2010 9th IEEE/IAS International Conference on Industry Applications
- INDUSCON 2010 -

# A Conceptual Scheme for Cyber-Physical Systems Based Energy Management in Building Structures

Peng Zhao, M. Godoy Simões, Siddharth Suryanarayanan
The Center for Advanced Control of Energy and Power Systems (ACEPS), Colorado School of Mines
pzhao@mines.edu

*Abstract-***Concerns about energy efficiency and carbon footprints are becoming more significant in the power industry and public policy, as evidenced by the concerted shift to renewable energy sources and energy conservation paradigms. One of the largest consumers of energy in the US is the residential and commercial buildings sector. This paper explores a conceptual framework of a cyber-physical system (CPS) for energy management in such structures, viz. a Cyber-enabled Efficient Building Energy Management System (CEBEMS), aimed at attaining some level of energy self-sufficiency.**

## I. INTRODUCTION

An accepted definition of a cyber-physical System (CPS) is one where "*physical and software components are deeply intertwined, each operating on different spatial and temporal scales, exhibiting multiple and distinct behavioral modalities, and interacting with each other in a myriad of ways that change with context*" [1]. The scope of this paper pertains to the definition of a conceptual framework of a CPS for efficient energy management in building structures.

A CPS-enabled energy management system in building structures is concerned with the sensing and control of energy flows. Modern buildings exhibit a tight integration of sensing, computation, and actuation within multiple physical domains [2]. For example, larger buildings usually contain a sensor network, with a variety of sensors that measure electric power flow, temperature, relative humidity, carbon monoxide and $CO_2$ levels [2]. They control the operation of the chiller and heating systems, and may have actuators to control the air-flow into and through the building, or building access. The energy management and control system uses the sensor measurements and determines actuation; the control of which can be of a hierarchical or distributed nature. The full potential to achieve efficient energy management in building structures requires information on the thermal behavior of the building, accurate predictions of weather and building use, input from spot energy markets, equipment efficiency characteristics, and possibly access to distributed generation (DG), energy storage, smart grid technology and an evolved communication infrastructure. The efficient management of energy in structures thus presents a ripe area for the exploration of deploying cyber resources.

Building operating systems such as heating, ventilating and air conditioning (HVAC) system, lighting, vertical transportation, other electrical loads depend on energy from a variety of sources such as electricity, oil, and gas, for providing acceptable levels of security and comfort to the user [3]. However, over 40% of energy consumed in residential and commercial buildings is associated with low efficiency heating and cooling loads; a behavior that has been enabled by the traditionally low-cost of fuels such as natural gas, propane, and fuel oil used in heating [4, 5]. As energy prices soar concomitantly with the needs of reducing dependence on fossil fuels usage and curbing carbon footprints, Building Energy Management Systems (BEMS) present an important avenue for the pursuit of end use energy efficiency. A possible solution includes incorporating local DG and renewable energy sources (RES) to offset the consumption of heating fuels and electricity from the grid. The control and use of a BEMS may present an ideal avenue for deploying CPS that may boost the overall efficiency.

In the face of looming energy and environmental challenges there is increasing interest to both retrofit existing and build new building structures with low- and zero-energy performance characteristics [6]. To achieve maximum energy efficiency in a building structure, a holistic perspective that considers both thermal and electrical energy systems in the presence of sensors is needed to anticipate changes in the environment and respond dynamically while maintaining comfort and efficiency [7]. Such a perspective would also consider the implications of distributed controls, DG, heat recovery techniques, and communications infrastructure [7]. A cyber-enabled distributed control methodology using multi-agent systems (MAS) for efficient management of both electrical and thermal energy systems is proposed here as a tool for realizing maximum efficiency energy management, which would provide heating, cooling and electrical services Efficient electric energy management within cyber-enabled buildings and interconnected operations with the electric grid are integral aspects of the philosophy of energy efficient building design [8, 9]. This may include control of DG sources, energy storage mechanisms and a user-friendly interface to make the structure customer-driven from the perspective of the electricity markets. At the interface between the electricity grid—the major provider of external energy—and the end user is a set of devices including a smart interface device (usually, a power electronic device with advanced capabilities) and a portal for exchange of information with the provider (i.e., a smart meter) [10-14]. Some of the functionalities of the smart meter include two-way communications between the end user and the utility

