A Case Study of Implementing a Localized Smart Grid in Developing Countries

Ahmed Omer and Fahad Javed and Naveed Arshad
LUMS School of Science and Engineering
DHA, Lahore, Pakistan
ahmedomer27 at gmail dot com
fahadjaved at lums dot edu dot pk
naveedarshad at lums dot edu dot pk
Phone:+92-42-35722670 Fax: +92-42-35898315

Abstract

Smart grids and its related applications can potentially provide us with a fascinating ways to improve existing electric distribution networks. However, to realize most of the applications envisioned in smart grid a large scale infra-structural transformation is needed in the current electric distribution network. This requires considerable resources as well as time. For developing countries this problems becomes even more problematic for two reasons: First, they have fewer financial resources to invest in smart grid technology, second most of these countries already have an energy crisis and need for better management is needed urgently. This study examines various technologies that are already available in developing countries which can be used for smart grid applications. The technologies in this study can provide a scalable communication backbone for demand side monitoring, management and control. We compare the cost and effectiveness of these technologies with existing methods used for mitigating supply shortfall related problems in developing world.

1 Keywords

Smart grid, Autonomic systems, Self-optimization.

2 Introduction

Developing nations are faced with the need to increase power production to keep up with the demand of electricity due to rapid industrialization, urbanization and electrification of new settlements. However, the development of electricity generation is costly and takes time. Thus many developing countries are unable to add energy generation sources fast enough. Due to these factors, there is an ever increasing gap between the electricity supply and demand. In many countries the only solution to fill this gap is to employ load shedding, i.e. cut electricity to some localities periodically. Not only this kind of power management is a great inconvenience to consumers, but this scheme is also detrimental to industrial development.

In the existing infrastructure the power demand calculations apply a top-down analysis. The total load over the system is monitored at power distribution points or grid stations. Various models are used to predict the total load of system. If this total load for a distribution network is more than the available power then an hourly plan is made to shutdown power to sub-regions of the network so that the system is not over loaded. This shedding of load is based on grid station-level granularity. However, in various situations, such as extreme weather conditions, changes in consumption trends are not captured adequately by top-down models [19]. Furthermore, with the advancement of information technology, ubiquitous communication and distributed generation and storage, it has been observed that bottom-up models provide better solution than the prevailing top-down models [8].

To incorporate bottom-up model, massive communication infrastructure and a level of intelligence is required at the consumer level. This addition of intelligence and communication can help develop various applications in conservation, alternate power generation and tailored services for customers. This integration of IT infrastructure into the power grid is called "**smart grid**". Our work is an application of smart grid for our local scenario.

To reap the benefits of smart grid, in this paper we aims at providing a survey of infrastructure needed to support a smart-grid inspired power management system. We look at the technologies, their associated costs and installation procedure and responsibilities. We have already discussed the planning methodology for such a system at another venue [11]. The social and legal aspect and various methods to use such a system effectively will be discussed at a future venue.

3 Related Work

Since electricity has been used for more than a hundred years, optimization variables such as power dispatch, varying of cable sizes etc. has a wealth of literature [18]. These techniques have been applied in field to good effect.

However, smart-grid is a relatively new field. Major contribution in the area of smart-grid are still in the nascent stages. Some of the core areas of research in smart grids are modeling, analysis and prediction mechanisms for distributed management of power. We shall discuss some of the relevant literature for modeling and analysis which is applicable in our work.

3.1 Optimized Electricity Distribution

Electricity distribution networks generally base their operations on predicted loads for the system. According to these predictions power is dispatched to a region [21]. The load calculation is done at the global level, that is the load of the entire grid is calculated. However, with the introduction of smart-grid, power grids are being driven towards a more decentralized systems. This raises the opportunities to generate energy locally and integrate it with the grid. He and colleagues proposed an architecture for such a system [9].

