METHODOLOGY FOR BUILDING-TO-GRID TESTBED IMPLEMENTATION

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Abstract

of

METHODOLOGY FOR BUILDING-TO-GRID TESTBED IMPLEMENTATION

by

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The University of California Berkeley created a building-to-grid (B2G) test bed facility at one of their buildings called Cory Hall to research and analyze the strategies useful in making buildings capable of responding to electrical critical pricing periods and simultaneously more baseline energy efficient. California State University Sacramento (CSUS) shadowed Cory Hall testbed to gain the knowledge on the processes involved and the problems that can be encountered while conducting this type of research. This project performs a comprehensive analysis of the testbed implemented at Cory Hall, investigates the process involved in setting up a smart grid testbed at any facility, examines the similar work done and discusses the transition required for reusing the knowledge gained in B2G project. Case studies performed at CSUS regarding the energy management operations at the campus, are also discussed in the report. The problems and the issues to be considered in terms of installation and implementation of monitoring and sensing devices are also discussed in detail. The various ways to approach the testbed problems and potential issues that could be caused by these are mentioned in this report. The B2G project saw installation of electrical monitors/meters and a steam condensate meter. The empirical results to date demonstrate success in pervasive energy monitoring within the building. This report
monitors the outcome of the testbed project and discussed the lessons learned from it. This report would serve as a guiding document to future researches on building-to-grid and demand response at campus level. The knowledge in this report can assist the management team of a building in making sound decisions about their load management, demand response and energy conservation.

Suresh Vadhva, Ph.D.

Date
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Chapter 1
INTRODUCTION

The decade of 1990s witnessed the increase in awareness about the potential climate change in future. This awareness greatly impacted Government policies and regulations within electrical industry of United States. Deregulation of power generation and distribution systems in 1998 was an outcome of the above event. This move forced the industry to rethink the energy practices and enable real-time communication of electrical supply capability, consumer energy demands and various system state and fault analysis data. This evolution in thinking gave birth to the concept of Smart Grid and hence, establishment of the Smart Grid Center at California State University Sacramento which will focus on smart grid research activities in the Northern California region.

In the near-term, the California Energy Commission (CEC) is funding research into various schemes to allow such real time communication. One such project was the Building-to-Grid (B2G) test bed at University of California Berkeley (UCB). Under grant number BOA-99-234-P, the B2G test bed project was set to examine aspects of electrical energy usage to determine total energy flows by functional use. As part of the same grant, California State University, Sacramento (CSUS) shadowed the UCB B2G project and documented the research test bed creation at Cory Hall building within the Berkeley campus. UCB investigated existing tools to accomplish this Smart Grid technology and adopted new tools as the research evolved. This initial test bed project established mainly the electrical load monitoring in a mixed industrial / commercial type of facility where future smart grid research may be conducted. Relatively small efforts were also been made to establish steam and chilled water consumption.
The California Energy Commission sponsored this grant as part of its energy system research that seeks to identify various technologies and resources that can be used to evade brownouts and blackouts during peak times and to develop Smart Grid technologies that assist total energy efficiency efforts at all levels of electrical energy usage – residential, commercial and industrial. The goal for UCB was to establish pervasive monitoring of a large complex electrical load to understand and track the energy consumption pattern of Cory Hall. This study could be used to identify the essential, non-essential and non time-critical load which would further help in electrical energy requirement forecasting, energy waste elimination, efficiency in operations, load shifting, adjusting and optimizing.

According to Andrew Tang, Senior Director at Pacific Gas and Electric Company (PG&E), it has been seen that people can reduce their energy consumption by 7-12% just by bringing a small change in their daily habits [1]. The electric load trend at PG&E indicates that 10% of the total annual capacity is consumed in just 51 hours [2]. In the utility region covered by Sacramento Municipal Utility District, 12% of the total load (due to summer peaks) occurs in just 40 hours of the year [3]. Generalizing this consumption tendency across United States, the U.S. DOE claims that 10% of all generation assets and 25% of distribution infrastructure are required less than 400 hours per year which is roughly 5% of the time [4]. Thus it becomes evident that the study of energy consumption patterns is very important and is a crucial step in establishing an effective Smart Grid.

The report starts by shedding some light on the background and need for Smart Grid. It is then followed by the fiscal background of Smart Grid market and explains the scope of B2G project in detail along with the challenges faced by the power industry today. A chapter has been dedicated
to demand response and load management. The methodology is described in detail in a chapter along with the observations made. A step-by-step summary of crucial steps has been included, followed by their detailed explanations. The components/monitoring types necessary to set up a testbed similar to Cory Hall have been discussed. A section is then dedicated to paint an overall picture of the B2G testbed project at Cory hall and its outcome. Another chapter discusses the case studies performed at CSUS for energy management. The report also mentions the issues and areas that need to be addressed in future in order to successfully implement a testbed communicating with Smart Grid. A chapter discussing the reuse of information learned from B2G project is followed by the conclusions.
Chapter 2

THE NEED FOR SMART GRID

Smart Grid is an evolving concept that at its base is concerned with the improvement of electrical energy generation and transmission. It does so while incorporating various renewable energy sources created in distributed energy islands using digital technology which boosts the reliability of the system. It comprises of a broad range of solutions that would ultimately optimize the energy value chain. Most of the groups involved in the smart grid energy sector (power generators, utilities, IT, product vendors, building owners, facility management, consultants, metering industry, large consumer groups, residential customers etc) like to define Smart Grid according to their own interests and usage. The United States Department of Energy (U.S. DOE) defines it as:

“An automated, widely distributed energy delivery network, the Smart Grid will be characterized by a two-way flow of electricity and information and will be capable of monitoring everything from power plants to customer preferences to individual appliances. It incorporates into the grid the benefits of distributed computing and communications, to deliver real-time information and enable the near-instantaneous balance of supply and demand at the device level” [4].

In a nutshell, the smart grid brings the power of networked, interactive technologies into electricity system, giving utilities and consumers unprecedented control over energy usage thus improving power grid operations and ultimately reducing customer costs.

Electrical energy consumption in the United States has increased by 30% from 1988 to 1998. The rate of change in consumption was 1.7 % per year from 1996 to 2006, while the country’s transmission capacity has grown by only 15 % during that period [5]. U.S. Energy Information Administration (U.S. EIA) forecasts an increase in electrical energy consumption from 3,903 billion kilowatt-hour (2007) to 4,902 billion kilowatt-hour (2030) [6]. Summer peak demand is
expected to increase by almost 20% in next ten years or more in the future as 40% of the population is predicted to live inlands by 2040 [7]. The United States electricity system despite being 99.97% reliable faces power outages and service interruptions that cost $150 billion each year. These trends indicate that action is required to combat growing energy demand which could saturate the existing electrical grid capacity. Efforts are underway to

- Achieve lower baseline energy usage.
- Improve energy efficiency.
- Cater an effective demand response.
- Incorporate renewal energy resources.
- Improve electrical grid reliability via various load management methods.

These efforts are very dynamic with a wide range of potential technologies but at its core rely on a robust and effective communications structure with an increased reliance on digital controls and pervasive sensors. Analysis shows that up to 30% reduction in distribution losses is possible from optimal power factor performance and system balancing [8].

California State University Sacramento is one of many universities, industrial and commercial partners that are examining the questions related to the new smarter grid of the future. CSUS is building a Smart Grid Center on its campus that will test suitable technologies in automated metering infrastructure and the possibility of automated demand response at critical times. The Smart Grid Center will develop feasible solutions for large-scale assimilation of Smart Grid Technologies at the on-going basis and will serve as a site for demonstrating its benefits [9]. The aim of Smart Grid Center is to respond to the state of the grid, become energy efficient by reacting to weather conditions, and provide increased reliability by opting for demand reduction.
Based on her research, the author thinks that Smart Grid can also result in the diminution in carbon emissions and hence carbon footprint of electricity industry by practicing demand response and load management effectively. Minimizing the peak time electricity consumption would allow for better utilization of equipment by not forcing the generators and transformers to run at their maximum capacities. This in turn would reduce the dependability on traditional thermal generation sources and consequently less fossil fuel would be consumed. This would also fulfill second of the three goals as mentioned for the Smart Grid initiatives in California [10]:

1. Integration of up to 33% of generation coming from central and local renewable sources.
2. Reduction of green house gas emission to below 1990 levels.

