Building to Grid (B2G) at the California Smart Grid Center

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Abstract

In 2009-2010, the California Energy Commission (CEC) funded the University of California Berkeley Building to Grid (B2G) test bed project to create a research facility that can examine aspects of electrical and other energy usage to determine total energy flows by functional use. CSUS shadowed the B2G project and documented the research test bed creation at Cory Hall on the UC Berkeley campus. The hybrid wired and wireless network topology employed in this test bed is generating a very large volume of tagged data that relates electrical energy consumption to time of day and ultimately to the building function consuming that energy. Much of this data is available under the Berkeley sMAP system which will be briefly introduced. Lastly this paper will discuss parts of the translation of the UCB methodology to future CSUS building to grid research.

Keywords: Smart Grid, Building to Grid, B2G, Demand Response, California Smart Grid Center

1. Introduction

The California Smart Grid Center at CSU Sacramento will be a focus of smart grid research activity in the Northern California region. The research is motivated by the evolving energy climate in the last decade which now emphasizes improving efficiency of energy use particularly by the ultimate end user. Smart Grid is an evolving concept that at its base is concerned with the improvement of electrical energy production and transmission of large blocks of electrical power that will incorporate various renewable energy sources created in so-called distributed energy islands. 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 U.S. Department of Energy (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*" [1]. Thus in the face of both national, regional, vendor and customer definition flavors, research needs to devise energy effective technologies that include devices, protocols, communication links, cyber security, and especially reliability enhancements. The challenge is underscored by the seemingly inevitable increase in consumer demand for energy – especially electrical energy.

Electrical energy consumption in the U.S. has increased at an average rate of 1.7% per year from 1996 - 2006. The U.S. Energy Information Administration forecasts a slightly lower growth rate in the future. The EIA expects an increase of about 26% in electrical energy consumption from 2009 to the year 2030. This is an increase from 3.71 terawatt-hour (2009) to 4,696 terawatt-hour (2030) [2]. These trends indicate that action is required to combat growing energy demand which could saturate the existing electrical grid capacity. Efforts are underway to achieve lower baseline energy usage, improve energy efficiency, incorporate renewal energy resources, and improve electrical grid reliability through various methods. One U.S. example is the ENERGY STAR program. ENERGY STAR is a joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy designed to save consumers money and protect the environment through energy efficient products and practices. California is well-known for its trend setting initiatives by various agencies such as the California Air Sources Board and the California Public Utilities Commission. The authors include these back-ground facts not in an effort to create another eye-watering comprehensive list but rather to paint a fairly chaotic picture of the Smart Grid working environment in the reader's minds. The various energy efforts are very dynamic with a wide range of potential technologies but at its core relies on a robust and effective communications structure with an increased reliance on digital controls and pervasive sensors. California State University Sacramento (CSUS) is one of many universities, and commercial partners that are examining the questions related to the new smarter grid of the future. A key point to return to later is the fact that all these sensors, monitors, meters, actuators and devices send and receive what is assumed to be actionable data.

CSU Sacramento is building the California Smart Grid Center (CSMC) on its campus that will test suitable technologies in automated metering infrastructure and the possibility of automated demand response at critical times. The CSMC will develop feasible solutions for large-scale assimilation of Smart Grid Technologies and will serve as a physical site for demonstrating its benefits [3]. Both wired and wireless communication systems, so-called large scale hybrid networks, will be called upon to collect the system state (sensor data combined with energy production metrics) and initiate local responses. Thus one aim of CSMC is to respond to the state of the grid, properly react to weather conditions, and provide increased reliability by opting for demand reduction. Smart Grid initiatives in California are intended to fulfill three main goals as defined below [4]:

1. Integration of up to 33% of generation coming from central and local renewable sources.
2. Reduction of green house gas emission to below 1990 levels.
3. Creation of zero net-energy facilities by 2020 & 2030.

Later in this paper, completed work will be discussed but at this point it is important to understand the distinction between pie-in-the-sky hopes and reasonable engineering goals. Much of what the Smart Grid hopes to achieve is low risk in that many devices are already at the manufacturing stage. Yet the discussion must admit to a potential Tower of Babel in disparate protocols, proprietary systems and conflicting business models. So one of the first questions to resolve is one of fiscal worth.

