Public Interest Energy Research (PIER) Program

FINAL PROJECT REPORT

CSUS DOCUMENTATION OF THE UC BERKELEY BUILDING-TO-GRID METHODOLOGY

Building-to-Grid (B2G) Technology Evaluation and Roadmap project

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PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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Building-To-Grid Testbed at Cory Hall, UC Berkeley: CSUS Documentation of the UC Berkeley Methodology is the final subreport for the Building-to-Grid (B2G) Technology Evaluation and Roadmap project, work authorization number BOA-99-234-R-1 conducted by UC Berkeley and CSU Sacramento. The information from this project contributes to PIER's Buildings End-Use Energy Efficiency Program.

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ABSTRACT

The University of California (UC), Berkeley has created a Building to Grid (B2G) testbed facility in one of their buildings named Cory Hall. The B2G testbed will allow research and test 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 the creation of the Cory Hall testbed to gain knowledge on the research methodology, the processes involved in creating a tested facility and the problems that may be encountered while conducting this type of research. This report describes the methodology developed by the UC Berkeley team to implement the testbed at Cory Hall. The California Energy Commission has funded this research project with the intent sharing the information gained with others doing similar work. Therefore, this paper also briefly discusses possible future translation of the UC Berkeley methodology to CSUS based California Smart Grid Center's building-to-grid research. The project saw installation of approximately 200 electrical current monitors/meters, a steam condensate meter and a hybrid communication infrastructure involving wired and wireless systems. The system is now in operation after commissioning in May 2010 and stores the various data in near real time. The empirical results to date demonstrate success in pervasive energy monitoring within the building. It is anticipated that the Cory Hall testbed project will showcase the benefits of continual monitoring the energy flow in a building, the ability to discover energy losses on an on-going basis and provide clear direction towards implementing load shedding and load shifting strategies by the Cory Hall energy management system.

Keywords: Building to Grid, B2G, Smart Grid, Automatic Demand Response, Load Management, Energy Efficiency, California Smart Grid Center

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EXECUTIVE SUMMARY

Introduction

A team of researchers from CSU Sacramento was invited to peer over the shoulder (shadow) the UC Berkeley Building-to-Grid (B2G) testbed creation from September 2009 through May 2010. Paraphrasing from the grant statement of work, the project's goal was to develop an RD&D roadmap through an examination of B2G commercial issues, and technical barriers to deploy B2G communications in a Smart Grid. The grant also tasked the researchers to perform technical analyses of various aspects of Smart grid technology. In order to examine specific Smart Grid strategies, Cory Hall on the UC Berkeley campus was modified by the installation of about 200 electrical power sensors, a few other energy monitoring devices, and a communication infrastructure to gather and then store all this data. Thus Cory Hall was transformed into a small-scale Building-to-Grid model with the sensor and system data to be analyzed in companion software models. This B2G project employed researchers from many other institutions such as the California Institute for Energy and Environment (CIEE), the Center for Information Technology Research in the Interest of Society (CITRIS), Lawrence Berkeley National Laboratory, as well as both graduate and undergraduate students from these universities. The methodology of the UC Berkeley team is summed up in a fourteen point flow chart that briefly describes the B2G implementation process from the entry level typical legacy energy management system to the pervasively monitored state of the art building to grid system able to respond to automated demand response signals.

Purpose

The creation of a B2G testbed in the Cory Hall building was predicated on the desire to more fully understand the energy flow within a typical commercial building. Recent advances in low-power sensors, instrumentation and wireless technologies have enabled a huge enhancement to common building energy management systems. Comprehensive building state data is now possible which, in the words on one researcher (Karl Brown), means we can now fairly completely determine a building's energy envelope. Thus a goal of B2G is to gain the knowledge required to understand how all the functions in a building lead to the energy consumption of the building or conversely how the energy flows to arbitrary functions of the building occupants. The UC Berkeley team has phrased this as "disaggregate the total building energy usage to specific functions, and then re-aggregate the functions to the total building load." When this can be done, the building managers can determine with much more certainty the impact of taking certain efficiency measures on the building's occupants. This approach moves beyond just altering the baseline energy consumption of the building in a manner similar to accomplishing an energy audit. Presuming the correct sensor types, placement and capability combined with near real time data collection and data manipulation, building managers could have predictive models of the building's near term energy needs under current conditions such as expected building functions, weather and electrical pricing. At this level of capability, the building systems could then respond to critical energy periods such as summer cooling loads which have in the past caused brown outs and black outs in California. The California Smart Grid Center (CSGC) at CSUS shadowed the UC Berkeley project with the goal of augmenting the CSGC's regional expertise in traditional power engineering with this project's current and in-depth review of B2G technologies. The CSUS team will be creating other similar scale projects on the CSUS campus and the UCB B2G project played a major role in the defining these future efforts. One of the future projects will be to provide visitors to the California Smart Grid Center dedicated resources to visualize the Cory Hall data and showcase the efforts and results of the UC Berkeley B2G research.

Objectives

Again, paraphrasing from the statement of work, there were eight tasks in Phase I of this grant. They were: (1) instrumentation and network architecture survey, (2) a design and review process that will establish the necessary specifications of the equipment, (3) equipment installation, (4) commissioning and qualification of the equipment and systems, (5) evaluation setup process documentation (this document), (6) utility liaison, (7) project review and summary, and (8) evaluation of the challenges.

EnerNex**,** an electric power engineering and consulting firm specializing in the development and application of new electric power technologies, performed Task 1. They reviewed hundreds of vendors of off-the-shelf devices including commercial electric meters, submeters, monitors and sensors that had seemed to have immediate application to the Cory Hall testbed. This task was accomplished by the beginning of October 2009, with additions made as needed during the remainder of the project. EnerNex provided a slide deck and MS Excel spreadsheet with details of devices and vendors.

The building-scale monitoring architecture, Task 2, was a joint effort by Lawrence Berkeley National Lab (LBNL) and UC Berkeley. LBNL implemented a demand response project in Building 90 of their facilities in 2003 to 2007 and has significant experience in the architecture issues. With the attention now focused on Cory Hall, the combined teams analyzed the information data model appropriate for B2G, investigated the use of standard, open communication protocols for wired and wireless sensor networks, suggested a design for the network architecture, and designed a data storage system for the access, aggregation and distillation of the various acquired data from the installed sensors and systems. This work continued into December of 2009 with considerable dialog with many vendors to flesh out the capabilities and attributes of appropriate off-the-shelf devices for B2G. The Task 2 team provided a slide deck to summarize their work.

Task 3 was the sensor network procurement and physical installation. This task occupied a large amount of time and effort including vendors, technicians, electricians and other physical plant support specialties. A fire in the semiconductor fabrication facility during the Fall 2009 academic quarter demonstrated the sensitivity of the building occupants to power disruptions. In light of the fire event, the building manager took exceptional efforts to coordinate future power interruptions to minimize the impact on activities within Cory Hall. Various preliminary infrastructure tasks such as installation of equipment cabinets and wiring routing were accomplished in February and March 2010. A few current transducers were also installed during this same time span where the installation would not interrupt any sensitive activity. A complete shutdown of Cory Hall was accomplished on March 22, 2010 for the purposes of completing the sensors installation and to correct some post-fire issues. The installation involved hundreds of sensors, various wireless and wired routers, access panels and associated hardware. The Cory Hall building manager, Scott McNally, provided building plans annotated with installation locations and photographs of the installation work.

The system qualification and commissioning, Task 4, was begun in early March and will end with the formal system demonstration in July 2010. UC Berkeley will develop analyses and empirical tests to evaluate the operational performance of the Cory Hall B2G system including the data reporting rate, scalability of the system to other facilities, the extensibility of the UCB B2G approach, and the fidelity and coverage of the installed sensors and systems. As of the writing of this summary, the work is on-going and will be detailed in other documents.

Task 5 is the testbed creation documentation performed by CSUS. This task is completed by this document, a flow chart of the B2G process, a slide deck showing installed device names and locations in Cory Hall, and a detailed week by week chronology record of the project as recorded by documents posted to the UC Berkeley bSpace web service. This methodology document was started in October 2009, with initial drafts in March 2010 and the final documents prepared late June 2010. This task cannot hope to fully document the entire project. The main effort was to encapsulate the method for others to review. Those anticipating embracing B2G will start with this methodology review and then proceed to other specific documents for the rather extensive details that are available.

A February 2010 addition to Task 5 is the incorporation of the UCB B2G testbed and the utility substation information exchange process into the California Smart Grid Center Roadmap. The revised roadmap and a report written by the CSGC team headed by Harold Galicer documents the B2G knowledge incorporated into planning for future CSGC projects. A significant impact of the UCB B2G work was the resulting CSGC emphasis on work at the campus level in demand response. The CSUS campus level work is largely enabled by the US Department of Energy Smart Grid Investment Grant (SGIG).