978-1-4244-8010-4/10/$26.00 ©2010 IEEE

regarding demand and supply schedules, dynamic electricity pricing (real-time or interval), and communication of the intention to island or stay grid-connected during system events [15]. It is expected that the design of smart power electronic systems with access to timely information and advanced control options at the consumer end will greatly enable the utilization of pervasive DG for energy efficient buildings [16]. This concept of cyber-enabled on-site electric energy production, consumption, management and trading with the electric grid is expected to align with the national policy to modernize the US electricity infrastructure through the Smart Grid Initiative [9].

The rest of the paper is organized as follows: Section II presents information related to energy aware buildings; Section III illustrates a CPS framework for building energy management; and Section IV concludes.

## II. ENERGY AWARE BUILDINGS

Annually, buildings in the U.S. consume 39% of the total energy and 68% of the total electricity while emitting 38% of $CO_2$, 49% of $SO_2$, and 25% of $NO_x$ [17]. Monitoring energy usage and energy efficiency at the end user facility may provide: 1) feedback about energy conservation and operational practices, and, possibly, 2) early warnings for system maintenance and repairs [18]. Energy aware buildings are expected to provide building users real-time information about energy use, including on-site generation capability and availability, dynamic pricing information, local load demands and forecast, and weather information. Building users should be enabled by this information to make better choices about their energy usage based on their own preferences and needs. In turn, BEMS will use the aggregated historical data to effectively deploy local generation or purchase energy from utility. The BEMS could also identify and address any inefficiency in energy usage and thus, increase the efficiency of energy conversion and consumption at optimum operating costs while decreasing the carbon footprint of the building structure. The following subsections describe some concepts of building energy management.

### A. Building Energy Information Systems

Energy information systems (EIS) in buildings consist of energy management and control software, data acquisition hardware, and communication networks so as to provide real-time information on consumption and efficiency to the BEMS and the service provider [19]. An EIS enables either the building users or an automated BEMS to access real-time energy consumption data, on-site generation data, dynamic price information, and local weather data to understand the energy trend of buildings and identify energy saving opportunities [19]; concurrently, utilities can be informed of accurate energy consumption data in facilities to manage energy supply and distribution. A secure portal may be used to access and manipulate energy usage patterns in the building by the appropriate entities.

In this paper, the authors extend the concept of EIS from [19] to a CPS for efficient energy management in building structures, i.e., the CEBEMS. The characteristic differences between the CEBEMS and the EIS concept are: a) Local BEMS with highly distributed controls enabled by cyber elements; b) incorporation of both electricity and gas usage in energy management including on-site generation sources; c) consideration of weather information and customer preferences; and d) active demand response participation enabled by emerging technologies including self-learning loads.

### B. Net Zero Energy Building

Over the last two decades of the 20th century, commercial buildings in the US doubled their electricity consumption [20]. Projections predict this consumption to increase by 50% by the year 2025 [20]. In this respect, the US DOE has established an aggressive goal to create the technology and knowledge base for cost-effective zero-energy homes and commercial buildings (ZEBs) by 2020 and 2025, respectively [21]. A net ZEB employs energy efficiency techniques and renewable energy technologies to serve the local energy requirements [20]. However, there exists a myriad of definitions for ZEBs based on the focus of the building design. For completeness of this paper, the following ZEB definitions are reproduced verbatim from [20]:

- *Net zero site energy: A site ZEB produces at least as much energy as it uses in a year, when accounted for at the site.*
- *Net zero source energy: A source ZEB produces at least as much energy as it uses in a year, when accounted for at the source. Source energy refers to the primary energy used to generate and deliver the energy to the site. To calculate a building's total source energy, imported and exported energy is multiplied by the appropriate site-to-source conversion multipliers.*
- *Net zero energy costs: In a cost ZEB, the amount of money the utility pays the building owner for the energy the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over the year.*
- *Net zero energy emissions: A net-zero emissions building produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources.*

Net ZEB designers usually decide on the apt net-zero energy definition subject to the project goals, input from the building owners and the principles of the design team [22]. The next section describes a conceptual framework of a CPS for building energy management—the CEBEMS.