2. Fiscal Background

Although the 2009/2010 global economic outlook is subdued at best, the Smart Grid sector of technology is perceived as a national-level critical component and 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 [5]. The research firm Zprӱme released a report in 2009 which states that current trends indicate sectors of the smart grid technologies market will increase from a 21.4 billion dollar market (2009) to 42.8 billion (2014) [6].

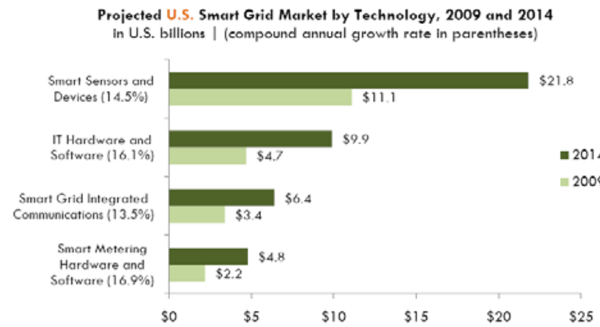

Figure 1. Zprӱme Market Analysis [7]

The Zprӱme report does not discuss the total impact of smart grid technologies since it does not review the effect of renewal resource integration, distribution fault detection and correction or other transmission line improvement efforts. The report does forecast a growth industry based on solid economic need. One key financial aspect of smart grid work is the power production company cultures. In general, utilities are very conservative and must operate within very specific operational guidelines. Any emerging smart grid technology employed in transmission and distribution efforts will need to pass stringent reliability and security concerns. But given the level of governmental interest, future commercial opportunity, and evolving electrical dependence on electricity as the primary and perhaps sole energy source, it is apparent that smart grid activities will be an active area for research, commercialization, and technological innovation in the foreseeable future. So given the smart activity seems fiscally reasonable, and that most industry analyst believe critical work stills needs doing, a UC Berkeley team proposed the creation of a sensor test bed for Building to Grid research.

3. Building to Grid (B2G)

Buildings account for 30-40% of total energy consumption and carbon footprint in most countries [8]. Carbon footprint can possibly be reduced by building fewer new fossil fuel power plants and using existing energy production more resourcefully. It is hoped by the authors that more energy efficient buildings will reduce the carbon footprint while simultaneously reducing the total energy consumption from previous levels. Thus several efforts seek to reduce the baseline energy usage of buildings through the use of pervasive sensors which help build a state model of the building. The CSUS work will result in a detailed building state model that allows near term energy usage prediction. Thus in automated demand response becomes feasible in a method known as building to grid (B2G).

The University of California Berkeley (Berkeley) is creating a test bed facility at Cory Hall to research and test strategies useful in making buildings capable of responding to electrical critical pricing periods and simultaneously improve baseline energy efficiency. For the test bed research at Berkeley, the Smart Grid is identified in simpler term as an intelligent electrical grid which has the capability to predict electrical power demand, supply that demand successfully, heal itself when needed and optimize generation and distribution based on the consumer demand. While the promise for a Smart Grid is achievable in the long term, the current emphasis is on a "smarter than current" grid that can be built using existing technology [9]. Berkeley is investigating existing tools to accomplish this Smart Grid technology and create new tools as the research evolves. The California Energy Commission (CEC) sponsored this work 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. CSUS is documenting the methodology followed by the Berkeley team to set up this research test bed within a framework of extending the Berkeley methodology to the CSUS Smart Grid Center efforts. The 2009/2010 Berkeley test bed project established the electrical load monitoring in a mixed industrial/commercial type of facility where future smart grid research may be conducted. A primary goal of the methodology is the dispersed and pervasive monitoring of a large complex electrical load to understand and track the energy consumption pattern of Cory Hall. This study would then be used to identify the essential, non-essential and non time-critical loads of the building which will help in electrical energy requirement forecasting, energy waste elimination, efficiency in operations, load shifting, adjusting and optimizing [10].