The next task, Task 6, was to liaison with local utilities such as PG&E and SMUD to formulate an approach for exchanging information between the building and the grid. Task 6, in particular, discusses the approach to communication between the substation supporting the UC Berkeley campus and Cory Hall. The issues of task 6 include communication security, system reliability, and other operational issues at the critical resource level of implementation. At the national level, NIST is charged with developing Smart Grid communication standards and has issued the First Release of Framework for Smart Grid Interoperability in January 2010. At the building to electrical substation tier there are no well-established standards yet for B2G communications. EnerNex (Bill Monicref) and CSUS (Suresh Vadhva) interviewed appropriate staff at both PG&E and SMUD about the nature of B2G communications. These two Northern California utilities indicated they are interested in communications that lead to grid responsive action but in general are waiting for standards to evolve. Both utilities felt that the California PUC regulated tariff structure will be the backbone for defining the specific needs of B2G and DR communication as regards the utilities.

The last two tasks are task 7 the project review and task 8 evaluation of the challenges and potential applications of B2G implementation. They are lumped together here since they are end of project reports that will expand on the lessons learned from the Cory Hall project. The author looks forward to reading these documents as they become available in July 2010.

Conclusions and/or Recommendations

The UC Berkeley Building-to-Grid testbed is operational as of May 2010. The building's new sensors and systems are pervasive to the extent that almost all electrical loads can be determined within a few percent. Other energy sensors such as steam condensate also allow for a better determination of the building's use of energy than was available prior to this work. But rather than consider the B2G testbed as a completed entity, the testbed should remain flexible and be augmented as ongoing research is performed in Cory Hall. Future research will target such areas as data visualization, automated demand response, application of sensor technology, efficient communication protocols, advanced HVAC control methods, and other building efficiency measures. Cory Hall now provides a typical commercial building with a level of sensors and systems that move beyond normal building operation and now enable a comprehensive platform for research.

CHAPTER 1: Introduction

CSU Sacramento under the auspices of the California Smart Grid Center (CSGC) shadowed the UC Berkeley Building to Grid (B2G) testbed creation project. The motivation for the CSUS participation in the project was the creation of the California Smart Grid Center in 2009 and the knowledge that the CSGC will be a focus of both Building to Grid and Smart Grid research in the Northern California region. The UCB B2G research is partly motivated by the changing energy climate in the last decade which saw the unbundling of major electrical power services. The U.S. power generation and distribution systems were deregulated in 1998 and this deregulation was confirmed in a U.S. Supreme Court challenge in 2002. The effects of that deregulation, the increase in electrical energy consumption both in total and by capita (for most states) and emerging energy opportunities created a perception that historic energy practices need enhancement to enable real-time communication of electrical supply capability, electrical consumer energy demands and various system state and fault analysis data. The UCB team chose to concentrate on developing systems that help create the building energy state model or in less formal terms – the various data that lead to understanding the energy use in the building.

The California Energy Commission and other governmental agencies are funding research into various schemes to lead to effective B2G communication and control. The UCB B2G testbed examines aspects of electrical energy usage to determine total energy flows by functional use. As part of the grant number BOA-99-234-P funded by California Energy Commission, CSUS shadowed the UC Berkeley B2G project and partially documented the research testbed creation at Cory Hall on the UCB campus. UCB investigated existing tools to accomplish this B2G technology and adopted new tools as the research evolved. This initial testbed project established mainly the electrical load monitoring in a mixed industrial/commercial type of facility where future B2G research may be conducted. Relatively smaller efforts were also made to establish steam and chilled water consumption in Cory Hall.

The California Energy Commission sponsored this B2G 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 UC Berkeley was to establish pervasive monitoring of a large complex electrical load in order to understand and track the energy consumption pattern of Cory Hall. This testbed can then be used to identify the essential, non-essential and non time-critical load which would further help in forecasting electrical energy requirements, reducing energy waste, improve efficiency in operations, and allow for load shifting, load shedding or other time critical energy use optimization.

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 percent just by bringing a small change in their daily habits [1]. The load trend in PG&E shows that 10 percent of the annual capacity is consumed in 51 hours [2]. In the utility region covered by Sacramento Municipal Utility District, 12 percent 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 percent of all generation assets and 25 percent of distribution infrastructure are required less than 400 hours per year which is roughly 5 percent 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.

CHAPTER 2: The Need for a Smart Grid

Smart Grid is an evolving concept that at its base is concerned with enhancing the use of electrical energy production and the resultant transmission of large blocks of electrical power. One aspect is the incorporation of various renewable energy sources created in so-called distributed energy islands that are presumed to be near the end use. Another aspect is the real-time control of some portion of the electrical demand to reduce the current load on the electrical grid. There are many other aspects considered to be a Smart Grid issue that are not detailed in this report. It seems that most of the groups involved (power generation, utility, 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].

Electrical energy consumption in the United States has increased by 30 percent from 1988-98, or at an average rate of 1.7 percent per year from 1996 – 2006, while the country's transmission capacity has grown by only 15 percent during that period [5]. The U.S. Energy Information Administration (U.S. EIA) forecasts a slightly lower growth rate in the future. The U.S. EIA expects an increase of about 26 percent in electrical energy consumption from 2009 to the year 2030. The Electric Power Research Institute (EPRI) predicts an increase from 3,717 terawatt-hour (2008) to 4,858 terawatt-hour (2030) [6]. Summer peak demand is expected to increase by almost 20 percent in next ten years or more in the future as 40 percent of the population is predicted to live inlands (away from climate effects that create local cooling typically in the late afternoon or evenings) by 2040 [7]. The United States electricity system is currently 99.97 percent reliable but already faces power outages and service interruptions that cost roughly $150 billion each year. These trends indicate that action is required to combat growing energy demand which will more often saturate the existing electrical grid capacity. Efforts are underway to

- Achieve lower baseline energy usage.
- Improve energy efficiency.
- Enhance an effective demand response.
- Incorporate renewal energy resources.
- Improve electrical grid reliability through various methods.

This Smart Grid effort is very dynamic with a wide range of proposed technologies from an impressively diverse range of governments, large well-known technology companies (such as Intel, Cisco, General Electric, and many others), and small entrepreneurial ventures. But at its core, Smart Grid relies on a robust, secure and effective communications structure with an increased reliance on digital controls and pervasive sensors. The CSUS CSGC is one of many universities, industrial and commercial partners that are examining the questions related to the new smarter grid of the future. Among other activities, the CSGC will test suitable technologies in the automated metering infrastructure and the develop strategies for automated demand response at critical times [8]. Smart Grid initiatives in California are intended to fulfill three main goals as defined below [9]:

1. Integration of up to 33 percent of generation coming from central and local renewable sources.

2. Reduction of green house gas emission to below 1990 levels.

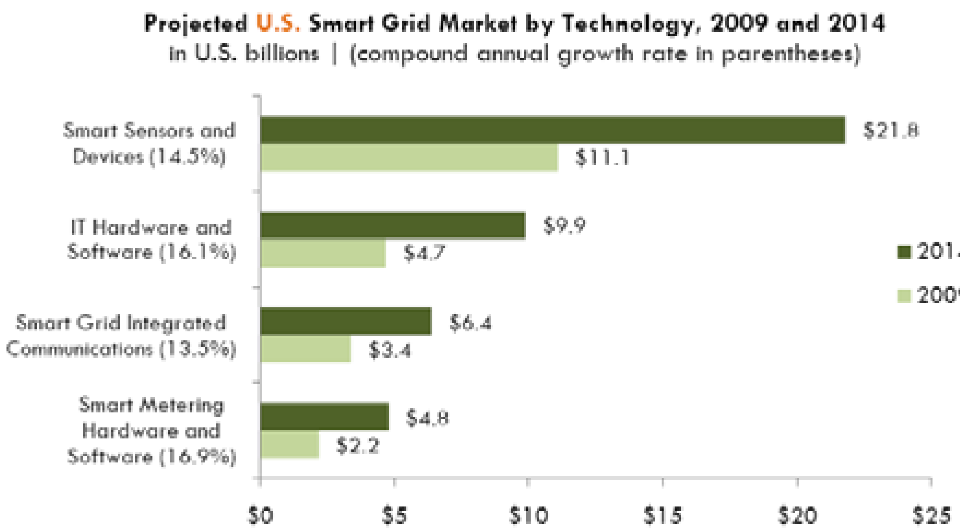
3. Creation of zero net-energy facilities by 2020 & 2030.