There have been proposal for ways to provide intelligence to the demand side for power load calculations and dispatch handling. Platt presented an architecture for such systems [15]. On a community scale Ashok proposed a model framework for power management with focus on Indian specifications [3]. Galus and Andersson proposed a method to dispatch electricity for recharging of plug-in hybrid electric vehicles(PHEV) in a closed environment [6]. Whereas the former approaches proposed an idea and provide basic guidelines for achieving the goal, Galus and Andersson provide a concrete implementation of intelligence at demand side combined with central management deriving benefit.

3.2 Modeling

There have been few models defined for predicting load of individual households which can be used for smart grids. These bottom-up models vary from Capasso model and Norwegian ERD model which uses stock of appliances in household and their usage patterns [5, 12] to the model presented by Willis for utility level modeling [23].

Whereas Capasso model requires extensive surveys, Willis model does not. However it is not detailed enough for meaningful load or consumption management.

A different method for bottom-up modeling is to use time-series data of usage of devices and construct the electric consumption from it. Widn and colleagues have used this method for modeling electric consumption for Swedish households [22].

There are models which do not require extensive survey yet are detailed enough. Examples of such models include model proposed by Paatero and Lund for household loads using stochastic processes to generate consumption and then use Capasso model for deriving a model[14].

To support work of modeling, Richardson and colleagues developed a method to generate synthetic data for models using Markov chain on time-series appliance usage data [16]. This work was further extended by Richardson and colleagues to construct a high resolution energy demand model for domestic lighting [17].

Large scale forecasting of electric loads has been focus of research for a long time. A survey of existing techniques is discussed by Alfares and Nazeeruddin in their survey [1]. However, forecasting for load using bottom-up approaches has not been explored in great detail. Recently, Wallin and colleagues recommend use of automatic meter readings for grid-level forecasting [20]. Wallin and colleagues further proposes some methods for bottom-up load predictions [19].

4 Motivating Problem: Power Shortage in Pakistan

Pakistan is a developing country. The economy of the country is growing rapidly, in the last 40 years it has grown at an average rate of 7.2%. This growth translates to higher energy consumption by existing infrastructure. In addition, new areas are being provided electricity. The infrastructure of electricity was limited to cities till recently. Since 1998 the number of villages with electricity provision has almost doubled to 133,463 from 67,183 [13]. This growth in economy and electric network has resulted in the net 41% growth in demand for electricity in last 10 years [13].

Due to economic reasons, resources to generate power has not kept pace with the growth in demand. This lack of power generation is aggravated even more during summer months. As Pakistan lies in the subtropical region of the northern hemisphere the summers are extremely hot. During these summer months, domestic air-conditioning cause a demand supply gap of up to 4000 megawatts. This gap is expected to grow to 8000 megawatts by 2010 [4]. This gap in supply and demand can cause overload in the system which can result in failure of entire infrastructure. In such a situation, load-shedding is used to overcome the problem.

It is interesting to note that 42% of electric consumption in Pakistan is by domestic users [13]. This disproportionate consumption in favor of domestic consumer is due to the use of air-conditioners in households during the evening time in summer months. This is in contrast to the consumption patterns of many other regions where the daytime consumption is more pronounced.

We noticed a similar trend of power consumption in place of extreme cold weather such as Sweden. In those regions, however, the peak consumption is in winter months due to heating requirements. However as both consumptions are driven by weather and are by residential users, we can postulate that similar solutions are applicable in both situations.

To study this consumption further, we use a classification of household devices. This classification will help us target the most significant part of consumption for conservation efforts. We then look at the communication, cost and responsibility aspects for implementing such a system.

4.1 Classification of Household Electric Devices

The current technology for management of electricity in a grid considers total load and power requirements for the entire network. However, recent research has shown that it maybe more suitable to model power consumption of each house or even individual devices instead [15].

This change in methodology has attracted attention of researchers to model the consumption of devices within a house. However, it should be noted that various devices tend to consume different types of energy and have different usage frequency and duration. This variation in power consumption and frequency can be very important for end-user device management.

We use this variation to classify household devices into four classes[11]. These classifications are based on power consumed and frequency of consumption. Examples of these four classes are shown in table 1.