Presently, some of the challenges faced by energy sector emanate from transitioning an existing and operation energy model towards a Smart Grid. These challenges include increasing customer knowledge and participation, allocating costs appropriately and fairly among stakeholders, developing and executing business case models, identifying and implementing best practices and standards throughout the industry and establishing a coordinated strategy that capitalizes on using smarter technology to evolve to a smart grid [11].
Chapter 3

SMART GRID AND THE ECONOMY

The information networks that are transforming our economy in other areas can also being applied to applications for dynamic optimization of electric systems operations, maintenance, and planning, saving significant part of the research effort. It has been estimated that an efficient Smart Grid would reduce the need for new electric infrastructure and hence the investments in the range of $46 billion to $117 billion over the next 20 years. The technologies introduced by Smart Grid would also potentially lower the power disturbance costs to the U.S Economy by $49 billion per year. This includes the technology that would allow consumers to easily control their power consumption to contribute $5 billion to $7 billion per year back into the U.S. economy by 2015 and $15 billion to $20 billion per year by 2020. Assuming a 10% penetration, distributed generation technologies and smart, interactive storage capacity for residential and small commercial applications could add another $10 billion per year by 2020. In addition, the efficient technologies can dramatically reduce total fuel consumption and thereby potentially reduce fuel prices for all consumers. This in flow would give a much needed boost to U.S. economy given the present recession [11] [12].

Despite of the current economic climate, the Smart Grid sector is perceived as a critical subject and therefore received considerable funding by the U.S. Government in the American Recovery and Reinvestment Act (ARRA) of 2009. The act authorized 3.4 billion dollars in grants which are to be matched by industrial and commercial activities totaling 8 billion dollars of investment money for smart grid related technologies [13].
The research firm Zpryme released a report in 2009 which states that current trends indicate sector of the smart grid technologies market will increase from a 21.4 billion dollar market (2009) to 42.9 billion (2014) [14]. Bar graph provided in figure 1 from Zpryme Market Analysis shows the breakdown of the market [12]. The Zpryme report does not discuss the total impact of smart grid technologies since it does not review the effect of renewal resource integration, distribution fault detection and correction or other transmission line improvement efforts. The report does forecast a growth industry based on solid economic need. One key financial aspect of smart grid work is the power production company cultures. In general, utilities are very conservative and must operate within very specific operational guidelines. Any emerging smart grid technology employed in transmission and distribution efforts will need to pass stringent reliability and security concerns. But given the level of governmental interest, future commercial opportunity, and evolving electrical dependence on electricity as the primary and perhaps sole energy source,
it is apparent that smart grid activities will be an active area for research, commercialization, and technological innovation in the foreseeable future.
Building-to-Grid (B2G) is a name given to the building which operates in accordance with a grid. It adapts the smart grid technology and communicates back and forth with the electrical grid system for the purpose of efficient energy consumption. It can be interpreted as the smart building which can effectively perform load management at all times with minimum intervention of human intelligence for efficient energy consumption. What this means is that a smart building has the ability to predict its short and long term energy requirements using the latest technology that includes sensors, meters, and state of the art building management systems. This high performance, low investment, flexible infrastructure integrates the dynamic information of parameters like occupancy, environment and energy conditions. This enables the system to manage the building energy consumption holistically by optimizing building operations with greater energy efficiency.

Buildings account for 30-40% of total energy consumption and carbon footprint in most countries [15]. Specifically within U.S., buildings use approximately 70% of the distributed energy [8]. Carbon footprint can possibly be reduced by building fewer new fossil fuel power plants and using existing energy production more resourcefully. It is hoped by the author more energy efficient buildings will reduce the carbon footprint while simultaneously reducing the total energy consumption from previous levels. Thus several efforts seek to reduce the baseline energy usage of buildings through the use of pervasive sensors which help build a state model of the building. The CSUS work will result in a detailed building state model that allows near term energy usage
prediction. Thus in automated demand response becomes feasible in a method known as building
to grid.

CSUS is building a Smart Grid Center at the campus that will test the suitable technologies in
automated metering infrastructure and the possibility of automated demand response at critical
times. The Smart Grid Center will develop feasible solutions for large-scale assimilation of Smart
Grid Technologies at the on-going basis and will serve as a site for demonstrating its benefits [9].
The aim of Smart Grid Centre is to respond to the state of the grid, become energy efficient by
reacting to weather conditions, and provide increased reliability by opting for demand reduction.

Apart from the introduction of new technology, most of the existing higher energy efficiency
appliances, such as heating, ventilation, air conditioning systems, consumer electronics, lighting
and other loads are changing from resistive loads (e.g., incandescent light bulbs) or rotating loads
(e.g., motors) to being inverter based loads. This transition in load means that the overall system
performance, especially with respect to power factor and reactive power needs, changes
dramatically over time. Building to Grid technology can offer utilities increased monitoring of
these rapid power changes and help them adapt control schemes and deploy capacitors and other
power factor control devices – including power electronics based devices in substations to
compensate [8].

One needs to understand the electrical energy consumption patterns and trends very clearly in
order to bring any effective changes for the grid betterment. A study conducted in 2007 shows
that the major consumer of energy in commercial buildings is the lightning (26%) followed by air
conditioned cooling (14%) and heating (13%) [15]. Thus measures such as double pane window
glass, energy efficient light bulbs, good insulation in the building structure, automated shading, movement based sensor lights, can be taken to reduce the energy demand of a building. All these initiatives and strategies towards efficient use of energy can be implemented and examined by building a test bed. This test bed would answer the vital questions like how can the load of a building be monitored accurately and in real time, the present operation of the building in terms of energy usage and the feasibility of creating an operational strategy that will reduce the peak demand both by load shaping and by short term load shedding when called upon to do so by electrical grid operators.

In the present day, our economy is facing many challenges in power sector. Some of these challenges can be solved by successful of establishments of smart buildings alone. These key challenges are discussed below:

1. *Rising cost of capital, raw material and labor to build new infrastructure* [8]: The present electricity system was in most cases, designed and built many decades ago and is starting to show the stress of ever increasing load consumption and shelf-life of its infrastructure. This rapidly aging electrical system requires efficient energy management in all of its sectors. The report from U.S. DOE reveals that the total electricity load in US increased by 30% from 1988 to 1998, while the transmission network saw an increase of only 15% during the same period [4]. As the country’s transmission lines are reaching their saturation limits, solutions must be introduced in the form of new transmission lines or eliminating losses during transmission to increase the grid capacity. This effort of building to grid hopes to minimize the necessity to build new power stations every ten years by investing effective load management and reducing energy wastage.
2. **Carbon Footprints and environmental impact of new electric infrastructure**: Reduction in building new generation/substation plants via smart buildings would reduce the carbon footprint and green house gas emission significantly.

3. **Rising consumer expectations** [8]: The growing dependency of electricity users on continuous, reliable and good quality of power establishes another challenge to avoid any black-outs or brown-outs which happen due to overloading on the system. Losses from one hour of outage at Chicago Board of Trade in 2000 caused losses worth $20 trillion while the 2003 Northeast blackout caused $6 billion and the Silicon Valley blackout cost United States economy $75 million. These examples very well depict the price of blackouts and the dire need for reliable energy delivery to the customers [16]. The uninterrupted supply of electricity is only possible if the demand stays below supply through load management which again leads to building to grid.

4. **Need for and viability of energy efficiency caused by the expansion of global economy** [8]: Building to grid can make overall energy consumption efficient through consumer education and participation in demand response / load management programs.

The examples discussed above showing the consumption pattern in United States depict that developing a demand-side Smart Grid will most likely be an on-going process that will be accomplished over time with continuous assistance from technical innovations, better load management techniques and changing general public’s energy consumption habits [17]. In addition to the current infrastructure, the new Smart Grid includes integrated communications system, advanced metering, sensing, measurement infrastructure, complete decision support and human interfaces [4]. It has been seen that electric power transmission can be made up to 300% more efficient than the present standard by using two-way intelligent communication between the
consumer and the supplier located on the grid and by providing a smart electrical infrastructure with the capabilities of self restoration, self protection and self optimization [18].

The Building-to-Grid testbed system needs to have two very important features within it – Persistency and Pervasiveness. Persistency could be defined as the state of continuously existing despite the interferences in the system. The building control should be persistent in order to continue performing on the guidelines of the original design eliminating the need of regular intervention and re-optimizing its operations after every disturbance or problem. It is very crucial that the building under test should not loose its main goal under the blanket of intricacies and complexities that introduce themselves in the process. Pervasiveness refers to the frequency of a device being present. Thus, pervasiveness of the monitoring equipments is essential in order to execute accurate checksums in different sections and throughout the building. Checksum in the context of this project refers is a quality control method, which provides the ability to validate the data collected through transmission. This consistency is needed to achieve stability in the monitoring operations of the building and further for the grid. Documenting the process and data monitoring are vital for attaining persistency in this project.