Key areas of Smart Grid enhancements include substation automation, smart meter communication, grid security, energy management, and data centers for all the resultant system state data. Substation automation will enable more effective fault detection/analysis/recovery and ease the entry of distributed energy into the grid. An unfortunate fact is that most renewable sources have much greater volatility than customary electrical generation sources. For example, the sun shines through the atmosphere and there can be remarkable changes in the solar flux at a ground based device within seconds much less minutes and hours. Substation controls make these distributed energy resources more available to the grid without inducing unacceptable instabilities in voltage, current or frequency. Smart meters that use digital methods to track consumer energy usage are being installed throughout the world. These meters have been installed for at least a decade and were often used as a cheaper alternative to the electromechanical meters in use for a century. But the communication method to and from the meter is still evolving with standards not yet well established. Part of this communication will require the common IT network structure to include very rugged devices that may be placed outdoors in the weather and yet survive for decades. IT technology already has extremely effective cyber security tools but the pervasive use of these cyber security tools is relatively new to the power industry. Likewise data center operations common to digital media companies will need to be modified to allow the type of automated control envisioned by most Smart Grid technology developers. And finally in this list is the use of energy management tools to allow the end consumer to modify their energy behavior through effective visualization of their consumption patterns. This project looks in detail at commercial and industrial consumers in what is called Building to Grid.

CHAPTER 3: Smart Grid Fiscal Realities

Although the 2009/2010 global economic outlook was rather subdued, the Smart Grid sector is perceived as a national-level critical component and it 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 [10]. The research firm Zpryme released a report in 2009 which states that current trends indicate the Smart Grid technologies market will increase from a 21.4 billion dollar market (2009) to 42.9 billion (2014) [11]. The bar graph provided in figure 1 from Zpryme Market Analysis shows a partial breakdown of the Smart Grid market [12].

Figure 1: Zpryme Smart Grid Market Prediction



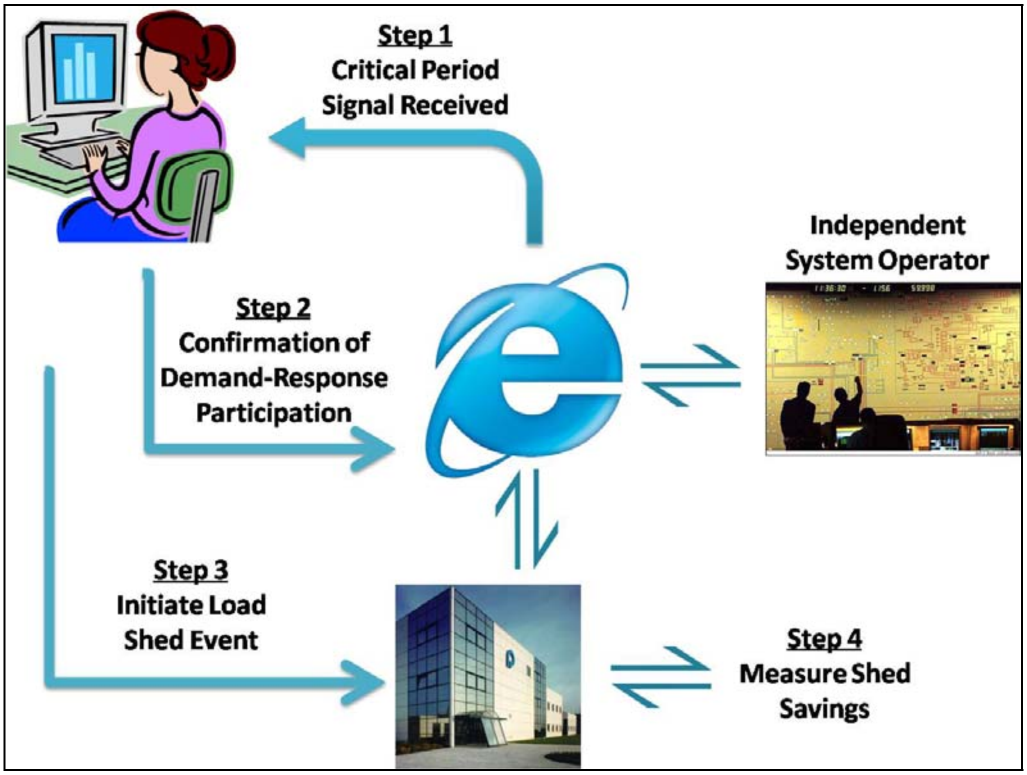
Source: Zpryme Inc., Smart Grid Industry Trends Snapshot

The Zpryme report does not discuss all the 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 factor affecting the 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 a primary and perhaps sole energy source for some consumers, it is apparent that smart grid activities will be an active area for research, commercialization, and technological innovation in the foreseeable future [13]. A yet unproven assertion is that the costs of implementing B2G will save the electrical energy consumer money and reduce baseline energy demand on the grid. It is already clear that demand response can reduce peak loads by significant amounts but the corresponding dollar savings are not so well established. Continued research seems well justified with the promising results discovered thus far.

CHAPTER 4: Demand Response

Demand Response is a load management practice in which electrical energy 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. The aggregated energy reductions from many different users result in a significant portion of the total power demand 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 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 events. ***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 for human intervention. Extensive DR work has been performed by LBNL including several large scale ADR implementations. In the Auto DR system, the consumer has the option of overriding the DR process if shedding the load is not desirable under the current conditions [20]. The long term value of Demand Response to the grid is dependent on being controllable, measurable, verifiable, and predictable. Figure 2 shows the process of automatic demand response and the steps associated with it.

Figure 2: Demand Response Steps



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 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 the US increased by 30 percent from 1988 to 1998, while the transmission network saw an increase of only 15 percent during the same period [4]. As the country's transmission lines are reaching their load carrying capacity, solutions must be introduced in the form of new transmission lines or eliminating losses during transmission to increase the grid capacity. This effort hopes to minimize the necessity to build new power stations every ten years which would further load the existing electrical power transmission system. 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 loss of trading worth $20 trillion while the 2003 Northeast blackout caused $6 billion in revenue 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 [15]. One of the possible objectives of a Building-to-Grid model is to test the load shedding at critical times. A building structure with consumption in tens of kilowatts (kW) would not be able to make any significant difference in its peak time load by shedding non-critical loads. Therefore, a participant of this research needs to be flexible enough to shed a minimum of few hundred kilo-watts for effective testing.

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 percent of the load could be shed from commercial buildings without causing any kind of discomfort to the end user [21]. A more aggressive strategy could lead to astonishing results of a 20 to 40 percent drop in electrical 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 of the California Energy Commission that standardized appliance energy efficiency requirements, which resulted in an almost flat curve of per capita electricity consumption in California for past 30 years while rest of the nation saw a demand growth of about 40 percent [22].

For demand response to be in equivalence with supply side resources, the emerging B2G tools and technologies play very critical roles. One example is the advances in metering infrastructure. Rather than just reduce the need for meter readers through the use of a relatively slow communication systems, some of the newer metering systems encompass digital meters which are able to communicate bi-directionally between the customer (meter) and the utility. The information passed by this communication includes customer notification of time of day energy usage pricing, and electrical energy use by the customer over various time spans usually in the 15 minute to 1 hour increments. The structure of the dynamic tariff plays a critical role in helping customers respond to usage timings and reduce their total energy demand. In California, most residential customers are not yet billed by time of day usage and smart meters are primarily used as a tool to encourage energy conservation by informing the user of energy usage patterns. In contrast, large electrical energy customers (commercial and industrial consumers) are usually billed under contractually determined tariff schedules based on time of day usage. According to interviews with PG&E and SMUD personnel, these tariff schedules are frequently unique to each customer. These large energy users thus have immediate potential incentive to participate in demand response as long as their business model allows such participation. For example, data centers such as those employed by Google and eBay have requirements of high availability round the clock. The variability of energy use within these data centers is typically therefore low. Demand response may not be a good fit with these customers unless other business model factors are considered. Other industries may see very large variability in the electrical energy usage patterns and seem a better immediate partner with demand response. The near term goal is to identify appropriate demand response partners and create systems that interact with existing building energy management systems. Linking these systems to pricing signals over the Internet or through other pre-agreed communication channels at least partially completes the demand response loop from utility to customer. These various technologies when coupled with energy efficiency programs and policies will most likely result in significant energy consumption reductions and total peak period consumption reductions.

CHAPTER 5: Building to Grid

So far in this report, the authors have presented a brief background of Smart Grid mostly from the demand side issues. Before burrowing into B2G and the UCB testbed creation, we need to acknowledge that a great deal of research will occur in the area from the meter (substation) to the transmission and generation electrical network. Building to grid is a demand side topic and the reader is referred to other supply side research for more information on that important aspect.