4.2 Hypothesis

Our hypothesis in this work is that if we somehow can optimize the use of the devices in the fourth category, we could eliminate or at least reduce the gap between supply and demand.

To manage these devices we require three modules. The planning module considers the power consumption habit for households, the total energy available and the service level guarantees. Based on this data, a planner will construct an hourly plan of 10 minutes windows. The details of this planning module are discussed in our previous work [11]. The goal of the plan is to synchronize all high power devices in a district so as to keep the consumption under the available supply while ensuring the service level guarantee.

As the plan will be constructed at a grid-station level granularity, we will need a distribution medium to distribute this plan to each device. Furthermore, we will need a hardware controller which will execute this plan on the device. We have to consider the fact that the electric network is widely distributed. To manage such a vastly distributed system, conventional networking methods will be costly and will take time to setup. Secondly, wired networks are fixed and require rewiring for every addition or movement of device. Instead we focus on wireless technologies available today with which we can connect the device and have the smart grid application available in lesser time with lesser installation and maintenance costs.

In the following sections we will discuss the feasibility for different available communication methods and provide implementation of a pilot hardware controller to implement our hypothesis.

5 Bottom-up Power Planning

Our vision of bottom-up power management entails a modeling scheme which considers each individual household or device as a basic managed element. We can monitor and plan for each device and can effect power supply to device remotely from a central authority. Need for such central authority is discussed elsewhere [11]. Here we discuss the various technical issues that need to be addressed for the realization of such a system.

The three issues are:

- Communication framework
- Hardware support for managing devices remotely
- Cost and responsibilities of installation

We have discussed issue of modeling of such a system in our previous work [11]. In the following sections we will discuss the remaining issues to elaborate the feasibility of application of our work.

5.1 Communication Framework

Managing hundreds of thousands of devices spread over a relatively large geographical location offer different challenge than computing net-

	Low usage		High Usage	
Low Power	Vacuum-Cleaner	200 watts	TV	70 watts
			Fan	50 watts
	Shaver	15 watts	Computer	150 watts
High Power	Microwave	1000 watts	Air Conditioner	2000 watts
	Toaster	1500 watts		

Table 1. Classification of household appliances according to power and usage profile

works in general. Since the devices are numerous and they are physically apart, reliability, and scalability are important factors. There are few communication protocols that researchers have use for such systems. Some of these protocols are discussed below:

5.1.1 ZigBee

ZigBee is a specification based on IEEE 802.15.4-2003 standard. It is a suite of high level communication protocols using small, low-power digital radios [7]. Since ZigBee is a low cost, low-power, wireless mesh standard, some projects have used ZigBee to monitor electric devices in a city district. ZigBee enabled power monitors are installed at each house and two way communication provides monitoring and actuator control over each house. Since ZibBee are applicable in ad-hoc sensor networks, they can easily be extended to monitor and manage individual devices. This is important because user devices can be added to or removed from a system. However, according to our knowledge large scale installations of ZigBee for management of devices has not been realized yet especially in the context of smart grid.

5.1.2 GPRS

General Packet Eadio Service (GPRS) is a packet oriented mobile data service. GPRS in general is used for mobile internet connectivity. Huang and colleagues have, however, used this protocol for power management of distributed systems [10]. Since GPRS networks are managed by Telecommunication industry and already has a large and scalable networks available in urban as well as rural areas, implementation of a GPRS based system is possible in the near future.

5.1.3 SMS

Short Message Service (SMS) is a communication service standardized in the GSM mobile communication system, using standardized communications protocols allowing the interchange of short text messages between mobile telephone devices. SMS service, in general is a very cheap and highly efficient transportation medium. Since it is more cost effective than GPRS and it satisfies the requirements for transportation protocol for management, SMS is being considered as the technology of choice for remote management of devices [2]. This is evident from the range of SMS based products available online for management of home automation. However use of SMS for large scale device management has not been observed by the authors yet.