For the purposes of load management and demand response, the electrical load can be classified into three categories.

**Essential Load** – the load that is absolutely critical and cannot be turned off at peak times.

Examples include – refrigerators, server systems, computers, electronic phone systems.

**Non Essential Load** – the load that is consumed quite frequently but could be turned off temporarily. Examples include mobile phone chargers, microwaves, extra lighting, air conditioner and space heaters.
Non time critical loads – the load that is not dependent on the time of day and could be easily postponed till off peak timings. Examples include dish washer, laundry at homes, steam generators, water chillers, water heating storage systems etc.
DEMAND RESPONSE AND LOAD MANAGEMENT

Demand Response is a practice in which the consumers voluntarily/contractually react to the peak load period by reducing their energy consumption temporarily, thus avoiding the need to generate more energy to meet the requirement. This action helps in addressing system reliability by deflecting electrical congestion at choke points, reflecting market conditions and energy prices, and finally supporting infrastructure optimization by eliminating the need for spinning generation reserves [19]. Spinning generation reserves are exclusive generation plants that are often kept running so that they could be used instantaneously to serve peak time demand. As a result demand response also reduces the operational energy costs due to spinning reserve plants. The aggregated energy reductions from many different users would result in a big portion of power being shaved off at the peak time. Demand Response can be classified into three categories based on the degree of human involvement. *Manual Demand Response* relies heavily on the consumer end to manually turn off the load when requested by the utility or ISO. *Semi-Automated Demand Response* can be applied when the consumer’s building energy management and control system (capable of load shedding) is pre-programmed by facilities staff for such times. This response requires human intervention either to receive utility’s request for load shedding or to initiate the demand response process by dropping off the load. *Fully-Automated Demand Response* or *Auto DR* uses the communication signal sent by utility about the current energy price to initiate its pre-programmed load shedding plan thus eliminating the need of human intervention. In the Auto DR system, the consumer always has the option of overriding the DR process if shedding off the load is not desirable [20]. Long term value of Demand Response is dependent on being controllable,
measurable, verifiable, and predictable. Figure 2 shows the process of automatic demand response and the steps associated with it.

For demand response to be in equivalence with supply side resources, tools and technologies play very critical role. One example of such a technology would be the advance metering infrastructure. The technology encompasses digital meters which are able to communicate with the customer about the hourly energy usage pricing. The structure of the dynamic tariff plays a vital role in helping customers respond to usage timings and reduce their total energy costs. Large customers with building energy management systems are linked to pricing signals over the Internet or through other pre-agreed communication channels. This technology when coupled with energy efficiency programs and policies (such as those directed by Arthur Rosenfield) result in energy consumption reduction and total peak period consumption reduction.

Load management could be defined as any activity which helps in the efficient consumption of energy. The activities could include optimizing energy usage based in real time electricity price, contractually obligated and voluntary curtailment, and direct load control or equipment cycling. Methods such as demand limiting and shifting can be utilized when the economics and reliability issues are predicted and communicated to each site in advance.

For smart grid management, it is very crucial that there is an accurate predictive capability for any given building. More variation in the daily load leads to difficulty in its prediction. This goal can be achieved by investigating the load consumption patterns of buildings in the campus, detecting energy losses if any and making the buildings more energy efficient. To achieve this goal, CSUS is installing smart meters for all buildings in the campus. Sub-metering, sensors and
monitors would also be installed inside selected buildings in the near future to identify the energy losses and redundant loads.

**Fig 2: Demand Response Steps**

Sources: Picture 1 – Microsoft Clipart Gallery
Picture 2 - Control Room at California Independent System Operator (ISO) in Los Angeles - USA
Picture 3 - Phenolchemie Office building, MBG Project in Germany

In 2003, various studies and field tests were conducted by Lawrence Berkeley National Laboratory (LBNL) to study the demand response strategies on different types of commercial loads. The outcomes suggested that 10% - 14% of the load could be shed from commercial buildings without causing any kind of discomfort to the end user [21]. An aggressive approach however, could lead to astonishing results of 20% to 40% drop in energy consumption as seen in Brazil and Juneau respectively [22]. Physicist Arthur Rosenfeld asserts “energy efficiency is by
far the fastest, cleanest, and cheapest energy resource available” [23]. Therefore he recommended initiatives by the Energy commission that standardized appliance energy efficiency requirements which resulted in almost flat curve of electricity consumption in California for past 30 years while rest of the nation saw a demand growth of about 40% [22].

The sophistication of the Energy Management Control System classifies the building into three types: advanced, common, and basic type. Basic buildings are typically old, small and have either limited (sometimes out dated) or no energy management system. Common buildings are the everyday average size buildings with standard energy management system, a few sensors and various degrees of Heating, Ventilation and Air Conditioning (HVAC) adaptability. Advanced buildings refer to the newer and generally larger buildings with state of the art digital energy management systems and adaptable control algorithms [19]. Given the role of technology in making the electric grid and the buildings smart, it is an obvious choice to prefer the advanced buildings for demand response implementation. But if demand response is experimented and learned only from these advanced buildings, which are relatively fewer in numbers, it would not be a fair reflection of the effect that demand response program can make on a state or a country’s grid. Thus, we need to include all types of buildings in device deployment and demand response.

A commercial energy management system consists of building management system, HVAC, thermal storage, energy dashboard, lighting control, security and surveillance. The EMS is then connected to storage systems, backup power and power quality system as described in figure 3.

Evaluating specific Smart Grid strategies calls for fabricating and testing small scale software and hardware models. For the purposes of this research, the smallest scale model to provide any useful information has been decided to be a single building with its annual electricity
consumption of at least 250 kW. One of the major objectives of a Building-to-Grid model is to test the load shedding at critical times. A structure with consumption in tens of kilowatts (kW) would not be able to make any significant difference in its peak time load by shedding its non-critical load. Therefore, a participant of this research needs to be flexible enough to shed a minimum of few hundred kilo-watts for effective testing.

Fig 3: Commercial EMS Application

Source: Carbon-Pros Analyst Blog Smart Grid Technology-Getting ahead of the curve [24]
6.1 Predicting Future Load Trends

While the process of a test bed implementation is carried out, a detailed study needs to be conducted to predict significant load changes in the future. There might be future plans for building expansion, adding new laboratories, shutting down or moving some load off the building. In case of UCB, one of the major loads – the Micro Fabrication Lab had been removed from the building after the initiation of Building-to-Grid testbed project. Owing to this move of Micro Fabrication Lab, there was a 250 KW of energy consumption alteration in the building with the resulting baseline load of 750 KW. Since the resulting building now consisted mainly of office type loads and a server room, this did not leave much margin to reduce significant amount of load during peak hours and hence perform demand response procedure effectively. On the other hand, CSUS has already committed to participate in a manual demand response with SMUD, agreeing to reduce the load by 400 KW at peak times. Studies done at University of California, Merced and at CSUS found that 50% - 75% of the load in a building complex or a campus that was shed for auto DR purpose was due to air supply handler fan in HVAC system and the mechanical load. Lighting in the buildings contributed 15% - 40% of the load saving while plug-in loads accounted for 7% - 10% [25].

6.2 Factors for approaching the Testbed

For understanding the consumption pattern of a building, the most vital step is to have sub-metering installed in the building. There are a large number of benefits obtained by sub-metering from engineering, management and business point of views. A few have been summarized here to
demonstrate its importance for the testbed project. From the perspective of engineering, first and foremost, sub-metering is the only means to determine the baseline load of a building. This baseline load alone can establish if the building can become a successful player in accomplishing Smart Grid goal of demand response and load shedding. Therefore if sub-metering does not already exist in the building, it should be implemented before any real work is done for the testbed. Sub-metering helps in identifying usage trends of each form of energy (e.g., boilers, chillers etc) and pointing out any anomalies in their behavior. Thus, it enables fast auto response to system component failures connected to energy management systems. Sub-metering helps in compiling baseline loads useful for setting contractual terms with any energy service company. For business and management purposes, sub-metering assists in prioritizing and deciding the order of building upgrades for multi-building complexes like university campuses based on their energy consumption in comparison to similar structures [26]. This type of regular feedback on the consumer’s energy usage, can lead to behavioral amendments and result in persistent demand reduction [27].