So why investigate building to grid? Buildings account for 30 to 40 percent of total energy consumption and carbon footprint in most countries [14]. So buildings are a significant consumer of energy. It is hoped by the authors that more energy efficient buildings will reduce the carbon footprint while simultaneously reducing the total energy consumption from prior levels. Thus several efforts seek to reduce the baseline energy usage of buildings through the pervasive use of sensors which help define a state model of the building. From the building model, effective control strategies can be developed that allow near term energy usage prediction. Automated demand response becomes feasible as well. Thus Building to Grid seeks to reduce baseline energy usage and to develop implementable strategies for load shedding or load shifting in times of high energy demand periods. Most residential customers do not have sophisticated energy management systems in their homes nor do most residences have the ability to shed large amounts of power. The authors feel that commercial buildings will most likely be an initial target of B2G strategies with residential efforts slowly incorporated into the energy saving landscape. In terms of this project, residential use of B2G technologies is not considered.

Evaluating specific B2G strategies calls for fabricating and testing software and hardware models. UCB proposed the creation of a hardware platform which in combination with software systems leads to the development and testing of that B2G strategies. The UCB team considered the smallest scale model that provides realistic information to be a single building with an annual electricity consumption of at least 250 kW. Cory Hall on the UCB campus has baseline electrical consumption on the order of 1,000 kW and meets the criteria of a realistic hardware platform (building) in an environment (academic building with publically accessible data) that is approachable by researchers.

The primary goal of B2G is to have a continuously updated building state model which is preferably updated by machine automation rather than people inputting data. Past studies have shown that energy saving initiatives are all too often near term successful due to heroic measures by energy saving champions. Those champions can become bored, move on to other assignments or be elsewise unable to commit the time required to keep the energy savings in place. By using pervasive sensors and instrumentation that communicate to a database system, programmers can create building state models that utilize data mining techniques to continually update the model. Hopefully, the machine level of interaction will be persistent and not as subject to the vagaries of human task assignments. Machine automation also allows for much higher levels of time granularity so that millions of sensor data can be employed in the building model. Initial system design is critical and the ability to adapt to future issues such as building remodeling, expansion and device replacement or addition should be features of the energy control system. A goal of the UCB team is to use open source software as much as possible and defer the use of proprietary systems and software where possible.

A study conducted in 2007 shows that the major consumer of energy in commercial buildings is lightning (26 percent) followed by cooling (14 percent) and heating (13 percent) [14]. 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 testbed. This testbed 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. This high performance, low (presumed) investment, flexible infrastructure integrates the dynamic information of parameters like occupancy, environment conditions (solar illumination, wind speed & direction, temperature, humidity) and energy supply conditions (load, time of day energy price). This model also takes into account occupant comfort, business model and constraints, local preferences and safety policy. This enables the system to manage the building energy consumption holistically by optimizing building operations with greater energy efficiency.

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 lighting (26 percent) followed by cooling (14 percent) and heating (13 percent) [17]. Thus measures, such as double pane window glass, energy efficient light bulbs, good insulation in the building structure, automated shading, movement-based lighting, can be taken to reduce the energy demand of a building. Thus 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 [18]. 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 percent more efficient 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 [19].

The Building-to-Grid testbed system needs to have two very important features within it – Persistency and Pervasiveness. The building's energy management system 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. Pervasiveness, as defined as using sensors to know most, if not all, of the building's energy parameters, is essential in order to execute accurate check sums in different sections and throughout the building. 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 understanding the consumption pattern of a building, a vital step is to have sub-metering installed in the building. In this context, sub-metering implies the ability to sense, record and track electrical usage that is at some point identifiable in terms of an occupant function. 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 an effective means to determine the baseline load of a building in a manner may be disaggregated to occupant function. The typical building revenue grade meter reports total electrical energy consumption but the B2G effort seeks to take action which reflects the needs of the occupants as well as the grid. Baseline load can establish if the building can become a successful player in accomplishing a 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. Sub-metering can also enable more detailed responses to system component failures connected to energy management systems since those systems will be monitored to a finer degree. 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 [16]. This type of regular feedback on the consumer's energy usage, can lead to behavioral amendments and result in long lasting demand reduction strategies [17].

Building scale monitoring for a testbed can be divided into three broad areas of Sensing, Networking and Model/Feedback [18]. Sensing is the base of this architecture and 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 electrical load levels (main point of entry, distribution, sub-panel, branch circuit, wall plug, etc) using various meters and controllers. Physical data includes vibration, temperature, humidity, PAR/TSR light photodiodes, again measured at different locations within the building. External influences provide a context for the buildings energy usage so sensing includes such external data as weather, season of the year, insolation, and other relevant impacts on the electrical load. The second layer of this architecture proposed by Tai and Hogain is networking. The data stored in the sensors and metering devices is passed to a database through appropriate communication interfaces in both a local area network and wide area network model. This network layer is complex in itself and deals with different routers and interfaces necessary for the communication. 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 [18]. The UCB B2G Cory Hall project implemented selected portions of this proposed architecture. In Cory Hall, the sensing layer includes the building's electrical load-is accurately monitored down to wall plug outlets in some cases. External data includes a nearby weather monitor and future monitoring of solar load is anticipated. A virtual private network (VPN) was created to enable secure communication of this sensor data to computer servers by a hybrid system of a many wired and a few wireless devices. The model/feedback portion of the proposed B2G architecture (Tai and Hogain) is beyond the current project's scope.

CHAPTER 6: UCB B2G Testbed Methodology

Cory Hall, UC Berkeley's Electrical Engineering Department is a 200,000 sq ft building and is the campus' 5th heaviest usage of electrical power - drawing an average of one MW from the grid continuously. It uses approximately 45 kilowatt-hours (KWh) of energy per sq ft annually supplied from two 12 kV three phase transformers awkwardly located in the basement of the building. Built in 1950 and remodeled several times, 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. Among the numerous renovations was the addition of a sixth floor up top of what was the old roof. The building infrastructure is more complex than typical of a building this size. Cory Hall also houses legacy electrical instrumentation, and a ventilation system that has been characterized as "very inefficient" which serves the building's six floors [16]. Cory Hall serves as an excellent test case for implementing B2G energy efficiency and building retrofit techniques.

6.1 B2G in 14 Steps

The UC Berkeley team followed a strategy of tracking power flow to specific occupant functions. The total electrical energy input comes from meters at the main point of power entry into the building. Submeters then further define the individual function which consumes this power. If done correctly, the sum of these submeters (which reflect various levels of occupant use) should nearly add up to the original input total. There will also be some level of unknown power use but the percentage should be managed to a low level as required by the specific system. This method is summarized by the expression "disaggregate (power flow) according to function then re-aggregate (all functions) to total power flow." In combination with communication systems, data storage and data visualization methods, the scheme allows for near real time analysis of the energy consumption in Cory Hall. The technique of *checksum* is a quality control method which enables validation of the data collected by the sensor/instrumentation system. This checksum process helps benchmark any energy losses in the building power system that escape sensor detection. Selection and placement of the sensors reduce the uncertainty in the measurements to some acceptable level determined by specific system constraints. This checksum information is then used to refine the sensor system by either eliminating or reducing these energy losses. Ideally the total input energy could be monitored down to specific devices and appliances with no unknown losses. Realistically such absolute monitoring is neither warranted nor financially reasonable. So in the case of B2G, the instrumentation system needs gather actionable data of sufficient detail so that the building manager can run the building in an energy efficient manner.

Measurement of the electrical load is performed using a system of electrical current transducers (CT). The CT is connected to an instrumentation device to condition the sensor reading, temporarily store a small set of readings and communicate readings to a central data storage computer. Nearly two hundred CTs were used for Cory Hall in an effort to reduce the unknown energy losses to a very low level suitable to a research quality testbed.

Once these measurements were acquired, the data must be communicated to a data repository such a computer server. Particularly in B2G, the nature of the communications is one of a hybrid system that attempts to use various methods tailored to the specific task. For example, existing buildings are very expensive to rewire and in this case there are many sensors of various types. In some cases, the current transducer is connected to a high voltage line and there is a risk of the sensor contacting that high voltage either through installation error, damage by natural causes such as lighting strikes, floods, earthquakes or other dramatic events. There is also the possibility of intentionally placed hazards. Wireless connections reduce the risk that these hazards will propagate high voltage to unwanted areas of the building. But more commonly, the building structure and cost place too high a burden on choosing a wired system. So the UCB team chose a hybrid communication system due to its flexibility and ease of installation. It should also be noted that the communication system differs significantly from the standard IT systems but not so greatly that it is considered a new or novel implementation. It is the marriage of a sensor platform to standard communication that leverages the well-developed IT platforms.

So let us presume a building management team has committed to a B2G implementation. How should they approach the B2G design?