## III. A CYBER-PHYSICAL SYSTEM FOR BUILDING ENERGY MANAGEMENT SYSTEM

In this section, an attempt to describe a conceptual framework of a CPS for building energy management, i.e., the CEBEMS, will be described with particular focus on a) the physical aspects, including some novel hardware, and b) the cyber aspects, including some energy management schemes.

### A. *Physical Aspects of CEBEMS*

The goal of this subsection on physical aspects is the description of the concepts behind some novel hardware that will enable efficient energy management in buildings by considering both the electrical and thermal energy systems. The objective of such a system is to achieve high overall energy efficiency, low emissions and economic feasibility, without compromising the preferences and comfort of consumers. Fig. 1. shows the building energy generation and storage and consumption units and the energy flow paths.

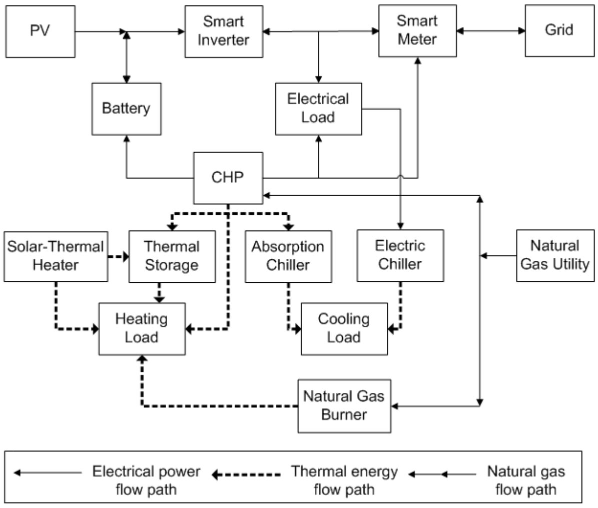

Fig. 1. The physical part of BEMS.

The proposed local BEMS has three zones of interest—the electrical zone, the heating zone, and the cooling zone. The electrical zone may possess some RES. In this formulation, a photovoltaic (PV) resource, grid connection, and combined heat and power (CHP) units are used as generation units and an energy storage unit (battery bank) is present in the system. This setup is responsible for powering the electrical loads in the building. The heating zone possesses a solar-thermal heater, recovered heat from CHP units, a natural gas furnace and thermal storage as heat generation and storage units. The heating loads may be divided according to space heating and hot water needs. The cooling zone may possess an air-conditioning unit and an absorption chiller that uses the recovered heat from CHP to provide space-cooling needs.

It is imperative to mention that the interface between the electric energy service provider (grid) and the building must include a power electronic (PE) device, such as an inverter, with intelligent controls. The PE interface contains the necessary circuitry to convert electric energy from one form to another, i.e., direct current or alternating current. The conversion circuitry may include both a rectifier and an inverter, or just an inverter, depending upon the form of electricity being converted and used. The inverter output is compatible in voltage and frequency with the area electric power system to which it will be connected and contain the necessary output filters so as to meet the standard requirements for connecting to the grid. The PE interface can also contain protective functions for both the distributed energy system and the local electric power system that allow paralleling and disconnection from the area electric power system. These functions would typically meet the IEEE Std. 1547 interconnection requirements [23], but can be set more sensitive depending on the situation and the local utility interconnection requirements. The PE interface may also contain some level of metering and control functionality. This will ensure that the distributed energy system can operate as designed.

