8. FUTURE WORK

We have not addressed in detail the controller services or other characteristics. This is in keeping with our architectural analysis of information flows. Clearly a concrete input is needed for implementation; there is much work in this area, and many products and pilots.

We have not addressed the necessary design of markets to support the pricing models we have discussed, in particular futures and more competitive "spot" markets for energy.

The next steps in this work are to define the services more fully, and validate our notion that the same service interfaces can (with perhaps extensions) apply from residential to commercial to industrial situations.

Demand elasticity information gathered from [4] and [5] will be a useful input into models to estimate energy consumption changes and peak demand changes to better determine cost-effective choices.

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Biography

William Cox is a leader in commercial and open source software definition, specification, design, and development. Bill is an elected member and Co-Chair of the OASIS Technical Advisory Board, where he advises the Board and membership of the leading XML and Web services standards organization in the world.

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, often working the boundaries between technology and business requirements. He was lead architect for Unix System V Release 4 and of follow-on highly scalable and secure Unix systems, service-oriented architectures and directory APIs for Novell, Web services and XML messaging and transaction systems, and other enterprise software.

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

Toby Considine has been integrating building systems and business processes for longer than he cares to confess. Since the Y2K push ended with the post-midnight phone call from the University of North Carolina Cogeneration Plant, Toby’s focus shifted to standards-based enterprise interaction with the engineered systems in buildings.

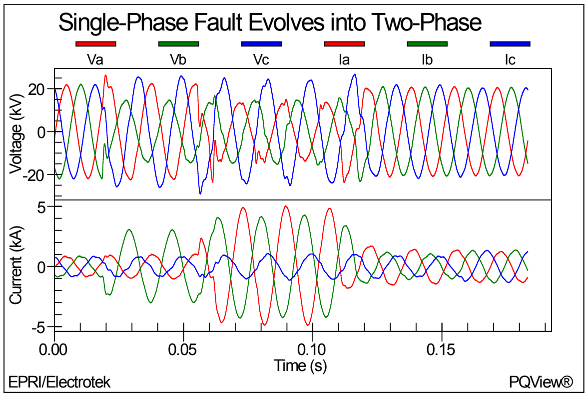
Toby has been chair of the OASIS oBIX Technical Committee. oBIX is an unencumbered web service designed to interface between building systems and e-business. In the summer of 2008, he became co-chair of the OASIS Technical Advisory Board. He is active on the NIST Smart Grid Domain Experts Group and works to promote applying information technology to with groups such as buildingSmart and FIATECH.

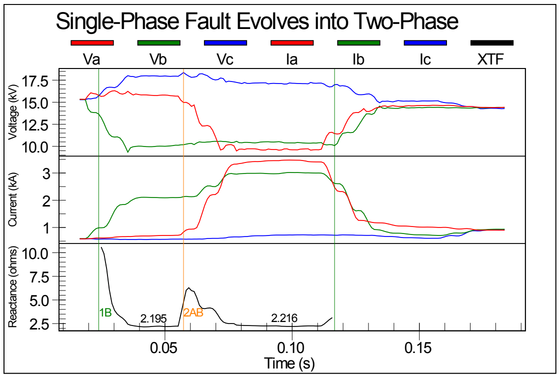
Before coming to the university, Mr. Considine developed enterprise systems for technology companies, apparel companies, manufacturing plants, architectural firms, and media companies old and new. Before that, Toby worked as a biochemist following undergraduate work in developmental neuropharmacology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

Mr. 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.

  - Web-based configuration of parameters for assessment of capacitor bank performance (voltage and current profiles, disturbance characteristics such as restrike transients, unbalance, harmonics)
  - Documented interface requirements for other systems needed - capacitor bank data, electrical models, GIS, operations data
  - Web-based configuration of reports and notifications

6. Foundation for ongoing development of a wide variety of advanced reports and applications
   - Reports and analysis functions to benefit both utility engineers and customers
   - Automatic identification of lightning-caused events and location of these events
   - Automatic identification of locations with harmonic resonance problems
   - Identification of equipment problems (voltage regulators, transformers, breakers, etc.)
   - Input to asset management and equipment health assessment applications