- The first option for enhancing 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 systems already installed in buildings.

- The second choice is organizing around electrical distribution system, more specifically by power feeder levels. It may be difficult to determine the occupant function by this method and not achieve actionable data as readily.

- The third way of dissecting the building is using its functional configuration. Buildings typically contain functional divisions such as office space, meeting rooms, mechanical systems, lighting and such. The classification may assist in the creation of an effective building state model. The configuration could be performed either on floor by floor basis or by classifying the building into the different functional areas. Although perhaps not accurate for the whole building (depending on the load measurement granularity), this approach would provide a "complete" picture of the functional sector. 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 UCB tem felt this might be waste time/effort in improving parts of the infrastructure which might not be contributing to any significant energy losses in the first place.

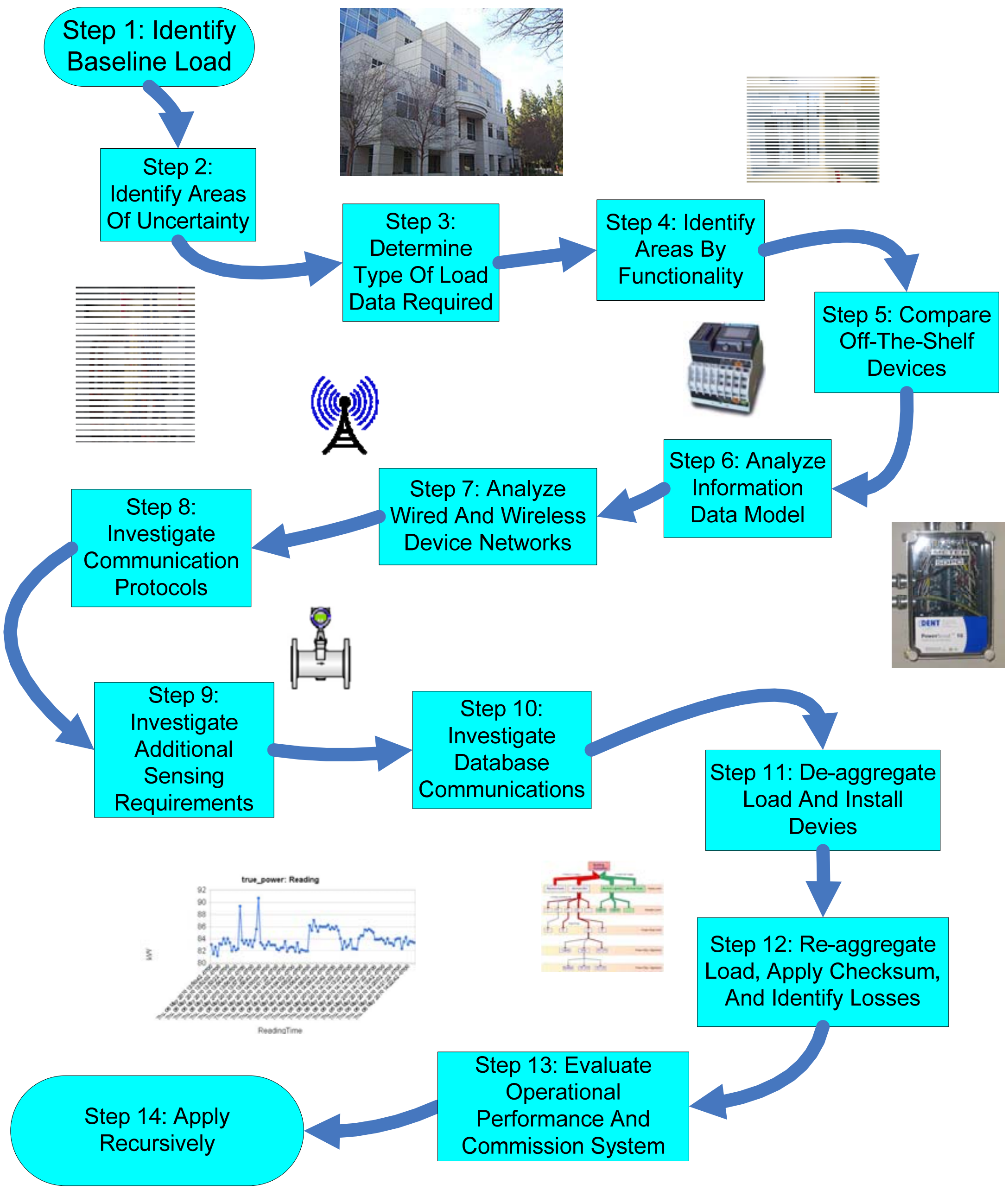
- A fifth approach is to preform an energy audit of the building, starting with the total energy first and then drilling down to floors, sections and stages based on cost and uncertainty factor of that stage. This course of action would make it easier to decide the crucial places to put energy monitors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

The UC Berkeley B2G methodology for implementing a testbed can be broken down into following steps which are encapsulated in figure 3.

- 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 etc.
- 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.

- Step 14: Iterate the above steps until the uncertainty in measuring the energy loads is at a level acceptable for the needs of the specific building/project.

Figure 3: Building to Grid Flow Chart



It is worthwhile deciding the personnel for planning, designing and installing meters. UC Berkeley 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, 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 the Cory Hall building manager (Scott McNally) to oversee the process. Much of this work is documented in the reports for Tasks 3 and Task 4 of the grant.

6.2 B2G Future Proofing

While the process of testbed 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 UC Berkeley, one of the major loads – the Micro Fabrication Lab was removed from the building after the initiation of B2G testbed project. Owing to this move of Micro Fabrication Lab, there is now a 250 KW of energy consumption alteration in the building with the resulting baseline load of 750 KW according to the building manager. Since the resulting building now consists mainly of office type loads and a server room, this does not leave much margin to reduce significant amount of load during peak hours and hence perform a large demand response procedure. But a detailed knowledge of the building state model is excellent knowledge for control algorithm design. So the authors do not see a requirement for a large DR response as having any significant impact on the B2G testbed research. Studies done at UC Merced and at CSUS found that 50 - 75 percent of the load in a building complex or a campus that was shed for auto DR purposes was due to air supply handler fans in the HVAC system and the mechanical system load. Lighting in the buildings contributed about 15 - 40 percent of the load saving while plug-in loads accounted for 7 - 10 percent [24]. As this section points out, careful planning of a B2G system will allow for future needs as an integral part of the system implementation.

6.3 Professional Assistance

In order to execute these above steps, professional level assistance 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.

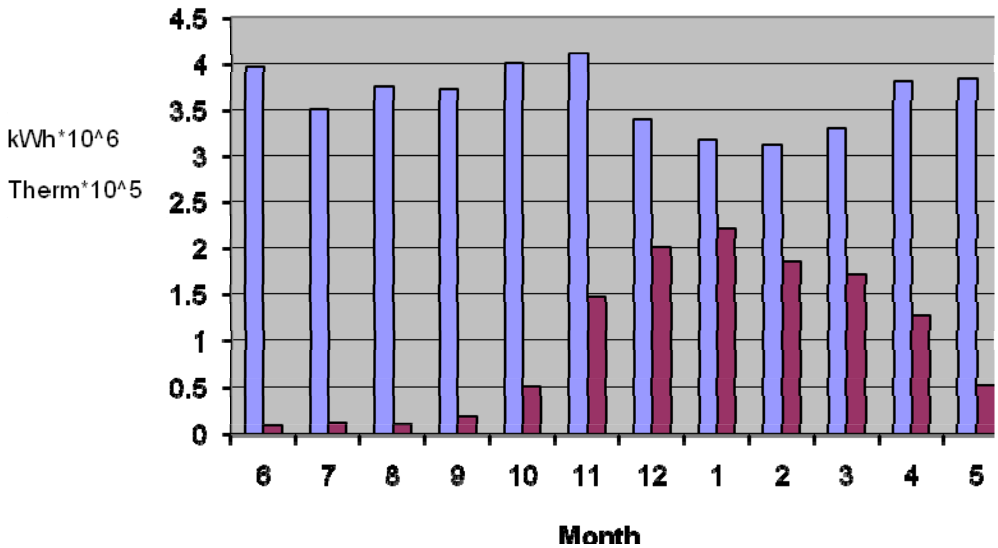
- Building Energy "Champion" or Facility Manager – to guide about the existing infrastructure & its loopholes.
- Professional Engineer – to oversee the safety aspect and signing off any invasive changes in building configuration like new device installations etc.

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 requires that applicable building code and regulations be consulted, understood and followed under a best practices approach. In such a scenario, it is vital to get an approval from professional engineer before all the installations and improvements are conducted. There could be other situations where professional opinion and consent might be required to meet the U.S. and state Occupational Safety and Health standards. Consultants and contractors come in very handy for different kinds of assessments in the building. Examinations like a 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.