The Building Scale Monitoring for testbed can be divided into three broad areas of Sensing, Networking and Model/Feedback. Sensing being the base of this architecture can be defined as examining the data where data is loosely referred to load divided into various functional areas. The electrical data can be monitored at different levels using various meters and controllers. Physical data includes vibration, temperature, humidity, PAR/TSR light photodiodes, again measured at different levels within the building. The external data includes weather, season, occupancy, server load etc which could be collected using software or commercial devices. The second layer of this architecture is Networking. The data stored in these devices is passed to a database through internet. This layer is a complex layer in itself and deals with different routers
and interfaces to communicate. Model/Feedback is the final brick that completes the testbed architecture. Here each section deals with a range of other sections independently and through in direct paths. The hub of this system is the information bus. Sensors and building management system pass their information to the physical side of the bus. User inputs his preferences to the user side of the bus. Generation, transmission, distribution and consumer demand systems communicate via the external grid side of the bus. The hub combines and analyzes all this information and advises the areas accordingly [17].

UCB has followed the aggregation and de-aggregation scheme to analyze the real time consumption in Cory Hall. This method involves de-aggregating the building load for the purpose of monitoring, aggregating it back to find out the total consumption of the building. Several different checksum algorithms have been implemented to calculate the checksum of the load data collected. This process ultimately helps in detecting the energy losses. Aggregation of load is performed using appropriate sensors to maximize the knowledge acquired of the building's power consumption and reduce the uncertainty in the measurements to some acceptable level determined by system constraints. This information is then used to devise a method of either eliminating or reducing these energy losses, making the flow of energy smooth and if possible, loss-less throughout the structure. Till date, the technique is working smoothly at Cory Hall and can be implemented at CSUS and other similar facilities for load disintegration.

While observing the process followed at UCB, the methodology for implementing a test bed that could be integrated for smart grid was understood and can be broken down into following steps:

- Step 1: Identify the baseline load using building sub-metering, building audit or any other suitable method.
• Step 2: Identify the areas of most uncertainty and energy losses.
• Step 3: Decide on the type and details of building load data required.
• Step 4: Identify the areas needing monitoring classified by functionality.
• Step 5: Compare commercially available off-the-shelf meters, sub-meters, monitors and sensors needed for measuring electrical energy consumption.
• Step 6: Analyze the information data model for encapsulating and communicating building data to control and monitor applications.
• Step 7: Analyze the advantages/disadvantages of incorporating wired or wireless sensors networks.
• Step 8: Investigate the protocols required to facilitate the integration of data through wired/wireless network into the larger system.
• Step 9: Identify the sensing requirements like local weather, season, room/building occupancy, server load, non-occupancy related load, auto-shutdown managing system.
• Step 10: Investigate how to transfer information from device to database.
• Step 11: De-aggregate the load and install monitors and sensors at every function level.
• Step 12: Re-aggregate the load and apply checksum technique to validate the transmitted data.
• Step 13: Perform empirical tests to evaluate the operational performance of the system and commission the system.

There could be many different ways to approach the building design. All of these should be considered carefully as the priorities and preferences could change from building to building. A few of these are mentioned here:
The first option for advancing in the building is organizing around HVAC which could then be broken down into classifying on the basis of air handler or the cooling source. This method is the most commonly used in energy management of the buildings.

The second choice is organizing around electrical distribution system, more specifically by power feeder levels.

The third way of dissecting the building is using its configuration. This again could be performed either on floor by floor basis or by classifying the building into different functional areas. Although not accurate for the whole building, this approach would provide a “complete” picture of the sector and relatively less time. However, it was observed that within Cory hall, there were several vertical sections including multiple partial floors therefore the building could not be accurately characterized by floors.

The fourth approach lays the emphasis on maximizing the mitigation efforts for the building which would in turn minimize the overall energy consumption and hence reducing the carbon footprint. If this technique is followed, there would be no effort to investigate the current energy consumption of the building rather the focus will be on remedying the problem without fully understanding the causes. While this sounds like a quick way to solve the problem at hand, the author thinks we might be wasting some time/effort in improving parts of the infrastructure which might not be contributing to any significant energy losses in the first place.

Alternatively, an energy audit of the building could be performed, starting with the total energy first and then drilling down to floors, sections and stages based on cost and uncertainty factor of that stage. This course of action would make it easier to decide the crucial places to put energy monitors and removing ambiguities in the load on way. UCB
followed this approach with slight modifications, drawing the inspiration from retrofitting works performed for Building 90 at Lawrence Berkeley National Lab.

6.3 Energy Sources

As mentioned previously, a building to grid is not possible without an efficient sensing layer in its building management system. Most of the existing buildings do not have any dedicated state sensor system which is required for load monitoring purposes. In order to make any building smarter, sensors, meters and communication equipments must be deployed in an effective and efficient manner.

The features that a building can monitor include anything and everything related to energy flow, consumption, environmental patterns. Specific examples of parameters to measure for a building using different types of meters include electrical load, amount of steam, chilled water consumption. Other factors that need to be considered by building management system are ambient temperature, outside temperature, condition & amount of ventilation, real time occupancy, the state of charge of its thermal energy storage, outside air supply rate, humidity, solar illuminance on all sides of the building, wind speed and direction, time of day energy price. The detail of the type of meters and sensors is discussed in chapters 6.5, 6.6, and 7.1. Today, human presence is easy to detect because of our close association and heavy use of technology such as mobile phones, iPods, security access cards, laptops, smart watches etc. These electronic devices when plugged in or transmitting wireless signals can become a critical medium to detect human presence. Using time of the day/year, motion detecting, carbon dioxide measuring, and various other sensors, buildings can also monitor the human activity which generally creates the energy demand in terms of ventilation, lighting, electricity, and air temperature control. This can
help the building in predicting the real time demand and forecast the upcoming energy demand and adjusting itself to the current demand.

Apart from detecting occupancy and weather conditions, a building should also be able to detect price fluctuations and act appropriately. For example, if the energy cost is beyond its permissible limit, it should shut down all the non time critical loads. It should constantly optimize these loads with energy cost in order to be economically efficient.

The buildings today meet their energy requirements through electricity and a number of other sources like solar panels, wind turbines, steam heating, chilled water for cooling etc. It is vital to know all these sources and the level of their efficiency in order to sketch a correct picture of consumption. Apart from the electricity supplied by a dedicated transformer, Cory Hall also draws its energy requirement from chilled water and steam. Air flow and ventilation play a critical role in distributing this energy efficiently throughout the building. The three different sources used to serve the energy demands of Cory Hall are discussed in details in Chapter 7.

6.4 Sector Selection and Panels
During the testbed implementation, it was observed that the structure of the building, its panels and sub-panels play a significant role in determination of the approach to analyze and dissect the building for monitoring. UCB initially decided that Cory Hall would use one whole facility meter, approximately ten zone sub meters, tens of data loggers/machine monitors and a few hundred state variable sensors for monitoring electrical load on all of its panels. In the course of investigation, it was noticed that due to the complexity of the building, strict timeline and financial constraints, it was not be possible to monitor the complete Cory Hall structure as
originally envisioned. Therefore the emphasis was given on monitoring the main electrical load and briefly on steam and water chiller consumption. In a typical B2G testbed, sector selection should be based on satisfying the following criteria:

- The sector that provides control volumes allowing comprehensive measurement of all electrical energy used within the volume.
- The sector that enables savings accounting and persistence of savings for monitoring-based commissioning.
- The sector that facilitates the analysis of potential energy efficiency retrofits.
- The sector that permits the analysis of chiller configuration options.
- The sector that enables demand-response potential.
- The sector that allows study of a range of building-typical and building-industrial sub-systems.
- The sector that enhances the ability of test bed to assist with campus energy management and climate protection goals.
- The sector that demonstrates the capability of wireless sensors.
- The sector that allows monitoring to perform internal checksums at different levels of measurement.

6.5 Meters

Meters and monitors are the key ingredients in doing a research project like this. These instruments are needed every step of the way to minimize the unknowns. It is beneficial to place the sensors/monitors in the sections with most uncertainty. This approach can aid in understanding the bigger picture of the building faster than spending time in installing metering everywhere. A few off the shelf commercial meters were analyzed and similarities were found in
the form of their digital nature and storage to communication capabilities. These meters can measure various parameters including energy (kWh), power factor ($\cos \phi$), real power (kW), reactive power (kVar), apparent power (MVA), voltage (V) and current (A) for each leg. It was noted in the meeting that UCB does not prefer to opt all the monitoring and metering system from a specific product family. In the author’s point of view, choosing reliable products with good reference from one family would eliminate or considerably minimize the compatibility issue within different devices and save a substantial amount of money spent on developing different communications and protocols. It would also be economically more efficient if different vendors are competing or/and collaborating for a similar type metering device. In terms of interoperability, there is no clear direction found yet. It is author’s opinion that the protocols that would be developed for standardizing these monitoring devices would be largely localized in the beginning.