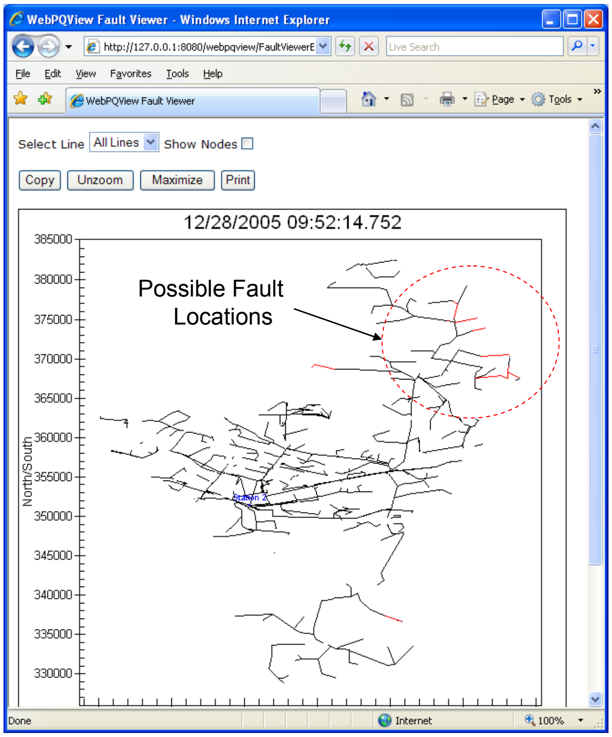


Figure 4. Example of fault location application using substation waveform data along with GIS and electrical model information to locate faults

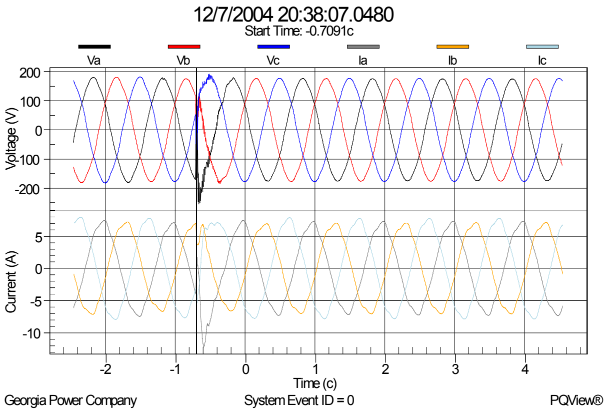


Figure 5. Example of transient waveform (capacitor restriking) that can be identified automatically to indicate a breaker problem.

DEVELOPING THE PLATFORM

The Next Generation Power Information System is being specified and a conceptual design is being completed by the Electric Power Research Institute (EPRI) in cooperation with a core group of initial sponsors – Tennessee Valley Authority, Con Edison, Southern Company, Salt River Project, and City Public Service of San Antonio.

The new platform will open power quality systems to a much greater variety of applications that use the power quality information in combination with data from a wide variety of other sources. This will be accomplished by implementing a modular software system with modules built in multiple tiers (see Figure 6).

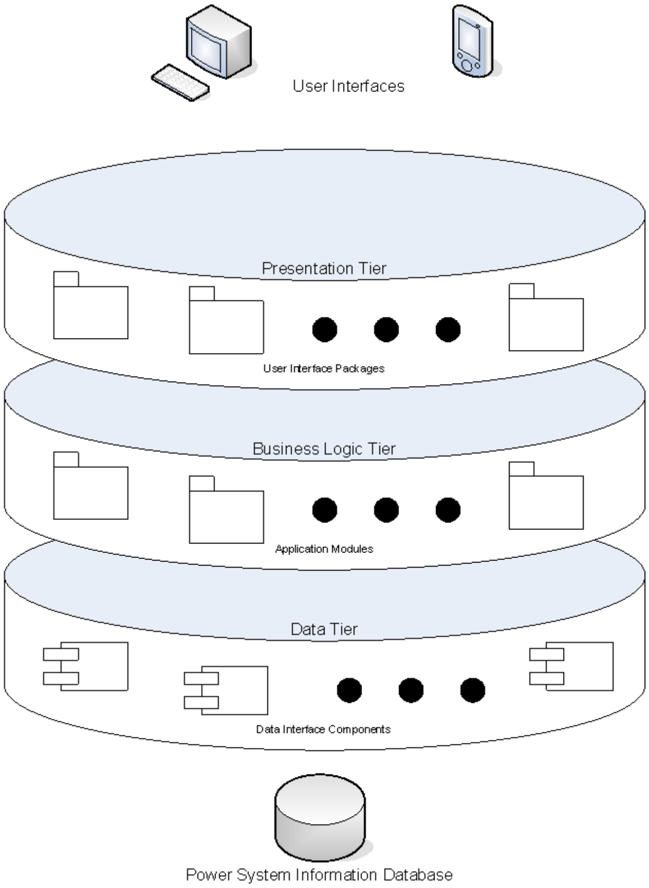


Figure 6. Concept of modular implementation of the next generation platform in multiple tiers to facilitate open development of advanced applications.