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%) followed by cooling (14%) and heating (13%) [11]. 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 [12]. 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 [1]. In 2003, various studies and field tests were conducted by Lawrence Berkeley National Laboratory (LBNL) to study the demand response strategies on different types of commercial loads. The outcomes suggested that 10% - 14% of the load could be shed from commercial buildings without causing any kind of discomfort to the end user [13]. An aggressive approach however, could lead to astonishing results of 20% to 40% drop in energy consumption as seen in Brazil and Juneau respectively [14]. Physicist Arthur Rosenfeld asserts "energy efficiency is by far the fastest, cleanest, and cheapest energy resource available" [15]. Therefore he recommended initiatives by the CEC that standardized appliance energy efficiency requirements which resulted in almost flat curve of electricity consumption in California for past 30 years while rest of the nation saw a demand growth of about 40% [14].

Cory Hall, Berkeley's Electrical Engineering Department is a 200,000 sq ft building and is the campus' 5th heaviest usage of electrical power - drawing 1 MW from the grid annually. It uses approximately 45 KWh of energy per sq ft annually supplied from a three phase 12 kV dedicated transformer. Built in 1950, this building has a collection of classrooms, offices, instructional and fume hood installed laboratories, machine shop, old elevators and a 10,000 sq ft micro-fabrication facility. In addition to these, Cory Hall houses legacy electrical instrumentation, and a ventilation system that has been characterized as "very inefficient" which serves the building's six floors [10]. Thus, Cory Hall serves as an excellent case for implementing energy efficiency and building retrofit techniques.

The CSUS campus spreads over 300 acres, consumes 90,000 – 94,000 Btu per sq ft per year of energy in the form of 43 million KWh/year of electricity and 1.2 million therms/year of gas, distributed across the campus. Three gas fired boilers are used 24/7 during the winter months to produce up to 115,000 pounds of steam every hour which provides heating to the campus buildings. 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. There is a contractual agreement in place, which in 2011 would see the installation of solar PV on many buildings in the campus 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.

UC Berkeley has followed the aggregation and de-aggregation scheme to analyze the real time consumption in Cory Hall. This method involves de-aggregating the building load for the purpose of monitoring, aggregating it back to find out the total consumption of the building and applying check sum to find the sections of energy losses. Check sum is a technique in which the individual appliance loads are summed to verify the room load. This process is continued until the functionality covers the complete building's energy usage. Any significant mismatches in the check sum of energy measurements are then investigated to find the possible energy losses. Appropriate sensors are selected to maximize the knowledge acquired of the building's power consumption and reduce the uncertainty in the measurements to some acceptable level determined by system constraints. This information is then used to devise a method of either eliminating or reducing these energy losses, making the flow of energy smooth and if possible, loss-less throughout the structure. Till date, the technique is working smoothly at Cory Hall and can be implemented at CSUS and other similar facilities for load disintegration.

The UC Berkeley methodology for implementing a B2G site can be broken down into following steps:

- Step 1: Identify the baseline load using building sub-metering or building audit.
- Step 2: Identify the areas of most uncertainty and energy losses.
- Step 3: Decide on the type of building load data required.
- Step 4: Identify the areas by functionality which needs monitoring.
- 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 identify any energy losses.
- Step 13: Perform empirical tests to evaluate the operational performance of the system and commission the system.

For smart grid management, it is very crucial that there is an accurate predictive capability for any given building. More variation in the daily load leads to difficulty in its prediction. The thermal energy storage (TES) shifts the CSUS campus peak electric loads (producing chilled water) to nighttime resulting in a flat daily load shape and a lower daytime peak. This makes it easier to predict the daily load more precisely, become prepared for the peak and commit to demand response with indemnity. Although a commitment to curtail up to 400 KW during critical pricing periods has been made by CSUS, the Facilities Management staff agrees that there is a broader scope to reduce the peak time energy consumption of the campus. Establishing the maximum possible energy load that can be shed off at critical times without hampering the operations at campus, and committing to it through automated demand response is another goal of Smart Grid Center at CSUS. This goal can be achieved by investigating the load consumption patterns of buildings in the campus, detecting energy losses if any and making the buildings more energy efficient. To achieve this goal, CSUS is installing smart meters for all buildings in the campus. Sub-metering, sensors and monitors would also be installed inside selected buildings in the near future to identify the energy losses and redundant loads.