6.4 Translation of the UCB Methodology to CSUS

Since part of the CSUS motivation is to extrapolate the methodology of the UCB team to the work of the California Smart Grid Center, it is useful to compare the UCB test bed to the CSUS facility. 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 for the entire campus. The dollar cost of the energy consumption is $3.5 million per year for electricity and $1 million per year for gas. The gas consumption year is typically from November to April as shown in figure 3. 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. There is no single building on campus which is a directly similar to Cory Hall at Berkeley. So the Berkeley methodology will be extended to a campus-wide effort on the CSUS campus similar to an industrial park or large corporate campus.

Figure 4: CSUS Monthly Energy Usage Trend for Academic Year 2008/2009



Source: CSUS Campus Facilities Management

The blue bars are the electrical energy consumed in kWh and the magenta bars are natural gas in therms.

The B2G effort recognizes that reduction in the demand of power is a critical aspect of energy policy. The B2G research is attempting to maintain current levels of perceived building occupant comfort and utility while implementing strategies to reduce the energy cost of that comfort and utility. The CSUS team was privileged to shadow the UCB testbed creation and gain insider access to the guiding concepts, the travails of the physical implementation, and enjoy an on-going dialog with the UC Berkeley faculty and staff on B2G topics.

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. It is the stated intention of the Berkeley team that the data gained from the Cory Hall sensors will be made available to other researchers including the CSUS team. Thus rather than creating another nearly identical facility on the CSUS campus, the Cory Hall data will be locally stored (on the CSUS campus), examined, modeled and visualized by CSUS faculty and students.

As part of another grant, CSUS will shortly 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 combination of high resolution data (Cory Hall) and large electrical loads (CSUS campus) leads to a better understanding of multiple building interactions and energy load shedding/shifting opportunities for the purposes of demand response. The CSGC 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.

This discussion is by no means complete and other fruitful topics will arise as the research evolves. It is the intention of the CSGC to create multi-disciplinary groups from many organizations to give this project a very high level scope and impact. In any good effort, team members need to blend skills, knowledge and assets that inevitably yield results beyond that of any one individual. In this case, the effort is indeed broad ranging and potentially critical to the future of energy in California.

6.5 Demand Response Effectiveness

For effective demand response, whether manual or automatic, it is very crucial to have an accurate predictive capability for your building. The high resolution data from the B2G testbed will enable very comprehensive models, at least for Cory Hall and most likely extrapolate to similar buildings as well. As more buildings are added to the control model, the interest of the utilities rises but so does the level of complexity for the campus control system. But in the interviews with PG&E and SMUD, it is clear that the power providers want to interact with a single point of contact. The DR model is then one of aggregation of many buildings and their individual DR response models into a campus DR response largely guided by the contractual agreement between the utility and the campus. Just like we think of a sports team as a single entity albeit with many players, the B2G DR reaction on the critical price playing field is a team coordinated effort. The trick is to get the players onto the same playbook.

An example is the use of thermal storage on the CSUS campus. The thermal energy storage (TES) shifts the CSUS campus peak electric loads (producing chilled water) to nighttime resulting in a flatter daily load shape and a lower daytime peak. While the use of the TES devices shifts cooling demand loads to off-peak hours, it also makes it easier to predict the daily loads more precisely since the other loads are typical lighting, and office equipment with a good degree of daily predictability. CSUS has already committed to curtail up to 400 KW during critical pricing periods in an agreement with SMUD, but the Facilities Management staff agrees that there can be an even broader scope to reduce the peak time energy consumption of the campus. 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 the CSGC. 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 get the energy use data, CSUS is installing AMI based smart electrical meters for most of the buildings in the campus. Sub-metering, sensors and monitors will also be installed inside selected buildings in the near future to identify the energy losses and redundant loads.

Seasonal load variability is another factor that decides the effectiveness of demand response. Berkeley, due to its geographical location, experiences relatively mild humid weather year round, 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 which will test the ability 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 unseasonable weather prevails. 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 [18]. 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 DR 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. CSUS satisfies all the above conditions and can become a very promising player in automated demand response program.

CHAPTER 7: B2G Components - Overview

While implementing a B2G testbed at any given facility, there are some main factors that are considered most important and contribute to the planning of the whole process. These are discussed below.

7.1 Energy Sources

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 8.

7.2 Selection of What Power to Monitor

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. Initially, it was 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. Hence an approach was needed to select specific sectors which would still serve the purpose of monitoring the load in the building and satisfying the following criteria:

- Select the sector that provides control volumes allowing comprehensive measurement of all electrical energy used within the volume.
- Select the sector that enables savings accounting and persistence of savings for monitoring-based commissioning.
- Select the sector that facilitates the analysis of potential energy efficiency retrofits.
- Select the sector that permits the analysis of chiller configuration options.
- Select the sector that enables demand-response potential.
- Select the sector that allows study of a range of building-typical and building-industrial sub-systems.
- Select the sector that enhances the ability of testbed to assist with campus energy management and climate protection goals.

- Select the sector that demonstrates the capability of wireless sensors.
- Select the sector that allows monitoring to perform internal checksums at different levels of measurement.

Collaboration Day was held at Berkeley 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.

7.3 Meters

Meters and monitors are key ingredients in research testbed project. These instruments are needed every step of the way to minimize the unknowns. However a distinction needs to be made between revenue grade meters and the research grade meters useful in the testbed. Revenue grade meters are essential to accurate billing of the power consumed. Millions of these revenue grade meters have been installed and have usually been well received. PG&E is facing some customer annoyance due to apparent billing inconsistencies after the installation of smart meters in its service area and has characterized the situation as a failure in customer support rather than a failure of the meter technology. The research grade metering will most certainly desire sampling of power parameters much more often and be interested in power quality measurements not typically given to consumers. In most cases, a B2G will employ many (hundreds) of power sensors and only one (or a few) revenue grade meters.

It is beneficial to place these 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. 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. A few off the shelf commercial meters of all four kinds 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. The initial discussion on Oct 15^{th}, 2009 at UC Berkeley indicated that for the purpose of monitoring, a CT would be installed at transformer level for mains power monitoring, 'Veris' type panel level monitoring for local loads on a floor and 'ACme' meter for plug-in type loads at appliance level. 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 economically be more efficient if different vendors are competing or/and collaborating for a similar type metering device. For example, in selecting the current transducers, the team noted that flexibility is required in a retrofit with the choice of clamp-on CTs versus open-loop Rogowski coils is partly dictated by the specific installation challenge and electromagnetic environment of the CT sensor.

UC Berkeley 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 8, the report addresses different devices briefly with more specific information contained in the manufacturer's documentation presented in the combine project documentation.

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 UC Berkeley, there are 15 branch points coming off the distribution panels, downstream of the main building transformer. Out of the 15 points, 13 of them have been equipped with monitoring devices. The finalized list of type and number of devices purchased is mentioned in the power point submitted along with this report. The equipment should reach for maximum achievable resolution so that they give the best possible information. UC Berkeley accomplished this high resolution by having at least ± 2 percent 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.

7.4 Sensors

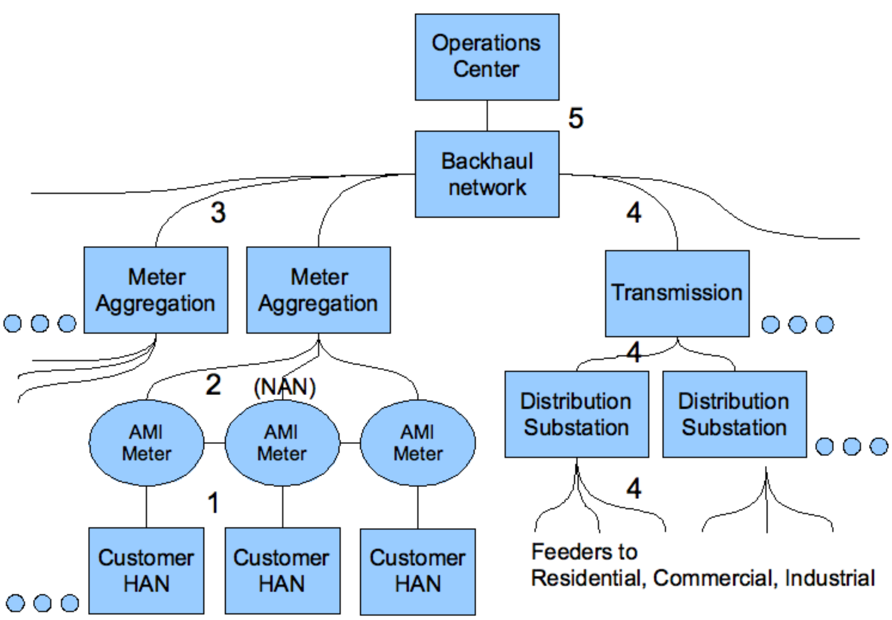
Sensors measure many measurands including the current and voltage in a given appliance. Generally, the sensors are permanently installed with the equipment to be monitored. The plans from the kickoff meeting at UC Berkeley for B2G testbed project indicated that in the building environmental infrastructure, the sensors would be installed at the condenser pump for sensing the total steam condensate level which is used to partially determine the energy input into the building. More sensors were planned for noting the humidity, temperature and pressure at expansion valve and the air vent of HVAC system. External sensing would be needed for local weather, season, room/building occupancy, server load, non-occupancy related load, auto-shutdown managing system and many more.