UCB investigated different products and communicated with various vendors in order to find the best commercial product that suits their research needs. A few of the products analyzed were from Landys+Gyr, D-Mon, Hioki, ChenYang, Satec, Dent, Veris, SquareD, ACme, Itron, GE, PSL, Electro Industries, UniPower, Honeywell and Ohio Semitronics. In chapter 7, the report addresses different devices in details.

It should be noted that it is vital to have high enough measurement resolution at critical points in the power tree so that future users of the testbed can be assured of a reference-grade set of parameters against which they may judge any changes their own test devices might make. In case of UCB, there were 15 branch points coming off the distribution panels, downstream of the main building transformer. Out of the 15 points, 13 of them were equipped with monitoring devices.
The equipment should cater for maximum achievable resolution so that they give the best possible information. UCB accomplished this high resolution by having at least ± 2% accuracy in the measurements, with all three phases being measured along with load factor and energy. This enables the detection of any imbalances in the circuit.

6.6 Sensors

Sensors use transducer technology to measure current and voltage in a given appliance. Generally, the sensors are permanently installed with the equipment to be monitored. The appropriate deployment of sensing and communication system should be optimized in such a way that it takes into the account – the cost of installation and periodic maintenance and the nature of information required for its operation. This estimation of operation could be performed using various mathematical models like Bayesian, inverse, or control theoretic model [28].

At Cory Hall, the sensors were installed at the condenser pump for sensing the vibration of the motor. A few more sensors were planned for noting the humidity, temperature and pressure at expansion valve and the air vent of HVAC system. For an efficient testbed, external sensing is absolutely critical as explained in the case studies for local weather, season, room/building occupancy, server load, non-occupancy related load, auto-shutdown managing system and many more.

6.7 Communications & Networking

The two-way communication allows for a dialog between the customer and the utility so that both can manage load and generation in more effective ways. This generation and load balance is a very dynamic interplay that varies by time of day, day of the year and, in the more long term, by
population growth. The customer needs to know the real time price of their electrical energy in order to make intelligent energy demand choices. The utility requires the real time power demand by its customers. B2G systems need to collect the total use data and pass relevant and appropriate load needs to the utility in a manner that does not impinge on privacy, needlessly curtail business operations, nor place untimely demands on the electrical grid.

Fig 3: Smart Grid Communication Network

Source: Carbon-Pros Analyst Blog Smart Grid Technology [24].

Building towards a smart grid requires effective back and forth communication between the consumer and the utility. In general, for efficient consumption and load shedding at peak time, the utility is interested in finding out the real time power demand of a customer in terms of the essential and non-essential and non time-critical load, the variability in regular load etc. The
customer is entitled to make some choices about what portion is available and when it is available for curtailment. Therefore, B2G system needs to collect the total use data and pass along the available portion and the times that it may be called upon. The building systems need a reliable data collector and trustworthy communicator.

The UCB used IPv6/6LowPAN mesh network with the standard API to transfer the information from meters and sensors into the database. This could permit high-granularity energy sub-metering, monitoring, and sensing to identify and implement B2G operational strategies for dynamically reducing the electric power consumed in the facility [27]. It has been observed that certain sensors when installed near very high voltage equipment develop a risk of conducting very high currents in them and hence passing it along the low voltage sensor wires. Figure 4 below describes a smart grid communication network in the form of a flow diagram.

6.8 Data

The information management would play a critical role in supporting advanced applications, automation and a complete system integration to smooth out the operation and maintenance issues along with maximum energy efficiency and auto demand response applications [5]. UCB chose OSIsoft to replicate the data into user friendly representation. The minimum configuration required by OSIsoft is 3 Windows 2000 operating system. There needs to be a floor by floor plan and listing of the data/access points to be populated. It should be noted that it is very important to have openness of database and software which will eventually be shared within the industry.
6.9 Professional Assistance

It is worthwhile deciding the personnel for planning, designing and installing meters. UCB had two choices - hiring professional contractors versus involving in-house electricians and other relevant people from Facilities Management. While hired professional contractors could be fast, more efficient in their tasks and sometimes cheaper in the short run, skilled employees from campus could learn a lot from the work and serve as equity buy-in for future projects. For the B2G testbed at Cory Hall, three campus electricians for the high voltage group, one contractor from Siemens, four electricians installing meters and dealing with backup power, and three personnel from Facilities were selected along with Building Project Champion to oversee the process.

In order to execute the above implementation steps, professional level assistance might be essential and is highly recommended. This comes in the form of

- **Electrical, Civil, and Building Consultants** – for researching and suggesting the best suited approach for advancement, cost effective solutions.
- **Contract Manager** – for energy auditing purposes.
- **Building Champion or Facility Manager** – to guide about the existing infrastructure & its loopholes.
- **Professional Engineer** – to oversee the safety aspect and signing off any invasive changes in building configuration like new device installations etc.

The nature of this research presses to implement a number of invasive measures in the building infrastructure and the energy systems controlling it. For example, planning to install low voltage monitors in same cabinets as high voltage transformer/CT could increase the risk of fire. In such a
scenario, it is vital to get an approval from professional engineer before all the installations and improvements are conducted out. There could be other situations where professional opinion and consent might be required to meet OSH standards. Consultants and Contractors come in very handy for different kinds of assessments in the building. Examinations like Building Audit, System Audit and Energy Audit can be conducted to determine the largest loads in the building, loads with most uncertainties, and identifying critical and non critical loads in the building.

One cannot rely on the complete picture of the building based on these audits. These inspections give a snapshot of a system for a particular time of day/week/month or season depending on the length of audit. But these often can become good start in understanding the whole concept of building’s load. There is a scope for studying the difference between audit performed by professionals or by simply buying commercial products from the market and analyzing the advantages of one over the other. Learning from the inspection outcomes, we need to understand the kind of operational strategies that can be applied or improved (if existing) for the peak load period. An advantage of conducting these audits before setting up the testbed is the discovery of trends, plans or existing operational methods that were not apparent to casual observer before the inspection. These findings can prepare the building manager for encountering many of the future problems.
Chapter 7
ENERGY MONITORING

The major source of energy used in all the buildings is electrical energy. However in university campus buildings, energy is also consumed in other forms like steam, chilled water using not just electricity but often solar panels and sometimes fuel cells and wind power. The electrical energy is mostly bought from utility, whereas solar and wind energy are typically generated on site. Under the scope of B2G Cory Hall project, UCB has not monitored non electrical energy sources in detail. It is very crucial to know their exact roles in understanding the building consumption and playing a role in demand response. This section discusses the approach to take in order to monitor the consumption of all energy types.

7.1 Electrical Monitoring

For this project, meters have been classified into four groups according to their function levels. These groups are: whole facility meters for measuring the overall electrical load in the building, sub-meters to measure electrical energy consumption floor wise, data-loggers for panel based monitoring and plug-in meters to measure the power usage of individual appliances or power strips. These are discussed in detail below.

7.1.1 Whole-Facility Monitors / Revenue Meters

These meters are used for monitoring a building’s total energy input and output. The facility type revenue meters focus on power and energy readings in 15-minute increments. This device primarily measures voltage and current and then calculates watts, watt-hours based on the above readings. The recorded data may be retrieved over the internet. A Windows program is required
for setting up the instrument while a different Windows program is used to retrieve the data. Commercial data display programs may also be used to interrogate the meter through the DNP 3.0 port [21].

7.1.2 Sub-Meters
These meters are helpful in measuring parts of a building like zones or floors. A few whole facility meters overlap their functions with sub metering and hence could be used here again. These meters are ideal for large load machines or processes and measure almost the same parameters as revenue meters. Some of these meters connect to an industrial MODBUS or LAN for networking [22].

7.1.3 Data Loggers and Power Quality Monitors
Data loggers address the need of data logging, data acquisition and weather monitoring required for Smart Grid testbed research. Some of the data loggers serve the special purpose of power quality monitoring. The mobile data loggers are intended to log long term performance of a device and may require the use of potential and current transformers in order to measure three phase voltage and current. Power Quality monitors record supplementary data in addition to the typical data loggers and offer real-time metering as well as historical information. This information can be presented in graphics ad tabular form along with logging in the events, sags, swells and outages. The data loggers are meant to watch branch circuits over time, record unbalance and conductor loading. They generally do not have real-time information on demand, and don’t have a display. When installed at a service entrance, these meters can monitor the electric consumption, time and duration of any abnormality [1]. These meters save the logs to a SD memory card at an average rate of about 1GB per year. There is also an Ethernet module for
email support, and web/ftp support for accessing files stored on the memory card. The basic
power quality monitors primarily measure voltage, but advanced models are capable of
calculating and reporting current, power in watts, apparent power in volt-amps, reactive power in
vars, power factor, watt-hours, and VA-hours. The interface seems to be simple but with very
extensive features for power quality. The best long-term value is the elimination of proprietary,
HASP-protected, annually renewable Windows software. The configuration can be easily
modified through a text file and data interpretation is done through GIF and CSV files. Some of
the power quality meters have been noted with an accuracy of 0.05% for voltage channels and
0.2% for current channels [2].