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 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 [12]. A structure with consumption in tens of kilowatts would not be able to make any significant difference in the peak time load by shedding its non critical load. Therefore, a participant of this B2G research needs have large enough loads and to be flexible enough to shed a minimum of a hundred to a few hundred kilowatts for realistic testing that will create interest in local utility companies.

4. Information Impact

While this paper has so far focused on the motivation for Building to Grid activities, it will be the communications and database structures that will enable B2G. In a given B2G 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. The authors have discovered the difficulties in rapid data acquisition and transmission in several projects over the last few years.

In the 2008-2009 academic year, one of the authors (Tatro) and faculty from the CSUS Mechanical Engineering department developed a simple heating and cooling control system run under a dedicated data acquisition server. The system could acquire about 65,000 samples a second from the 38 sensors. The HVAC system was controlled by six actuators and relays.

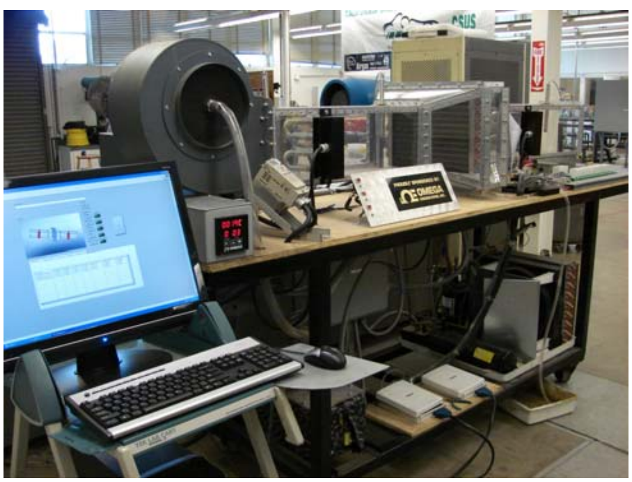

Figure 2. CSUS HVAC Test Bench

In terms of simplicity, this is the lowest level B2G and the authors discovered that the overhead of managing the sensors in the data acquisition function was often overwhelming the computer even in this simple case. It quickly became apparent that the different data functions should be separated, and data aggregated prior to control function implantation.

In the same 2008-2009 academic year, a commercial grade heat exchanger control system was also developed by a separate undergraduate team and installed in the CSUS Energy Lab using the distributed data acquisition model. The Alerton based control system featured many dedicated sensor acquisition system that communicated via a ModBus over TCP/IP interface to the main controller. In this project, there were only about a dozen sensors and roughly the same number of system actuators. But the authors were able to verify that the distributed sensor management significantly reduced the central controller requirements. Thus the research now led to a more comprehensive stage with the CSUS participation in the UC Berkeley B2G test bed creation.

The paper has already detailed the system and scope of the UC Berkeley an energy monitoring test bed. The simplified view is that pervasive sensors are aggregated by various monitors that in turn transmit data in a hybrid wired and wireless network to any number of remotely located data storage servers. After commissioning the physical hardware in late spring 2010, the UC Berkeley team began the process of data transmission, storage and visualization with the use of the Simple Monitoring and Action Profile (sMAP). The sMAP architecture is expressly "optimized for sensors, meters and actuators in building environments" [18]. The motivation for another profile is to move existing building energy management systems that are often "stovepipes" of proprietary protocols to a more interoperation method. This would make available the existing sensor data in a building to other data storage and decision making software. The Berkeley sMAP architecture is built on HTTP/REST and uses JSON as the object format for the desired interoperability. Up-to-the-minute sMAP data can be viewed at local.cs.berkeley.edu/smap/. Table 1 below shows a sample data record for the main transformer electrical load on Friday June 18, 2010.