7.5 Communications & Networking

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 loads. For B2G type communications, the utility is interested in knowing about a customer's load, the load that can be shed off at peak times, 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 initial meeting for Cory Hall specified that IPv6/6LoWPAN mesh network in a hybrid wireless/wired system would be used to transfer the information from meters and sensors to a computer server for storage. LoWPAN is a simple "low" throughput wireless network typically utilizing low cost and low power devices. This would 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 [17]. There was a long discussion about choosing wired or wireless networking at different nodes. One of the concerns was being able to achieve enough density to enable a good mesh network. UC Berkeley evaluated the pros and cons of both types of networking methods and settled with a mostly wired network except for those places and situations were wireless was clearly a better choice. As previously mentioned, certain sensors where installed near very high voltage equipment and there is a risk of conducting very high currents through the sensor system. In this situation, the choice of wireless is also a safety decision. Figure 4 below describes a smart grid communication network in the form of a flow diagram.

Figure 5: Smart Grid Communication Network



Source: Carbon-Pros Analyst Blog Smart Grid Technology [25].

7.6 Data and Data Visualization

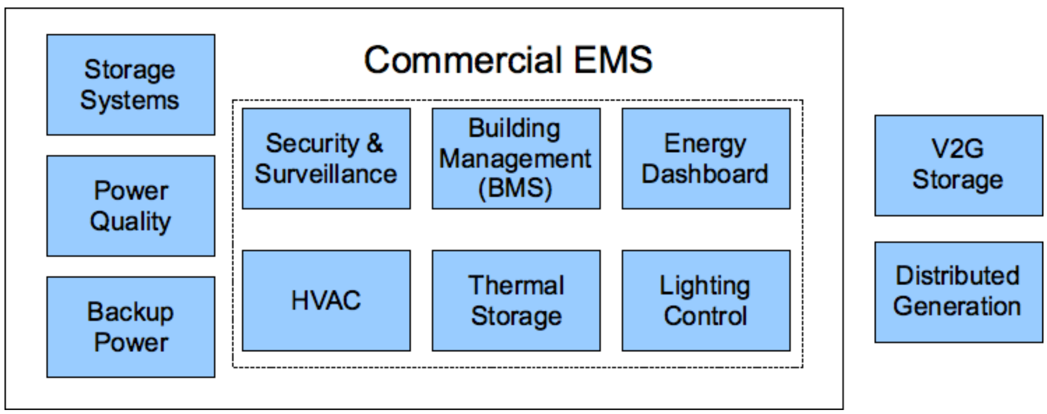
Information management will play a critical role in supporting advanced applications envisioned in future. Applications included energy system automation, system integration to smooth out the daily operation and maintenance issues along with maximum energy efficiency and auto demand response [5]. UC Berkeley will expand on the sMAP software and develop data visualization models but the challenges in handling this large number of sensor data points are significant. OSIsoft, a commercial database vendor, licensed and installed the PI System to replicate the data into user friendly representation as a counterpoint to the open source work of UCB. The minimum configuration required by OSIsoft is three computers running the Windows 2000 Server operating system. UC Berkeley intends to create a floor by floor plan and list 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. It is their intention to dual-track the data with an open-source solution as a back-up.

The Simple Monitoring and Actuation Profile (sMAP) software was created by researchers at UC Berkeley for the intent purpose of "bringing a flexible distributed architecture to the building." [26] sMAP accesses installed sensors and legacy HVAC systems by a simple RESTful application programming interface (API). The initial commissioning indicates that the software has satisfactory performance and has been scalable to building level sensor density.

7.7 Energy Management System

Presently Cory Hall is using a Barrington System for its energy management. A commercial energy management system (EMS) 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 briefly outlined in figure 5. Each block of the diagram may be connected by one of many different interfaces and very often the entire system is proprietary in nature from a specific vendor.

Figure 6: Commercial EMS Application



Source: Carbon-Pros Analyst Blog Smart Grid Technology-Getting ahead of the curve [25]

7.8 Summary of UCB B2G Completed Work

The Berkeley 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. One of the project champions at UC Berkeley interfaced with the campus facilities management staff to diffuse possible concerns on the project impact on daily HVAC system operation and to effectively coordinate campus wide resources required for the installation and commissioning of the monitoring systems. The UC Berkeley 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 is now in place and ready for future tweaks typical in a research project. Early data has already shown how pervasive energy monitoring can pinpoint operational energy losses in the case of a chiller running during a cool weather period. sMAP software for data communication is interfacing successfully with the meters.

CHAPTER 8: Monitoring Energy Sources

8.1 Electrical Monitoring

The major source of energy used at Cory Hall and other buildings at UC Berkeley campus is electrical energy. Thus the B2G project concentrated on metering the electrical load of Cory Hall to the extent the sensor data could confirm all major loads and most minor loads had been identified. At the point of entry into the building, the total electrical load was determined to within 5 percent. The subpanel loads were estimated and current monitors installed to cover the vast majority of the known total electrical load. This report will not detail device specifics since that information is available elsewhere in the grant documentation. The interested reader should find complete lists of devices and specifications available in the complete documentation package.

8.1.1 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].

8.1.2 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].

8.1.3 Data Loggers and Power Quality Monitors

Data loggers address the need of data logging, data acquisition and weather monitoring required for B2G 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.

One of the power quality meters analyzed and later used for this project was PSL's PQube. The meter is a small compact unit at an approximate price of $1500 - $2000 depending on the accessories chosen. From the research conducted for this project, it was established that this meter is very advanced, offering many features in one package. When installed at a service entrance, this meter can monitor the electric consumption, time and duration of any abnormality [1]. The all-in-one package comes with clip-on add-on modules and standard DIN rail options. DIN rails are a popular system for mounting industrial control equipment so named by its standardization by the Deutsches Institut fur Normung (DIN). This meter is designed to save the logs to a SD memory card at a rate of about 1 GB per year. There is also an Ethernet module for email support, and web/ftp support for accessing files stored on the memory card. The base model only makes voltage measurements, but with an additional current module, the unit is capable of calculating and reporting watts, VA, VAR's, true power factor, watt-hours, and VA-hours at about twice the revenue meter's accuracy. 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 common file formats such as GIF and CSV files. PQube has an accuracy of 0.05 percent for voltage channels and 0.2 percent for current channels, as specified in its scorecard. Power engineer and architect Erich Gunther rates PQube 90/100 on SGN Smart Grid Score Card for its performance in power quality [2].

8.1.4 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 UC Berkeley. It fits in between the expensive network energy monitors and cheap LCD watt-meters. The ACme network can be connected to the individual AC 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 [19]. 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].

Figure 7: ACme Plug-in meter

Source: Design and Implementation of a High-Fidelity AC Metering Network [26]

8.2 Steam Monitoring

For various reasons, sometimes within a building, simultaneous heating and cooling are going on at different ends or different floors. This may be to reduce humidity, a result of poor or inadequate insulation or other factors, and does point the dynamic interaction required from the HVAC systems. All energy inputs into a building need monitoring to establish the interactions in the building although, for this project UC Berkeley placed its focus on monitoring the electrical power in Cory Hall, the steam or chilled water usages are inescapably intertwined with the electricity consumption in the air-conditioning systems. A steam condensate meter was installed as a good but indirect measure of an energy input into Cory Hall.

8.2.1 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 reheat. 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.

8.2.2 Quantity to Measure

The steam consumption could be measured in volumetric or mass flow rate of condensate. 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 is obtained by applying the latent heat of vaporization to the mass flow rate. Common assumptions for this reduction all typically carry much less error that the determination of volumetric flow rate: no superheat of steam supply, no sub-cooling of condensate, assumed rather than measured temperature/pressure.

8.2.3 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.

8.2.4 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.

8.2.5 Accuracy

The uncertainty associated with steam measurement is significantly greater than for electrical measurements. The inaccuracy could vary by ± 10 percent 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.