SUMMARY

A new information management system is described that will provide web-based access and management to a wide variety of power system information. It is built around integration of monitoring information with other enterprise information systems. The new architecture will facilitate a variety of important aspects of the smart grid:

- The system will provide web-based interfaces for all key functions. This greatly reduces the software support requirements within utilities and dramatically increases the value of the system by making access to information, reports, and analysis results available to a much wider range of users, both internal and external to the company.
- The system will facilitate application level interfaces to other key information systems, especially GIS, electrical models, operations, and equipment databases.

- The reporting functions of the system will be structured with web-based interfaces for flexible configuration of reporting at both the site and system level so that users can define their specific reporting and notification needs.
- The system will be scalable to support the wide variety and dramatically expanding range of information resources becoming available to characterize the power system and equipment performance. Instead of supporting monitoring data from hundreds of power quality monitors, the system must be able to support information from throughout virtually every substation, transmission system, distribution system, and even every single customer on the power system. The number of points to support is quickly growing to the tens of thousands and will be migrating to the millions.
- The system will provide an open, documented interface for third parties to access the information, facilitating the development of advanced applications by a wide range of internal and external developers. These application interfaces to the system can be thought of as a "developer's toolkit".

BIOGRAPHIES

Fred L. Elmendorf is the Power Quality Manager for Power System Operations of the Tennessee Valley Authority (TVA), in Chattanooga, Tennessee. He is responsible for all long term PQ monitoring projects within TVA, and the integration of other data sources including digital fault recorders, solid state relays, and revenue meters, into the Power Quality system. He is also responsible for managing TVA's lightning data systems including the National Lightning Detection Network (NLDN), the Fault Analysis and Lightning Location System (FALLS), and the integration of PQ and lightning data.

Fred has been with TVA for over 28 years, and has been increasingly involved with PQ since 1992, and lightning data since 1995. In addition to PQ and lightning, he has developed and supported applications in many engineering research areas including active and passive solar thermal storage, renewable energy sources, and conservation and energy management. Fred received a B.S. degree in Computer Science from the University of Tennessee at Chattanooga.

Mark McGranaghan is a Director in the EPRI Power Delivery and Utilization (PDU) Sector. His research area responsibilities include overhead and underground distribution, advanced distribution automation, Intelligrid, and power quality. Research priorities include developing the technologies, application guidelines, interoperability approaches, and standards for implementing the smart grid infrastructure that will be the basis of automation, higher efficiency, improved reliability, and integration of distributed resources and demand response. He is also directing EPRI's extensive smart grid demonstration initiative (5 year effort) to help coordinate the industry approach for distributed resource integration with the operation of the grid.

Zhiming Dai is a Software Development Manager at EPRI. His current research activity focus on developing next generation power information system, he has been in charge of developing various high tech business and application development executive with background in telecommunication industries and electric industries. Zhiming Dai received his Computer Science B.S degree from Shanghai Industry University, Computer Science M.S. degree from Oklahoma State University and EMBA from MIT.

Christopher J. Melhorn is a Program Manager in the Power Quality program area of EPRI's Power Delivery and Markets Sector. His current research activities focus on developing intelligent applications of monitoring systems for member utilities, managing EPRI's MyPQ.net Web site, and performing power systems research for the private sector. His previous activities included management of the EPRI Distribution Power Quality (DPQ) II study.

Before joining EPRI in 2000, Mr. Melhorn worked at Electrotek Concepts, Inc. In his role there as Manager of Power Quality Products and Services, he was responsible for developing new products and services related to state-of-the-art monitoring systems for Utilities and Large Industrial & Commercial end-users.

Mr. Melhorn received a B.S. in Electrical Engineering Technology from the Pennsylvania State University and an A.S. Degree from York College of Pennsylvania. He has authored over 35 technical papers, was a contributing author on three technical books related to power systems and power quality, and has developed and taught numerous seminars and workshops related power systems and power quality.