Fig 5: ACme Plug-in meter developed by University of California, Berkeley

Source: Design and Implementation of a High-Fidelity AC Metering Network [29]
7.1.4 Plug-in Meters

For individual energy measurement requirements, plug-in meters can be used. They are small devices (size of a laptop AC adaptor) which can be plugged in the wall socket to wirelessly monitor and control AC devices. “ACme” is a good example of plug-in meters and is an invention of UCB. It fits in between the expensive network energy monitors and cheap LCD wattmeters. The communication network can be connected to the individual meters via direct IP communication. This scheme of ACme system has three layers in it – the node for metering and controlling interface to an electrical outlet, a mesh of network to export the interface to IP endpoints, and applications which use this networked interface to provide power-centric applications [18]. The research shows that ACme system can be installed in the building using clamp on methods for current to voltage conversion. Depending on the installation parameters, the system has some disadvantages as discussed in [20].

7.2 Steam Monitoring

It has been observed in some CSUS buildings that simultaneous heating and cooling are going on at different ends or different floors as mentioned in the case study. While this could be an approach adopted by energy management systems depending on direction of sun or some other parameter, but it clearly highlights the need to have accurate monitoring of all energy sources being consumed in a building. Although, for this project UCB places its focus on monitoring mainly the electrical power in Cory Hall, the steam or chilled water usages are inescapably intertwined with the electricity consumption in the air-conditioning systems.
7.2.1 Use of Steam in HVAC

For most of the multi-zone air conditioning systems, simultaneous heating and cooling schemes for temperature control are used. Multi-zone air conditioning system is a system with multiple temperature control zone settings for same air-handler. A typical example of this could be the variable air-volume re-heats. Air is cooled to the temperature required by most heavily loaded zone with a margin for safety. The air is then reheated through steam supply to temperatures needed to maintain less populated areas and spaces like corridors in a building. Therefore to apply demand response to this kind of scenario, the concurrent use of steam along with electricity for AC consumption needs to be understood and measured. The demand response in this case would also result in the reduction of steam which would further allow the available steam for use in cooling, displacing electric chiller usage [30].

7.2.2 Quantity to Measure

There are two different ways to measure steam consumption in a building - volumetric flow rate and mass flow rate. For research and benchmarking purposes, conversion to energy per unit time is also acceptable. Volumetric flow rate can be measured by installing a condensate meter. Mass flow rate is obtained through a state determination for saturated liquid, using a pressure or temperature measurement. Energy per unit time can be obtained by applying the latent heat of vaporization to the mass flow rate. In this reduction, it is assumed that

1. There is no superheating of steam supply.
2. There is no sub-cooling of the condensate.

These assumptions typically carry much less error than the determination of volumetric flow rate.
7.2.3 Ideal Metering Combination

The building steam usage including the waste ‘steam’ is at a very low flow rate, orders of magnitude lower than the peak rate. Steam supply meters will not register at all under these low flow conditions, thus making the measurement through them inaccurate. Therefore, condensate meters are more popular and preferred for steam measurement. However, a steam meter can complement a condensate meter as a leak detector as in the case of Cory Hall. If both meters are monitored under flow conditions high enough to obtain accurate readings from the supply meter, differences can be interpreted as leaks. The leaks can then either be fixed or taken into account in the measurement process. Thus a combination of supply and condensate meter is the ideal, with each meter supporting the other's weakness.

7.2.4 Steam Traps

In any given steam system, there is always some level of thermal loss and some rate of condensation of the saturated steam pervading the steam supply piping network. This liquid fraction must be continuously removed from throughout the system and bypassed to condensate lines. This is done with steam traps. Steam traps are hard to maintain and often leak gas phase through to the condensate side. This is a major mode of waste in steam systems, both inside and outside campus buildings. Traps are the source of constant low flows, even with no end-uses active.

7.2.5 Accuracy

The uncertainty associated with steam measurement is significantly greater than for electrical measurements. The inaccuracy could vary by +/-10% but due to the limited knowledge of steam
usage and for the purpose of this research project, this type of monitoring is considered most suitable approach.

7.2.6 Practicality of District Steam Systems

It should be noted that in the present environment, steam is not the preferred method for thermal energy distribution within the UCB campus. The present system of this thermal energy distribution has been inherited as part a more than 100 years old legacy. Many university campuses like University of California, Irvine and University of California, San Diego have used hot water for thermal distribution. Stanford University is planning to replace its steam system by hot water distribution system and local steam generation for certain high temperature uses.

7.3 Chilled Water Monitoring

As mentioned before, measuring chilled water is crucial for tracking the energy consumption of AC during peak hours. Metering of chilled water energy requires measurement of water flow and differential temperature using a “Btu Meter”. Similar to steam measurement, chilled water flow has some difficulties associated with its measurements. However, the accuracy of meters is better in comparison to steam.
The testbed project was aimed to determine how to best implement building-to-grid communication with a “smart” electric grid, including evaluation of commercial issues, technical barriers to deployment, and technical analysis of smart grid technology. The project developed a research and development roadmap for technological progress based on the initial evaluation. In order to evaluate specific smart grid strategies, CITRIS scientists are building and testing small-scale software and hardware models. The knowledge gained could help determine the feasibility of a large facility test bed with commercial and industrial loads that can provide detailed load information to the grid (subject to privacy constraints) to allow for better grid management. The study involving the building to grid testbed would help in identifying these loads more clearly which would further help in energy requirement forecasting, energy waste elimination, efficiency in operations, load shifting, adjusting and optimizing.

UCB created a test bed facility at Cory Hall to research and test strategies useful in making buildings capable of responding to electrical critical pricing periods and simultaneously improving baseline energy efficiency. For the test bed research at Berkeley, the Smart Grid was identified in simpler term as an intelligent electrical grid which has the capability to predict electrical power demand, supply that demand successfully, heal itself when needed and optimize generation and distribution based on the consumer demand. While the promise for a Smart Grid is achievable in the long term, the current emphasis is on a “smarter than current” grid that can be built using existing technology [16]. UCB investigated existing tools to accomplish this Smart Grid technology and is aiming to create new tools as the research evolves. CSUS documented the
methodology followed by the UCB team in order to extend this research framework at the California Smart Grid Center in Sacramento. A primary goal of the methodology was the dispersed and pervasive monitoring of a large complex electrical load to understand and track the energy consumption pattern of Cory Hall.

Cory Hall UCB’s Electrical Engineering Department, is a 200,000 sq ft building and is the campus’ 5th heaviest user of electrical power. It draws an average of 1 MW from the grid annually. It uses approximately 45 kilowatt-hours (KWh) of energy per sq ft per year supplied from a three phase 12 kV dedicated transformer. Built in 1950, this building has a collection of classrooms, offices, instructional and fume hood installed laboratories, machine shop, old elevators and a 10,000 sq ft micro-fabrication facility. Recently, the micro-fabrication facility has been moved into another building as mentioned above. In addition to these, Cory Hall houses legacy electrical instrumentation, and a ventilation system that has been characterized as “very inefficient” which serves the building’s six floors [26]. Thus, Cory Hall served as an excellent case for implementing energy efficiency and building retrofit techniques.

Collaboration Day was held at UCB with the intention to expand the association with the prospective and suitable vendors for metering instrumentation, implement their technologies into the project and share the information gained from their presentations in order to reach a final decision about the product brands. The guidelines for participation in the project including the type of indemnifying language found were specified. The documentation supplied/supported by the vendor for an adaptor interface that conforms to an open standard was requested. A template was provided to the vendors to complete in order to become a participating partner.
The UCB B2G project installed approximately 200 electrical current monitoring devices, a steam condensate meter and commissioned a system that collects and stores all this monitoring data in near real-time. The UCB team actively sought assistance and input from established vendors in the electrical power field which resulted in the selection of devices and software which are proven, meet established electrical power code guidelines and achieve research level data gathering capability. The electrical monitoring was installed in March 2010 and was prepared for future tweaks typical in a research project. The data collected through various tests showed how pervasive energy monitoring could pinpoint operational energy losses in the case of a chiller running during a cool weather period. sMAP software was used for data communication and interfaced successfully with the meters. The tests conducted suggested that the software met satisfactory performance criterion. The empirical results from the meters demonstrate success in pervasive energy monitoring within Cory Hall. It is anticipated that the testbed would highlight the anomalies in flow of energy, losses and a clear direction towards load shedding capabilities of Cory Hall.
Chapter 9

CASE STUDIES

9.1 Case Study A: Thermal Chiller in Utility Plant at CSUS

The CSUS campus spreads over 300 acres, consumes 90,000 – 94,000 British thermal units (Btu) per square foot per year of energy. For the academic year of 2008/09, the energy consumption was 43 million KWh/year in terms of electricity and 1.2 million therms/year in terms of gas, distributed across the campus. In fiscal terms, the energy consumption is split as 3.5 million dollars per year on electricity and 1 million dollars per year on gas. The gas consumption year is typically from November to April as shown in figure 6.