5.2 Hardware Support for Managing Devices Remotely

Our method for optimizing electricity usage and distribution is by controlling user devices at their premises. This requires the propagation of plan and affecting the devices according to the plan. For this we require a "controller". This device controller will interface with the communication layer for receiving the plan, and will interface with the electric circuitry to implement the plan. In the following sections we present a pilot implementation of this device controller.

5.2.1 Hardware Implementation

Switches are used to make or break an electric circuit causing the current to stop or flow through a loop respectively and driving the associated electrical device on or off. The first focus of this implementation is to automate this action so that the switching on and off of an electric device is done automatically based on some criteria without any human intervention. This automated switching technique is already available in many devices such as air-conditioners, etc. Usually this automated switching is done through relays with some controller controlling the relay. In our implementation we use similar hardware to implement the controller for the hardware.

5.2.2 Working with Relays

We connected 12V relays in series with the electrical device operating on 220V. In our implementation, the relay is connected so that by default, when no input voltage is supplied to the relay, the circuit of the electric device is complete and the device is switched on. This choice of electric path through the relay was based on the consideration that if the relay fails, it must not break the electric circuit. Of course, if the nature of use demands the opposite requirements, the other conducting path of the relay can be used. As soon as the relay gets a 12V input, it switches connections to break the circuit of the electric device to switch it off. Thus, using a 12V supply to the relay, a 220V circuit is established and broken.

5.2.3 Interfacing Relays to Micro-Controller

We used a standard micro-controller to control the relay for our device. Fig. 1 is the schematic for the micro-controller interface with the relays. The micro-controller used is 18F452, which has ports that can be used either as an input or output. In the scope of this implementation, these ports are used

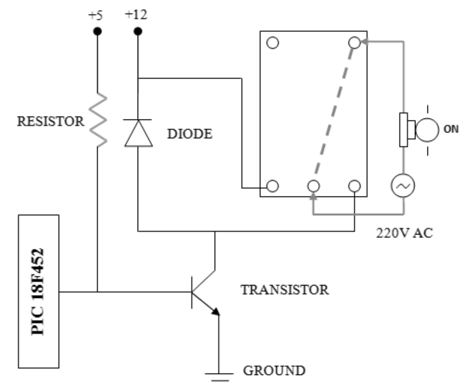

Figure 1. Relay interfacing to microcontroller

to provide signals to the relays that are connected in series with the electric devices. Of the two pins of the relays across which 12V is supplied, one of them is connected directly to a +12V and the other is connected to a pin of the micro-controller port through a transistor - the polarity does not matter in this context. Effectively, the relay changes its state whenever the associated micro-controller pin changes state from HIGH to LOW or from LOW to HIGH. Our micro-controller manages the relay which in turn manages the user's electric device. To control the micro-controller we can connect it with an SMS, GPRS or ZibBee communication device. For our pilot implementation we use SMS as our transportation medium.

5.2.4 Communication Medium

Although there are many communication mediums to choose from such as GPRS, SMS, Wi-Fi, Bluetooth, for this pilot we use SMS as the communication channel to provide commands to the microcontroller from a remote location.

The 18F452 microcontroller sits on the easyPIC2 development board by mikroElektronika. We used this device because it is easily programmable from a PC through USB and assists RS232 interfacing to micro-controller to communicate with the serial port.

A GSM modem by Enfora is connected to RS232 on the easyPIC2 development board through a serial cable. Below is a male connector, two of which are used to create serial cable for connecting the GSM modem to RS232 on the development board.

The GSM modem serves to receive SMS messages and transmit them to the microcontroller for processing and action. The feedback from the microcontroller against the action taken, error or warning is transmitted back via an SMS to the number from which the command was received.