Another enabling feature of the physical infrastructure of the CEBEMS is schedulable local loads that may be deployed based on several parameters including customer preference, comfort, needs, attractive electricity pricing, and incentives for participating in demand response programs initiated by the service provider [24]. Such loads may be operated in tandem with critical loads that are to remain online at all times in order to sustain the efficient functioning of the building and its occupants.

An underlying layer of communication infrastructure is assumed to be in place that interconnects the control systems with the controlled entities. A smart meter interface with the electricity service provider is also a part of this communication infrastructure at the point where the building electric system interfaces with the grid.

### B. *Cyber Aspects of CEBEMS—A Multi-agent System Approach*

Energy management systems in modern buildings represent complex systems, with a potential for use of cyber-enabled distributed controls, a wireless network of sensor/actuator arrays, information systems, while incorporating the preferences of the end user. Some earlier control approaches for energy management in structures have relied on centralized schemes, i.e., data collection and decision-making process were concentrated at a given point. Centralized energy management may present some difficulties when dealing with large-scale distributed systems due to the limited capabilities of centralized computing, data collection, and control requirements that do not favor. MAS are aggregations of loosely coupled, networked agents, each with a set of inherent goals and limited purview to enable the implementation of scalable, flexible and distributed control systems [25, 26]. MAS aim to achieve system-wide objectives, which may not be solved using a single agent, but by coordination and communication among the agents [25].

The proposed CEBEMS is achieved by a MAS approach as shown in Fig. 2. In each zone identified in Section IV.A, the energy conversion, storage and consumption are precisely measured and dispatched by the intelligent agent embedded in each zone. The respective agents are the E-agent for electricity, the H-agent for heating, and the C-agent for cooling. These agents shall be collectively referred as main agents in the following text. The communication between the main agents can be achieved by exchanging a virtual token based on preset control rules [27].

The information input to the main agents in the CEBEMS are: a) load forecast and battery state of charge (SOC), which are measured by sensors and reported by lower level agents embedded in the respective domains or zones; b) net energy

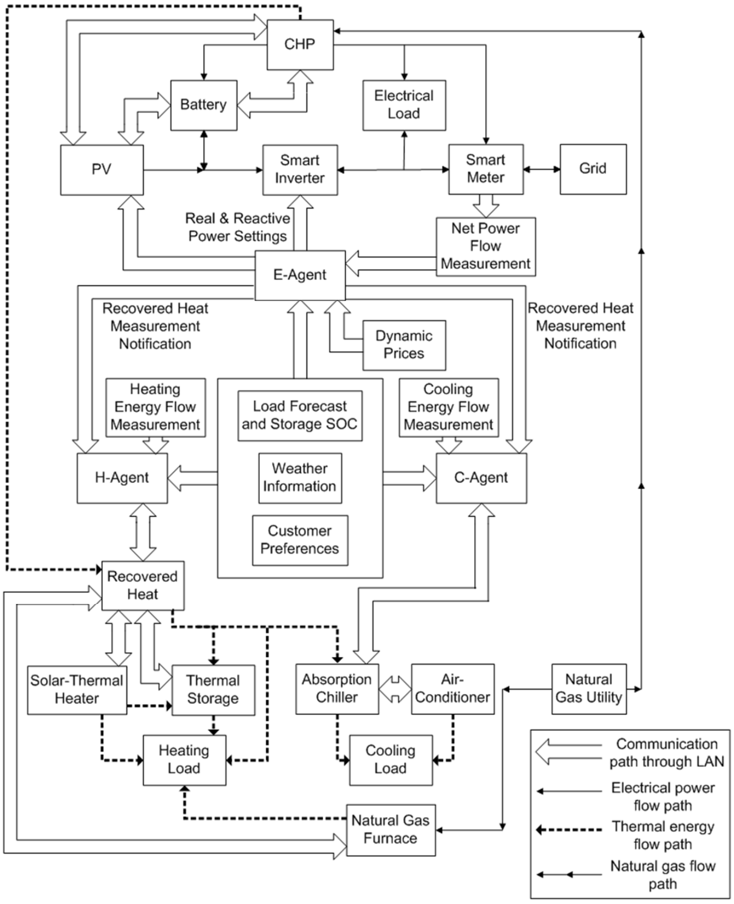

Fig. 2. Cyber physical systems of efficient energy management in buildings through a multi-agent system approach.