Fig 6: CSUS Monthly Energy Usage Trend for academic year 2008/09

Source: Data collected from Campus Facilities Management, CSUS
Gas fired boilers are used 24/7 during the winter months to provide heating to the campus buildings. Two of three boilers are equipped with a capacity of 45,000 pounds/hour and the third one produces 25,000 pounds of steam every hour. Three water chillers - 1250 tons each, produce chilled water at night and store it in Thermal Energy Storage (TES) tanks for supplying air conditioning loads. In addition to these, the campus has limited solar photovoltaic (PV) installed on a few buildings for charging electric carts and parking lot lights. Solar energy is also used to heat water for limited areas in the campus like Yosemite hall and Riverfront Center. There is a contractual agreement in place, which in 2011 would see the installation of solar PV on many buildings in the campus like library, parking structures etc to produce electricity. All the buildings on campus have external temperature sensors to feed the building management system about the changes and react accordingly [31]. There is no single building on campus which is a directly similar to Cory Hall at UCB. Thus, this methodology from UCB will be extended to a campus-wide effort on the CSUS campus similar to an industrial park or large corporate campus.

The Public Interest Energy Research Program (PIER) study (with LBNL) suggested that buildings with a baseline load above 200 KW and equipped with centralized controls are the ideal customer targets of a demand response program. This is due to such building’s energy needs, their ability to shift energy use by use of an energy management system and their potential to reduce the load at critical times [17]. A structure with consumption in tens of kilowatts would not be able to make any significant difference in the peak time load by shedding its non critical load. Therefore, a participant of this B2G research needs have large enough loads and to be flexible enough to shed a minimum of a hundred to a few hundred kilowatts for effective testing. California State University Sacramento satisfies all the above conditions therefore; it can become
a very promising player in automated demand response program and can accomplish desirable results more effectively.

The thermal energy storage shifts the CSUS campus peak electric loads (producing chilled water) to night time resulting in a flat daily load curve and a lower daytime peak. This makes it easier to predict the daily load more precisely, become prepared for the peak and commit to demand response with indemnity. Although a commitment to curtail up to 400 KW during critical pricing periods has been made by CSUS, the Facilities Management staff agrees that there is a broader scope to reduce the peak time energy consumption of the campus [31]. Establishing the maximum possible energy load that can be shed off at critical times without hampering the operations at campus, and committing to it through automated demand response is another goal of Smart Grid Center at CSUS.

Seasonal load variability is a crucial factor that decides the effectiveness of demand response. Berkeley, due to its geographical location experiences relatively mild humid weather year round and has reduced air conditioning requirements without extensive heating needs. Sacramento in comparison, receives abundance of sunshine resulting in hot summers reaching an occasional 110 °F transiting to cool winters. This provides good weather variability to reduce CSUS campus load due to air conditioning in the summer months and heating needs during the winter. For energy efficiency, the steam producing boilers are typically switched off for the summer months of May till October unless unreasonable weather prevails.
9.2 Case Study B: Riverside Hall at CSUS

The Riverside Hall at CSUS receives a lot of sunshine during summer months. Presently there is no sensor or other instrument to detect the amount of sun light falling on the building windows and exterior walls. This implies that the air conditioner does not reflect the temperature change when west side of the building gets too hot in the afternoon. It has been seen that while the top floor on west side reaches a temperature of 110 degree Fahrenheit in summer afternoons, the first three floors on the east side sit at a temperature of around 85 degree Fahrenheit. At peak time of 4pm during summer months, the desk computers are often seen automatically hibernating due to excessive heat in the west facing rooms. Sometimes, the building is still running the air conditioner at 65 degree Fahrenheit while the outside temperature has dropped to 60-70 degrees as well. In a building to grid, the sensors would be able to detect different temperatures in different areas and would adjust accordingly in those areas. This would eliminate the unnecessary load on the grid as well as avoid energy wastage. Although it has been mentioned above that for energy efficiency, the chillers and heaters operate for fixed months irrespective of the outside temperature, the author estimates that if the campus adapts an efficient building management system, much more energy could be saved in terms of HVAC.
Chapter 10

POTENTIAL ISSUES TO ADDRESS

The development of the testbed presented many interesting challenges along with the lessons learned on way. Nevertheless, there are still a few issues that need to be addressed and investigated beyond the scope of this project.

10.1 Solar Flux

The emphasis in the Cory Hall Building- to-Grid project has been laid on the “purchased” energy from the utilities such as electricity, gas and water. For certain areas such as Sacramento, the solar load varies a lot (in terms of timings as well as direction) and makes a huge impact on the overall energy consumption within the campus. Therefore it is crucial to determine the solar flux measurements from solar cell installations on the campus. Generally, this kind of data cannot be inferred from the models. In terms of empirical/benchmarking focus of building-to-grid - solar flux, external weather conditions, air intake and exhaust should be included to other energy modelers as potential users of the testbed.

10.2 Industry Needs and Security

The Smart Grid research needs to address the unique business and regulatory drivers in order to successfully and smoothly implement the testbed in the industry. Integration of new and existing systems, combination of electrical and other energy sources and security of the system while still being open and transparent are some topics that need to be dealt with in the future. North American Electric Reliability Corporation (NERC) has developed Critical Infrastructure Protection Standards to improve protection, automation and increased reliability and control [8].
It is predicted that smart meters, sensors and advanced communications networks can themselves increase vulnerability of the building and ultimately of the grid to cyber attacks. Therefore, a testbed needs to address these cyber security concerns which requires comprehensive, built-in security during implementation.

10.3 National/International Standards

Given the load consumption trend at Cory Hall, it was decided that the monitors should sample data every fifteen minutes roughly along with the capability to measure instantaneous data. However, to make the accurate comparison of monitoring with other buildings implementing smart monitoring, it would be wise to conform to the metering standards. The SGN scorecard can be used as a benchmark to check various products available off the shelf against Smart Grid standards set in the industry. The present compilation of standards and industry models are based on the knowledge set by the American National Standards Institute, the Electric Power Research Institute, GridWise Alliance, the International Electrotechnical Institution, National Rural Electric Corporative Association, and the Institute of Electrical and Electronic Engineers [8]. Other associations like Common Information Model (CIM), Utility Communications Architecture (UCA), Application Service Element 2 (TASE-2), and the Grid Wise Architectural Council concepts all contain valuable knowledge to assist utilities and integrators in achieving interoperability. Hence, there is scope and need for detailed investigation of the standards which are approved by IEEE and conforming to them.
Chapter 11
INFORMATION REUSE AND FUTURE WORK

California Energy Commission sponsored the UCB Building-to-Grid project so that the operational methodology behind B2G could be researched and tested in a real world building which draws an accurate portrait of energy consumption. The long term goal of B2G research is to attempt maintaining current levels of perceived building occupant comfort and utility while implementing strategies to reduce the energy cost of that comfort and utility.

As mentioned previously in the report above, to the author’s knowledge, there is no building on CSUS campus which is equivalent to Cory Hall’s energy consumption. Nor does there appear be a need for such a direct one-for-one equivalency. However, in the process of finding the ideal building, the CSUS team recognized that part of the work would be best suited at campus level. The data gained from UCB would be used by CSUS and other research institutions for examining, modeling, and visualizing rather than duplicating the testbed at every institution. This data could be used by facility managers to create more effective demand response strategies needed for load management.

As part of another grant, CSUS would be installing smart meters on key campus buildings. Thus the CSUS campus will likely be able to acquire significant data on a suite of buildings along with the high resolution electrical energy map of Cory Hall. This would lead to a better understanding of campus level interactions and energy load shedding/shifting opportunities for the purposes of demand response. This research will deliver descriptions of the current campus systems, planned
changes and updates, and create a range of electrical power simulations which model the physical plant.