5.2.5 Micro-controller Software

Our micro-controller receive commands from the GSM modem as a string of ones and zeros, act upon them by setting the states of its pins and provide feedback. In this implementation, when an SMS is received at the GSM, it stores this SMS message in the SIM card and sends an interrupt to the micro-controller. Micro-controller retrieves the string over an RS232 line. The data that the micro-controller retrieves contains an index number at which the message is stored in the SIM card. The micro-controller sends an instruction to the GSM modem with this index number to retrieve the message containing the schedule encoded as a string of ones and zeros. The program parses this string analyzing each index and setting the desired state at the pin associated with that index. The program loops again to wait for another command. In the lab environment, the program was also tested for multiple instructions in a single SMS with a gap of a predefined time frame between the instructions and this was a successful feature incorporated in the implementation later which allowed the user to pre-program the system and define the states of the electrical devices for the time to come.

5.2.6 Discussion on Hardware Implementation

The use of micro-controller to control the switching of electrical devices and interacting with the machine running the algorithm over a wireless channel also introduces a great level of flexibility in terms of how the system should interact, how it should handle the different signals, how it should respond to a failure and recover from it, how it should provide reports and feedback and even how it should authenticate a machine. This level of flexibility makes it possible to use this system in a custom environment and adapt to different policies accordingly and hence it steps forward as a generic system that can programmed as per any requirement of the user. Although, this system is not limited to these features and can be put forward in many different variations, some of the most notable features are explained below.

- **Pre-programming:** We can pre-program our system to define a timeline whereby the system automatically sets the states of associated devices at specific intervals.
- **Plan Recovery During Failure:** SMS messages are stored in the SIM which acts as a backup storage for retrieval of plan in case of power failure.
- **Low Cost:** Estimated cost for custom made system equivalent to our test bed is roughly \$65 to \$75.

5.3 Putting It All Together

In the previous sections we have discussed the feasibility of communication infrastructure and a pilot hardware implementation as a proof of concept for large scale smart grid application without affecting the existing electric distribution network. We now briefly discuss how we plan to weave this picture together.

As we have discussed in section 4, our hypothesis is that if we can control the devices which consume the most power and regulate these devices then we can save the maximum power. This is in contrast to load shedding where electricity of a whole city district is turned off to manage the load. Furthermore, we would like to provide customers of these high powered devices with some service level guarantees that the device will be turned off for X% of time in an hour.

Our planning module will be deployed at grid stations. Using a simulated grid environment, our initial evaluations revealed that our planners can plan for a 100,000 devices within 150 seconds on a commodity machine. Thus the planner is scalable and a commodity machine will be sufficient for grid station level planning. This plan will be passed to the telecommunication provider through their communication service. The plan will be uploaded to the SMS delivery queue of the cells located in the vicinity of the grid station. Telco providers usually guarantee a fast and reliable delivery of SMS messages to the recipient after they are delivered to the local cell. Thus we can be sure that our plan will reach the device in time. The hardware similar to discussed above will receive the SMS and save it in their GSM sims. The micro-controllers will read this plan and power the relays accordingly whereby synchronizing the power consumption of an entire district.

We have discussed the technical details for implementing our smart grid application. We now discuss two of the most pertinent questions regarding the practicality of our system, the cost and responsibility of installation.

5.4 Discussion on Cost and Responsibilities of Installation

Managing electricity to specific devices in residential electric networks is a novel idea. There are various aspects to consider for such a system. Some of the key issues that need to be considered for deployment of such a system are the costs of installation and responsibility for the cost. In this section, we will discuss the costs associated with the communication infrastructure for the system we are designing and how we can dispense the responsibility of installation and cost of user side device.

5.4.1 Existing Setup

To cope with the load shedding , most of the domestic users install Un-interruptible Power Supply (UPS) units from their own expenses. These UPS units store electricity in batteries and provide supply for category 2 electric devices (fans and lighting) during the load shedding hours. A UPS generally costs close to$175 for installation. In addition, UPS batteries have a life of 1000 recharges. With frequent power outages, a battery is changed usually every year at the cost of close to $88.