flow in the respective zones, obtained from sensor measurements in each zone; c) weather information, which can be obtained in real time from possibly the internet through a secure local area network; d) customer preferences, which are input by the building users through an energy management software interface. The customer preferences can be preferred temperature of space heating/cooling, hot water and lighting illumination, which may be compared with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) thermal comfort standard [28] and lighting requirements [29] by employing some intelligent technique. It is expected that the choices of customer preferences will affect the energy flow in each zone.

The conceptual framework recommends that all the parameters vis-à-vis energy purchase, conversion, storage, consumption and cross-zone energy exchange in this building energy system be precisely measured and controlled by the distributed intelligent agents, enabled by a communications infrastructure.

It is expected that not all the blocks shown in Fig. 2. need to be employed in the CEBEMS. The selection and combination of the appropriate blocks depends on the building size and energy needs. This is driven by the fact that while CHP systems represent an acceptable scenario for inclusion in large systems, they may be prohibitively expensive for systems rated at less than 1,000 kW [30]. So in a home energy management system, the electrical energy zone may include a PV setup with the appropriate PE interface devices, grid connection and possibly, energy storage elements, [31], and the heating zone may include a solar thermal heater for most, if not all, heating needs during the day, and a natural gas furnace and water heater setup for heating needs during the night, and the cooling zone may include only an air-conditioner unit. However, in the area of commercial building energy management systems, it is likely that CHP will be employed. For medium-sized commercial buildings, which represent 23% of all buildings in the US [30], BEMS simulation and studies of practical cases have been performed [32-34]. At the Massachusetts Institute of Technology (MIT), a gas-fired CHP system cut the annual energy bill of the institute by 40% and reduced emissions by 40% [35].

### *C. Demand Response and CEBEMS*

In modern commercial buildings, demand response systems (DRS) have a significant impact on system reliability, cost savings, system efficiency, risk management and environmental issues [36]. In this subsection, some early concepts relating CEBEMS to demand response are explored.

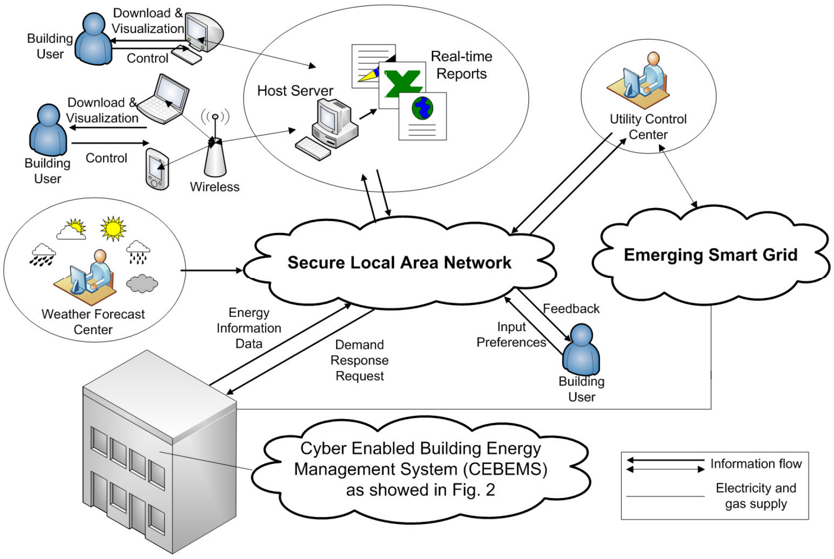

Fig. 3. The demand response of cyber-enabled efficient building energy management system

Fig. 3. shows the demand response using the CEBEMS. All data related to energy consumption and on-site generation data may be collected by metering devices installed in the building, and then dispatched through a secure portal (i.e., the smart meter), possibly through an intranet– a home area network (HAN) for residential buildings–to a database server (e.g. host server). The database server stores and archives the data and EIS users can access the database server and may download appropriate real-time reports using dedicated or generic tools. The local BEMS, could analyze the real-time reports for achieving higher efficiency of local energy consumption.