Necessary infrastructure like wireless routers, computer servers, sensor test platforms, and various forms of instrumentation systems would be required to feed the upcoming research. This research is by no means complete and other fruitful topics will arise as the research evolves. In this case, the effort is indeed broad ranging and potentially critical to the future of energy in California.

While this paper was primarily focused on the Building-to-Grid activities, it will be the communications and database structure that enable B2G. In a given system, there will hundreds of sensors, both wired and wireless, sending data over time intervals as short as fractions of a second. This data will need efficient tagging, transmission to a central storage point, and the development of capable data mining algorithms that lead to successful control of the building or campus system. This will be a multi-disciplinary effort requiring development of low-power low-cost sensors for pervasive monitoring of many building and environmental factors, interfaces to existing building energy management systems, extensive integration of renewal resources and systems capable of time-shifting energy use.
Chapter 12

CONCLUSIONS

The report describes the methodology needed to implement Building-to-Grid test bed and discusses various terms that are used in this project such as Smart Grid, Building-to-Grid, Demand Response and Load Management. A step-by-step summary of crucial steps have been included followed by their detailed explanations. The work done by UCB, in terms of the approaches they followed and the monitoring devices have also been included. Lessons learned, observations made while shadowing the B2G project have all been discussed from time to time in the report. Emphasis has been laid on the potential problems that could be encountered and approaches to consider while conducting similar research. The report also mentions the issues and areas that need to be addressed in the future for more successful communication with Smart Grid. The building-to-grid research at UCB resulted in acquiring extensive sensor and monitoring data to see trends in electrical energy consumption. Relatively less emphasis was put on steam and chilled water monitoring which the author described as crucial components in load management and energy efficiency. This report could be used by the customer (in this case CSUS facilities management team) to gain the knowledge and therefore the use their power to make the most financially intelligent decision concerning their energy consumption.
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[30] Electronic mail conversation between Karl Brown (Facility Manager) and Scott McNally (B2G UCB Project Champion), March 18, 2010.

[31] – In interview with Nathaniel Martin (Energy Conservation Coordinator, California State University, Sacramento) April 2010.
# GLOSSARY

<table>
<thead>
<tr>
<th>ABBREVIATION / TERM</th>
<th>DEFINITION</th>
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<tr>
<td>API</td>
<td><strong>Application Programming Interface (API)</strong> is an interface implemented by a software program at an abstract level that enables it to interact with other software programs or set of functions used by components of a software program.</td>
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<tr>
<td>Carbon Footprints</td>
<td><strong>Carbon Footprint</strong> is a measure of how our daily activities can affect the environment, and in particular climate change. It relates to the amount of greenhouse gases produced by an organization, event or product.</td>
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<tr>
<td>Checksum</td>
<td><strong>Checksum</strong> is a value which is computed which allows us to check the validity of something. Typically, checksums are used in data transmission contexts to detect if the data has been transmitted successfully. Several different checksum algorithms have been implemented to calculate the checksum from the transmitted data.</td>
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<tr>
<td>Circuit Breaker</td>
<td><strong>Circuit Breaker</strong> is an automatically-operated electrical switch designed to protect an electrical circuit from damage which is caused by overload or short circuit. Its basic function is to detect a fault</td>
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condition and, by interrupting continuity, to immediately discontinue electrical flow.

<table>
<thead>
<tr>
<th>Data Acquisition</th>
<th><strong>Data Acquisition (DAQ)</strong> is the process of sampling of real world physical conditions and converting resulting samples into digital numeric values that can be manipulated by a computer.</th>
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<tbody>
<tr>
<td>Database</td>
<td><strong>Database</strong> is an organized collection of data for one or more multiple uses. A database is a collection of information that is organized so that it can easily be accessed, managed, and updated.</td>
</tr>
<tr>
<td>Data Loggers</td>
<td><strong>Data Logger</strong> is a small, battery powered, portable and microprocessor based device that can read various types of electrical signals (including but not limited to temperature, humidity, voltage etc...) and log the data in internal memory for later download to a computer.</td>
</tr>
<tr>
<td>Data Models</td>
<td><strong>Data Model</strong> in software engineering is an abstract model that describes how data are represented and accessed. It also models relationships between data elements.</td>
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<tr>
<td>Electrical Load</td>
<td><strong>Load Management</strong> is the process of balancing the supply of electricity on the network with the electrical load by adjusting or</td>
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<tr>
<td>Energy Generation</td>
<td><strong>Electricity Generation</strong> is the process of creating electricity from other forms of energy. This is the first step that is performed by electric utilities to transfer electricity to the customers.</td>
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<tr>
<td>Energy Distribution</td>
<td><strong>Energy Distribution</strong> refers to the process of transporting energy from transmission systems to end-use customers.</td>
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<tr>
<td>Energy Transmission</td>
<td><strong>Energy Transmission</strong> is the bulk transfer of electrical energy, from generating plants (e.g. hydroelectric, nuclear, natural gas, wind, solar, geothermal) to substations.</td>
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<tr>
<td>Energy Loss</td>
<td><strong>Energy lost</strong> or wasted in the transmission of energy from the generator to the eventual customer.</td>
</tr>
<tr>
<td>Energy Management Systems</td>
<td><strong>Energy Management System (EMS)</strong> is a system of computer-aided tools used by operators of electric utility grids to monitor, control, and optimize the performance of the generation and/or transmission system.</td>
</tr>
<tr>
<td>Fully-Automated Demand Response</td>
<td><strong>Fully-Automated Demand Response</strong> or <strong>Auto DR</strong> is the pre-programmed load shedding plan that uses the communication signal</td>
</tr>
<tr>
<td><strong>HVAC</strong></td>
<td><strong>HVAC</strong> is an acronym that stands for the closely related functions of &quot;Heating, Ventilating, and Air Conditioning&quot;.</td>
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<tr>
<td><strong>Intranet</strong></td>
<td><strong>Intranet</strong> is a private computer network that uses Internet Protocol technologies to securely share any part of an organization's information or operational systems within that organization.</td>
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<tr>
<td><strong>Load Shedding</strong></td>
<td>When the electric power supplier company receives more demand for electrical power than its generating or transmission or installed capacity can deliver, the company resorts to rationing of the available electricity to its customers. This act is called <strong>Load Shedding</strong>. Load shedding can also be referred to as Demand Side Management or Load Management</td>
</tr>
<tr>
<td><strong>Manual Demand Response</strong></td>
<td><strong>Manual Demand Response</strong> is the process where the operator of the building physically turns off the load when requested by the utility or ISO.</td>
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<tr>
<td><strong>Mezzanine</strong></td>
<td><strong>Mezzanine</strong> (architecture), an intermediate floor between main floors of a building.</td>
</tr>
<tr>
<td>Routers</td>
<td><strong>Router</strong> is a networking device consisting software and hardware that interconnects two or more computer networks, and selectively interchanges information between them.</td>
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<tr>
<td>Semi-Automated Demand Response</td>
<td><strong>Semi-Automated Demand Response</strong> is the process where the consumer’s building energy management drops off a pre-specified amount of load upon receiving a signal from the ISO/utility.</td>
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<tr>
<td>Sensors</td>
<td><strong>Sensor</strong> is a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument.</td>
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<tr>
<td>Smart Grid</td>
<td><strong>Smart Grid</strong> is an automated, two-way communication systems implemented using digital instrument which can be used to deliver electricity from suppliers to consumers using two-way digital technology in order to control appliances at consumers' homes to save energy, reduce cost and increase reliability and transparency.</td>
</tr>
<tr>
<td>Step up Transformers</td>
<td>A &quot;<strong>transformer</strong>&quot; changes one voltage to another. A &quot;step-up transformer&quot; converts the low voltage at the input terminals and converts it into higher voltage. Thus, it can be used in conjunction with a device that requires high voltage power supply.</td>
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<td>Tabular Row</td>
<td>Step down Transformers</td>
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<tr>
<td>Transmission Lines</td>
<td>Transmission Line is the material medium or structure that is used to transfer energy (e.g. Electromagnetic waves, electric power transmission) from one place to another.</td>
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<tr>
<td>Wireless Mesh Networks</td>
<td>Wireless Mesh Network (WMN) is a communications network made up of nodes organized in a mesh topology. Major components of WMN are mesh clients, mesh routers and gateways.</td>
</tr>
<tr>
<td>Wireless Sensor Networks</td>
<td>Wireless Sensor Network (WSN) is basically a collection of autonomous sensors which are distributed spatially throughout the building. WSN is basically used to monitor physical or environmental conditions, such as temperature, sound, pressure, humidity etc.</td>
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