It should be noted that UPS does not produce it's own energy rather it stores electric energy in form of chemical energy. This transformation usually results in loss of energy. This loss is dependent on the technology and quality of batteries. Since this charging is done from the same electric supply, the amount of energy that is stored in UPS is drawn from the distribution network and the user is charged for it. Hence due to the energy losses, subscribers pay more for each unit consumed of electricity through this indirect method.

5.4.2 Cost

Cost of installation for management device is dependent on the technology of communication and number of devices to be managed in a house. We have three competing communication strategies. ZigBee, GPRS and SMS.

The quickest way possible is to use GSM mobiles available in the market connected with relays to control the device. These GSM devices then can manage the electric devices and can be controlled through a communication protocol over SMS.

In Pakistan a GSM mobile phone can be purchased for as little as $20. The cost of an SMS is as low as $0.0037 per message. If we consider hourly planning then our total yearly cost for messaging will be or $33.

Zigbee is designed for low-cost sensor networks. The hardware required for ZigBee is minimal. We do not have any ZigBee enabled meters available in Pakistan but it can be assumed that such meters will cost marginally more than the existing meters available in the market.

GPRS enabled controllers are perhaps the most expensive option that we have considered. GPRS enabled mobile phones are expensive however, chip-sets with GPRS technology embedded are available in the market. The cost of these devices start from $50.

In conclusion, we find that price of a management gadget can cost at the maximum of or $125 for installation and $33 as yearly cost which is roughly 29% and 37% of corresponding costs of a UPS. Furthermore managing of high-consumption devices will provide a better service to consumers than the UPS at lower cost of energy.

5.4.3 Responsibility of Installation

There are various methods employed by power companies to share the cost and responsibility of power meter installed at user premises. These methods are based on the legislation related to power in a country. For example, in Pakistan utility provider charges a rent for meter installed in user premises. Furthermore, in case of damages caused by user actions, the user is responsible for any repair costs to the meter. In comparison, in Sweden some cities have made it mandatory for utility providers to install meters for all the subscribers without any cost to the subscriber.

Our electric management framework provides a facility through which population of the entire region can benefit. That is, through this framework users can get benefit of continuous power supply for categories 1,2 and 3 devices whilst limited usage of category 4 devices at times of shortage of supply. Since this benefit is shared by all, it is imperative that legislation should be put in place so that all users can benefit from this technology.

6 Conclusion and Future Work

In this paper we have provide the infrastructural groundwork for a smart-grid inspired micro-management of end user devices to mitigate load-shedding. We discussed the differences between prevalent top-down modeling and the proposed bottom-up models. We discussed the power issues of Pakistan and how we categorize the electrical devices used in household.

We described four important aspects that we feel are needed for implementing such a system: communication framework, hardware controller and costs and responsibilities. We discussed in detail the communication frameworks that can assist our system. We have provided a proof of concept for the device controller. Finally, we analyzed the costs that are applicable for our system and described a way to define responsibilities of installation for the system.

We found that the communication framework and associated hardware needed for smart grid will have significantly lower installation and running costs in comparison to the prevalent UPS based system. Furthermore, our system will consume less power in total than the UPS based systems. We found that a smart-grid based system will be a better way to mitigate power shortage than the top-down, blanket load-shedding that is being applied today.

Smart grid can be used for variety of purposes such as fault detection, enhanced metering etc. However, our smart grid application is focused on managing electricity of end-user devices using existing communication and hardware infrastructure. As part of our future work we investigate various applications of smart grid which can benefit from our work.

References

[1] H. K. Alfares and M. Nazeeruddin. Electric load forecasting: Literature survey and classification of methods. *International Journal of Systems Science*, 33(1):23–34, Jan. 2002.

[2] A. Alheraish. Design and implementation of home automation system. *Consumer Electronics, IEEE Transactions on*, 50(4):1087–1092, Nov. 2004.

[3] S. Ashok. Optimised model for community-based hybrid energy system. *Renewable Energy*, 32(7):1155 – 1164, 2007.

[4] M. Asif. Sustainable energy options for pakistan. *Renewable and Sustainable Energy Reviews*, 13(4):903 – 909, 2009.