It is expected that the smart grid will employ wide area monitoring through the use of an extensive sensor network infrastructure [37]. Smart meters with two-way communication capability will also give utilities the ability to communicate with end users, thus presenting a scenario for engaging the end user more actively in demand response. Enabled by information from measurement centers in the grid and from real-time energy reports of a specific end user (e.g., a building), the utility control center can notify the end user to participate in some demand response action. A common demand response action relates to load management during system peak loading; in such cases, a demand response action by the end user may not only relieve the stress on the grid but also provide an avenue for the end user for receiving economic incentives for participation and alleviation. To avoid the stress on the system during periods of peak demand, the utility may engage the participation of users in demand response action ahead of the daily peak hours. Then, the building users may decide on participating in the demand response action based on several parameters [19]. The same philosophy may also hold true for other services such as reduction in natural gas consumption. At the time of writing this paper, a situation involving a natural gas line leak in a major US metropolis forced the utility to engage its end users in an impromptu curtailment [38]. It is envisioned that a CPS such as the CEBEMS with communication links to the service provider and the ability to engage active demand response participation will yield desirable effects.

Building users may monitor their demand reduction through a user-friendly interface in real-time and the data used for participation in a demand response action may also be available for access and manipulation after the event [19]. However, the users do not have to be acutely involved in the demand response event; the CEBEMS may be equipped with appropriate learning algorithms that can progressively learn the usage patterns using historical data. This knowledge may then be used to program the CEBEMS to automatically engage in demand response and to meet certain thresholds of energy efficiency.

## IV. CONCLUSIONS

A conceptual framework for a cyber physical system for energy management in building structures is presented in this paper, with the intent of increasing energy efficiency, lowering dependence on the grid, and providing an economic incentive for the end user. Integrating RES and DG sources will be critical to the success of the ideas presented here. CHP is expected to play a significant role in commercial building energy efficiency improvement. Energy storage is also expected to be an integral part of the solution to energy efficiency, especially when considering RES with erratic input such as solar and wind. Finally, evaluating the overall energy efficiency of the CEBEMS proposal is future work of the utmost importance. The overall goal of the CEBEMS architecture is to increase energy efficiency and reduce environmental impacts. This evaluation will provide an avenue for quantifying the cost to benefit ratio of a proposal such as the CEBEMS.

## ACKNOWLEDGMENT

This work was supported by the National Science Foundation under Award No. 0931748. The authors acknowledge the comments and contributions of Ms. Josune M. Armas and the proof-reading by Ms. Hilary E. Brown, former graduate students in the Division of Engineering, Colorado School of Mines, Golden, Colorado 80401.

## REFERENCES

[1] National Science Foundation, "Cyber-Physical Systems (CPS) nsf08611," [Online]. Available: http://www.nsf.gov/. [Accessed: Dec. 1, 2009]

[2] M. Brambley, P. Haves, S. McDonald, P. Torcellini, and D. Hansen, "Advanced sensors and controls for building applications market assessment and potential R and D pathways," Pacific Northwest National Laboratory, 2005.

[3] Dr. Lal Jayamaha, *Energy-efficient building systems*. New York: McGraw-Hill, p. xiii, 2007.

[4] S. Suryanarayanan, T. L. Vincent, R. Braun, M. G. Simões, and K. L. Moore, "Cyber physical systems for energy efficient building structures," [Online]. Available: http://www.ece.cmu.edu/~nsf-cps/file.php?id=169. [Accessed Oct. 15, 2009].