Table 1.
Sample sMAP record – Cory Hall Main Transformer

Reading Interval	10
Reading Time	18 Jun 2010 09:03:48
Reading	1138
Unit of Time	Second
Unit of Measure	Amps
Meter Type	Electric
Multiplier	1000
Interval Since Last Reading	1 second
Sampling Period	10 seconds

The following figure shows an example of monitoring a main electrical energy input into a building which in this case is Cory Hall on the UC Berkeley campus.

Figure 3. Main Transformer Current Transducers

5. Conclusion

Our initiative with the Building to Grid research at CSUS is not only to acquire extensive sensor and monitoring data to see trends in energy consumption but to create an environment where the customer (in this case our facilities management team) has the information and therefore the power to make the most financially intelligent decision concerning their energy consumption. According to Andrew Tang, Senior Director at PG&E, it has been seen that people can reduce their energy consumption by 7-12% just by bringing a small change in their daily habits [16]. In the utility region covered by SMUD, 12% of the total load (due to summer peaks) occurs in just 40 hours of the year [17]. Generalizing this consumption tendency across United States, the DOE claims that 10% of all generation assets and 25% of distribution infrastructure are required less than 400 hours per year which is roughly 5% of the time [1]. 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. 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 acquired sensor data will result in millions of data points that need storage, datat mining for trends and manipulation into actionable visualizations. The Berkeley team (Cory Hall) and the CSUS Smart Grid center are willing to share this extensive data set for others in their research. With information like the UC Berkeley sMap readily available viewers are able to instantaneously view live data from the sensor systems. Likewise, the exchange of data concerning the devices used throughout the system aid researchers in coming up with design solutions in a manner fast enough to keep up with the market. The willingness to communicate between these facilities creates an environment where technological advancement thrives. 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.

References

[1] Department of Energy, *The Smart Grid: An Introduction,* 2009.

[2] Electric Power Research Institute, *Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in US (2010 – 2030),* 2009.

[3] Macari, Emir, *CSUS Smart Grid Center,* California Energy Workshop May 13, 2009.

[4] California Energy Commission, *Statement of Work BOA-99-234-P*, Building-to-Grid (B2G) Cory Hall Test bed Phase 1, 2009.

[5] Department of Energy, *President Obama Announces $3.4 Billion Investment to Spur Transition to Smart Energy Grid*, October 27, 2009.

[6] Ricketts, Camille, *U.S. smart grid market poised to double by 2014*, GreenBeat, Green.Venturebeat.com, December 16, 2009.

[7] Zprỳme Inc., *Smart Grid Industry Trends Snapshot*, 2009.

[8] World Business Council for Sustainable Development (WBCSD), *Transforming the Market: Energy Efficiency in the Buildings*, 2009.

[9] Sverdlik, Yevgeniy, *Is the Smart Grid an Intelligent move, Part I*, Datacenter Dynamics, February 15, 2010.

[10] UC Berkeley B2G team, *UC Berkeley B2G Cory Hall Test bed*, UC Berkeley grant presentation, October 15, 2009.

[11] U.S. Department of Energy, *Buildings Energy Data Book 2007*

[12] Tai, H. and Hogain, E.O., *Behind the Buzz [In My View]*, IEEE Transactions of Power and Energy, vol. 7, pp. 96 – 92, Mar.- Apr. 2009.

[13] Public Interest Energy Research Program , California Energy Commission, *Automated Demand Response Cuts Commercial Building Energy Use and Peak Demand*, CEC Technical Brief #31

[14] Charles, Dan, *Leaping the Efficiency Gap*, Science, Vol 325, 14 August 2009

[15] Brownstein, Ronald, *One Foot in the Future*, National Journal, page 55, January 16, 2010.

[16] Greentech Media, *PG&E's Next Smart Grid Moves: An interview with Andrew Tang*, January 12, 2010.

[17] Sacramento Municipal Utility District, *Smart Grid Investment Grant Application*, submitted to U.S. Department of Energy, August 6, 2010.

[18] Xiaofan Jiang, Stephen Dawson-Haggerty, and David Culler, *sMAP – Simple Monitoring and Acutation Profile*, IPSN"10, April 12-16, 2010, Stockholm, Sweden.