[5] A. Capasso, W. Grattieri, R. Lamedica, and A. Prudenzi. A bottom-up approach to residential load modeling. *Power Systems, IEEE Transactions on*, 9(2):957–964, May 1994.

[6] M. Galus and G. Andersson. Demand management of grid connected plug-in hybrid electric vehicles (phev). *Energy 2030 Conference, 2008. ENERGY 2008. IEEE*, pages 1–8, Nov. 2008.

[7] D. Geer. Users make a beeline for zigbee sensor technology. *Computer*, 38(12):16–19, Dec. 2005.

[8] R. Guttromson, D. Chassin, and S. Widergren. Residential energy resource models for distribution feeder simulation. In *Power Engineering Society General Meeting, 2003, IEEE*, volume 1, pages –113 Vol. 1, July 2003.

[9] M. He, E. Reutzel, X. Jiang, R. Katz, S. Sanders, D. Culler, and K. Lutz. An architecture for local energy generation, distribution, and sharing. *Energy 2030 Conference, 2008. ENERGY 2008. IEEE*, pages 1–6, Nov. 2008.

[10] Y.-W. Huang, S.-C. Chang, and C.-H. Wu. Gprs-based embedded remote power management system. In *Sensors for Industry Conference, 2005*, pages 105–110, Feb. 2005.

[11] F. Javed and N. Arshad. A penny saved is a penny earned: Applying optimization techniques to power management. In *16th IEEE International Conference on the Engineering of Computer-Based Systems (ECBS 2009), 13-16 April 2009, San Francisco, CA, USA*, 2009.

[12] B. M. Larsen and R. Nesbakken. Household electricity end-use consumption: results from econometric and engineering models. *Energy Economics*, 26(2):179 – 200, 2004.

[13] M. of Finance Pakistan. Economic survey of pakistan. *Economic survey of Pakistan*, 2009.

[14] J. V. Paatero and P. D. Lund. A model for generating household electricity load profiles. *International Journal of Energy Research*, 30(5):273–290, 2006.

[15] G. Platt. Linking it all together-an intelligent demand side. *Energy 2030 Conference, 2008.*, pages 1–4, Nov. 2008.

[16] I. Richardson, M. Thomson, and D. Infield. A high-resolution domestic building occupancy model for energy demand simulations. *Energy and Buildings*, 40(8):1560 – 1566, 2008.

[17] I. Richardson, M. Thomson, D. Infield, and A. Delahunty. Domestic lighting: A high-resolution energy demand model. *Energy and Buildings*, 41(7):781 – 789, 2009.

[18] D. Sun, D. Farris, P. Cote, R. Shoults, and M. Chen. Optimal distribution substation and primary feeder planning via the fixed charge network formulation. *power apparatus and systems, ieee transactions on*, PAS-101(3):602–609, March 1982.

[19] F. Wallin, C. Bartusch, E. Thorin, and E. Dahlquist. "important parameters for prediction of power loads - a bottom-up approach utilizing measurements from an automatic meter reading system". *Power Engineering Society Conference and Exposition in Africa, 2007. PowerAfrica '07. IEEE*, pages 1–7, July 2007.

[20] F. Wallin, E. Dotzauer, E. Thorin, and E. Dahlquist. "automatic meter reading provides opportunities for new prognosis and simulation methods". *Power Tech, 2007 IEEE Lausanne*, pages 2006–2011, July 2007.

[21] X. Wang, Y.-H. Song, and Q. Lu. A coordinated real-time optimal dispatch method for unbundled electricity markets. *Power Systems, IEEE Transactions on*, 17(2):482–490, May 2002.

[22] J. Widn, M. Lundh, I. Vassileva, E. Dahlquist, K. Ellegrd, and E. Wckelgrd. Constructing load profiles for household electricity and hot water from time-use data–modelling approach and validation. *Energy and Buildings*, 41(7):753 – 768, 2009.

[23] H. L. Willis. Spatial electric load forecasting:, 2002.