8.2.6 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 UC Berkeley 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 UC Irvine and UC 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. However, Berkeley has no such plan in the near future due to monetary reasons [27].

8.3 Chilled Water Monitoring

Measuring chilled water is crucial for tracking the energy consumption of AC during peak hours. The chilled water to Cory Hall is supplied by Hearst Memorial Mining Building. 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 [27].

CHAPTER 9: Future Issues

The development of the testbed presented many interesting challenges along with the lessons learned. The UCB team delivered a research grade testbed with very high time granularity of electrical energy measurements. Future work will address creation of a building state model that leads to building energy control adaptable to DR and changing functions within the building. The following topics address some of the future work.

9.1 Solar Load

The emphasis in this project is on the "purchased" energy from the utilities such as electricity, gas and water. For certain areas such as Sacramento, the solar load on a building varies considerably in terms of time of day and direction of the sun on the building. The solar has 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 solar flux models since real time data is desired whereas the models are seasonal averages. In terms of empirical and benchmarking energy usage applicable to B2G - solar flux, external weather conditions, air intake and exhaust should be included as time stamped data points useful to energy modelers of the testbed.

9.2 Industry Needs and Security

The Smart Grid research needs to address the unique business and regulatory drivers in order to successfully and smoothly implement a B2G building in the commercial sector. 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. Commercial building operators are generally sensitive to business operational secrets that may be revealed if energy use data is not properly secured. Cyber security, physical device security, and issues of reliability and robustness are critical future topics.

9.3 All the sensors for B2G

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. The UCB team (Cory Hall) and the CSGC are willing to share this extensive data set for others in their research. Thus there is real hope that these governmental owned facilities can provide high resolution data that aids others in researching specific approaches to energy efficiency. This comes at a time when the energy industry is more often than not restricting access to their customer data for appropriate business reasons.

CHAPTER 10: Conclusion

This report described the methodology needed to implement a Building-to-Grid testbed. The fourteen steps developed by UCB were detailed so that others may use it as a roadmap for configuring a B2G facility elsewhere. So far no technological show stopper has arisen. While low power or even no power sensors are very valuable to a B2G project, that technological appears already capable enough for early adopters. The hybrid wireless and wired network topology is functioning smoothly but high grade cyber security has not been implemented yet. Such high grade wireless security at individual sensors may prove a technological challenge. However in B2G applications, it is the control of the energy management system that needs to be most heavily defended. At the EMS device level, low power is no longer a primary issue as the device is almost always wired into the power and IT infrastructure. The report also discussed various terms that are used in this project regularly such as Smart Grid, Building-to-Grid, Demand Response and Load Management. A step-by-step summary of crucial steps were included followed by their detailed explanations. The work done by UC Berkeley, in terms of the approaches they followed and the monitoring devices have also been included. California State University Sacramento has shadowed UC Berkeley Cory Hall testbed to gain the knowledge on the processes involved and the problems that can be encountered while conducting similar research. The summary of installed devices and their level of success were briefly discussed. The report also mentions the issues and areas that need to be addressed in the future for more successful communication with Smart Grid.

The B2G testbed will enable future researchers in developing timely and effective energy management devices and control strategies. B2G is quickly leaving the laboratory stage, but will not likely see wide distribution until vendors embrace the B2G initiative and have a market willing to buy. Building owners, HVAC vendors, EMS system vendors, and other related business parties need further concrete research to show a compelling argument for both B2G and demand response. Various governmental agencies are considering regulations that will prompt these parties to adapt. Work by UC Berkeley and the CSUS based California Smart Grid Center will continue to arm the energy discussion with solid facts upon which both government and industry can rely. Everyone is anxiously anticipating the new projects starting soon in the B2G testbed.

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GLOSSARY

TERM/ABBREVIATION	DEFINITION
ADR DR	**Automated Demand Response** also called Demand Response is a set of technologies that allow for real-time signaling of and response to ISO level requests to reduce electrical energy demand by end users. See the many LBNL publications for more information.
API	**Application Programming Interface (API)** 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.
B2G	**Building to Grid** is a term used to describe a collection of technologies, control systems and communication methods to optimize a building's energy usage particularly in response to electrical pricing and/or electrical power availability signals provided by regional grid operators such as the California Independent System Operator (CA-ISO).
CEC	**California Energy Commission**
CSGC	**California Smart Grid Center** which is located in the Riverside and Santa Clara Halls on the CSU Sacramento campus.
CSUS	**California State University Sacramento** which is also called Sac State.
Carbon Footprints	**Carbon Footprint** 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.
Checksum	**Checksum** 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.

TERM/ABBREVIATION	DEFINITION
Circuit Breaker	**Circuit Breaker** 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 condition and, by interrupting continuity, to immediately discontinue electrical flow.
CT	**Current Transducer**
Data Acquisition (DAQ)	**Data Acquisition** is the process of sampling a real world physical parameter and converting the resulting samples into digital values that can be manipulated by a computer.
Database	**Database** is an organized collection of data for one or more multiple uses. A database is a collection of information so organized that it can easily be accessed, managed, and updated.
Data Loggers	**Data Logger** 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.
Data Model	**Data Model** in software engineering is an abstract model that describes how data are represented and accessed. It also models relationships between data elements.
Electrical Load Management	**Load management** is the process of balancing the supply of electricity on the network with the electrical load by adjusting or controlling the load rather than the power station output.
Energy Generation EG	**Electricity generation** 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.
Energy Distribution	**Energy Distribution** refers to the process of transporting energy from transmission systems to end-use customers.
Energy Transmission	**Energy Transmission** is the large scale transfer of electrical energy from generating stations to the distribution devices called substations.

TERM/ABBREVIATION	DEFINITION
Energy Loss	**Energy** loss is the wasted energy in the transmission of energy from the generator to the eventual customer.
Energy Management Systems EMS	**Energy Management System (EMS)** 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.
HVAC	**HVAC** is an acronym that stands for the closely related functions of "Heating, Ventilating, and Air Conditioning".
Intranet	**Intranet** 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.
IT	**Information Technology** is a term most commonly associated with the day-to-day operation of computer based information systems and the management of internet access.
LBNL	**Lawrence Berkeley National Laboratory**
Load Shedding	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 load shedding. Load shedding can also be referred to as Demand Side Management or Load Management.
Mezzanine	**Mezzanine** (architecture), an intermediate floor between main floors of a building.
NIST	**The U.S. National Institute of Standards and Technology** is an agency of the U.S. Commerce Department.
PG&E	**Pacific Gas and Electric Company** is an investor owned utility.
PUC	**The California Public Utility Commission** regulates privately

TERM/ABBREVIATION	DEFINITION
	owned electric, natural gas, telecommunications, water, railroad, rail transit, and passenger transportation companies.
Router	**Router** is a networking device consisting software and hardware that interconnects two or more computer networks, and selectively interchanges information between them.
Sensor	**Sensor** is a device that measures a physical quantity and converts it into a signal which can be read by an observer or bay an instrument.
Smart Grid	**Smart Grid** is an of electrical power grid with two way communication systems and automation that aids power quality, relieves grid current congestion and improves system fault detection/analysis/recovery.
SMUD	**Sacramento Municipal Utility District** is a publicly owned electric utility.
Step up Transformers	A "transformer" changes one voltage to another. A "step-up transformer" 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.
Step down Transformers	A "step-down transformer" converts the high voltage at the input terminals and converts it into lower voltage. Thus, it can be used in conjunction with a device that requires a low voltage power supply.
Transmission Line	**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.
UCB	**University of California Berkeley**

TERM/ABBREVIATION	DEFINITION
Wireless Mesh Networks	**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.
Wireless Sensor Networks	**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.

Hardware Devices

TERM/ABBREVIATION	DEFINITION
Cisco Network Building Mediator	**Cisco Network Building Mediator** (NBM) provides a network-based framework for the convergence of multiple disparate building systems. Vendor: Cisco System, Milpitas, California.
Dent PS 18	**Dent PowerScout 18** (PS 18)meter is used to monitor the voltage, current, power and energy of a single three phase system. Vendor: Dent Instruments, Portland, Oregon.
Eagle220	**Eagle 220 Power Monitor** is the first digital recorder to monitor real-time PQ data and download it remotely. Vendor: Power Monitors Inc., Mt Crawford, Virginia.
Nexus 1500	**Nexus 1500** is Advanced Power Meter with sophisticated power quality analysis which is used for advanced power quality monitoring and communication. Vendor: EIG Industries/Gauge Tech, Westbury, New York.
PQube	**PQube AC Power Monitor** is a power quality and energy monitor/analyzer that can be used to detect sags, dips, swells, interruptions and impulses in power quality. Vendor: Power Standard Lab, Alameda, California.