[5] S. Suryanarayanan, M. G. Simões, P. Zhao, "CEEMS: An application of cyber-physical systems to energy management in building structures," accepted, Proc. 2010 US-Korea Conference on Science, Technology and Entrepreneurship (UKC 2010), Seattle, WA, Aug 2010.

[6] B. Griffith, P. Torcellini, N. Long, D. Crawley and J. Ryan, "Assessment of the technical potential for achieving net zero-energy buildings commercial buildings," presented at ACEEE Summer Study, Pacific Grove, CA, Aug. 14–18, 2006.

[7] L. L. Horton,"Basic research needs to assure a secure energy future," presented at Work Shop on Neutrons and Energy for the Future, Oak Ridge National Laboratory, Jun. 4, 2004. [Online]. Available: http://neutrons.ornl.gov/workshops/nmi3/presentations/horton_edited.pdf. [Accessed: Oct. 15, 2009].

[8] R. S. Thallam, S. Suryanarayanan, G. T. Heydt, and R. Ayyanar, "Impact of interconnection of distributed generation of electric distribution systems-a dynamic simulation perspective," in Proc. IEEE Power Engineering Society General Meeting. Montreal, Quebec, 2006.

[9] *110th Congress of the United States, Smart Grid, Title XIII, Energy Independence and Security Act of 2007 (EISA)*, Washington, D.C., Dec 2007.

[10] R. Carnieletto, S. Suryanarayanan, M. G. Simoes, and F. A. Farret, "A multifunctional single-phase voltage source inverter in perspective of the Smart Grid Initiative," in Proc. 2009 IEEE Industry Applications Society Annual Conference, pp. 1-8, Oct. 2009.

[11] M. Venables, "Smart meters make smart consumers," *Engineering and Technology*, vol. 2, no. 4, p. 23, 2007.

[12] A. Roshan, R. Burgos, A. Baisden, F. Wang, and D. Boroyevich, "A DQ frame controller for a full-bridge single phase inverter used in small distributed power generation systems," in Proc.2007 IEEE Applied Power Electronics Conference (APEC) pp. 641-647, 2007.

[13] U. Miranda, L. Rolim, and M. Aredes, "A DQ synchronous reference frame current control for single-phase converters," in Proc. *36th* IEEE Power Electronics Specialists Conference, pp. 1377-1381, Jun. 2005.

[14] S. Chung, "Phase-locked loop for grid-connected three-phase power conversion systems," *IEEE Proceedings-Electric Power Applications*, vol. 147, pp. 213-219, May 2000.

[15] "SmartSynch: The SmartMeter," [Online]. Available: http://www.smartsynch.com/ Smart- Synch smartmeter.htm. [Accessed: Dec. 10, 2009].

[16] B. Kroposki, C. Pink, R. DeBlasio, H. Thomas, M. Simoes, and P. Sen, "Benefits of power electronic interfaces for distributed energy systems," in Proc. IEEE Power Engineering Society General Meeting. Montreal, Quebec, pp. 1- 8, 2006.

[17] The Whole Building Design Guide, "Optimize energy use," [Online]. Available: http://www.wbdg.org/design/minimize_consumption.php. [Accessed: Sep. 12, 2009]

[18] J. Lewis, "The case for energy information," in *Information technology for energy managers*, the Fairmont Press, 2004, p. 92.

[19] N. Motegi, M. A. Piete, S. Kinney and K. Herter, "Introduction to web-based energy information systems for energy management and demand response in commercial buildings," in *Information technology for energy managers*, the Fairmont Press, 2004, PP. 55-66.

[20] P. Torcellini, S. Pless and M. Deru, "Zero energy buildings: A critical look at the definition," presented at ACEEE Summer Study, Pacific Grove, CA, Aug. 14–18, 2006

[21] "Zero energy goals," [Online]. Available: http://www1.eere.energy.gov/buildings/goals.html. [Accessed: Dec. 16, 2009]

[22] "Net-zero energy commercial building initiative," [Online]. Available: http://www1.eere.energy.gov/buildings/commercial_initiative/zero_energy_definitions.html. [Accessed: Dec. 10, 2009]

[23] *IEEE Standard for Interconnecting Distributed Resources With Electric Power Systems*, IEEE Standard 1547, 2003.

[24] H. E. Brown and S. Suryanarayanan, "A survey seeking a definition of a smart distribution system," in Proc. 41st North American Power Symposium, Starkville, MS, Oct 2009, pp. 1-7.

[25] K. Y. Lee and S. R. Eisenbarth, "Agent-based wireless sensing/Actuation Networks," [Online]. Available: http://www.ece.cmu.edu/~nsf-cps/. [Accessed: Nov. 10, 2009].

[26] F. Jacques, *Multi-agent systems: an introduction to distributed artificial intelligence*, Addison Wesley Professional, 1999.

[27] J. Lagorse, D. Paire, A. Miraoui, "A multi-agent system for energy management of distributed power sources," *Renewable Energy*, vol. 35, no.1, pp. 174-182, Jan, 2010.

[28] "*Thermal Environmental Conditions for Human Occupancy*," 1992, The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard: ANSI/ASHRAE 55.

[29] "*ANSI/ASHRAE/IESNA Standard 90.1-1999*," Building Energy Codes Program, *U.S. Department of Energy*.

[30] "Guidebook: CHP for buildings integration test center at University of Maryland," [Online]. Available: http://www.chpcenterma.org. [Accessed: Nov. 20, 2009].

[31] J. M. Armas, S. Suryanarayanan, "A heuristic technique for scheduling a customer-driven residential distributed energy resource installation," in Proc. 15th Int'l Conference on Intelligent Systems Applications to Power Systems (ISAP), Curitiba, Brazil, Nov. 2009, pp. 1-7.

[32] C. Marnay, M. Stadler, G. Cardoso, O. Mégel, J. Lai, and A. Siddiqui, "The added economic and environmental value of solar thermal systems in microgrids with combined heat and power," [Online]. Available: http://der.lbl.gov/new_site/DER.htm. [Accessed: Oct. 20, 2009].

[33] C. Marnay, J. Lai, M. Stadler, and A. Siddiqui, "Added Value of Reliability to a Microgrid: Simulations of Three California Buildings," [Online]. Available: http://der.lbl.gov/new_site/DER.htm. [Accessed: Oct. 20, 2009].

[34] M. Stadler, C. Marnay, A. Siddiqui, J. Lai, B. Coffey, and H. Aki, "Effect of heat and electricity storage and reliability on microgrid viability: a study of commercial buildings in California and New York States," [Online]. Available: http://der.lbl.gov/new_site/DER.htm. [Accessed: Oct. 20, 2009].

[35] D. Hinrichs, R, McGowan, and S. Conbere, "Integrated CHP offers efficiency gains to buildings market," [Online]. Available: http://www.sustainablefacility.com. [Accessed: Dec. 15, 2009]

[36] M. A. Piette, M. D. Sohn, A. J. Gadgil and A. M. Bayen, "Improved power grid stability and efficiency with a building-energy cyber-physical system," [Online]. Available: http://www.ece.cmu.edu/~nsf-cps/. [Accessed: Nov. 10, 2009].

[37] G. Manimaran, V. Vittal, Z. Wang, "Embedded sensor network and algorithms for future energy infrastructure," [Online]. Available: http://www.ece.cmu.edu/~nsf-cps/. [Accessed: Nov. 10, 2009]

[38]. Anonymous. "Xcel Energy repairs natural gas line leak," [Online] Available:http://www.xcelenergy.com/Colorado/Company/Newsroom/Pages/12-12-2009---Repairsgaslineleak.aspx [Accessed: Dec, 2009]