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Convergence for the Smart Grid -
On the technology opportunities for Future Cyber-Physical Energy Systems

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National Priority

The current electric grid in the U.S. is about 100 years old and while incremental upgrades to it have been made over the last few decades, the advancements in fields such as Information Technology, Internet, wireless/mobile technologies, have been slow to transition into the grid. It is the convergence of a number of factors that provides for a perfect storm today that is expected to make a revolutionary change in the nature of the electrical grid.

The convergence is of various factors as follows, and this convergence

- Technology advances make it possible
- Increase in Global warming
- Changes in the utility business worldwide
- Deregulation in various parts of the world
- Rapid reduction in limited natural resources
- Rise in population
- Rising cost of energy
- Better awareness and education among consumers
- Increase in renewable, distributed, and smaller power generation
- Increase in power storage capability
- RFIDs and sensors having narrowed the virtual distance between physical and cyber world

As a result, there is tremendous impetus at the government, industry and consumer level to innovate and various entities have articulated their visions into what the Future / Smart Electric Grid should look like. For example the DOE has a vision for the Modern Grid Strategy as follows: (source http://www.netl.doe.gov/moderngrid/opportunity/vision.html) - "Before we can begin to modernize today's grid, we first need a clear vision of the power system required for the future. Given that vision, we can create the alignment necessary to inspire passion, investment, and progress toward an advanced U.S. grid for the 21st century. A modernized grid is a necessary enabler for a successful society in the future. Modernizing today's grid will require a unified effort by all stakeholders rallying around a common vision".

At this juncture, United States has decided to make this a national priority, and various agencies have actively been working on various parts of the complicated puzzle. Exactly what the Smart Grid architecture will look like at a national level is still not clear. While researchers such as the author of this article are working towards developing technology or adopting technology to solve a particular and focused problem, the bigger picture today is not clear. Also, while the vendors pursue a more short-term strategy, a 40,000 foot view is needed for open discussion bringing together academics, industry, and, government.

A vision of the Cyber Physical Energy System– Wireless Internet SmartGrid

In our vision, the Smart Grid of the Future consists of the I.P. network layer that monitors, controls, repairs, automates the power generation, distribution, and consumption, with a unique three layered architecture. In this model, at the edge of the network are physical devices and artifacts with sensors sending data, at the middle of the network is the messaging, transfer and control function and at the center of the network are the intelligent servers and databases. Our model for the future of the grid involves the use of various wireless technologies connected to devices via sensors since installation of wired infrastructure is becoming increasingly uneconomical.

Our Technological Approach

Our group has developed a technology to support this vision called the WINSmartGrid Technology which brings together this three-layered architecture and is based on the UCLA Reconfigurable Wireless Interface for Networking of Sensors or REWINS (http://winmec.ucla.edu/rewins).

The Edgeware is a combination of software and firmware that connects to physical infrastructure such as the temperature monitors, humidity RFID tags, motion detectors or X10 controllers on refrigerators. A variety of monitors/sensors are supported within WINSmartGrid including temperature, humidity, current, voltage, power, shock, motion, chemicals, etc. The Edgeware controls and utilizes the wireless networks that connect to the WINSmartGrid hub. The WINSmartGrid hub supports wireless protocols such as Zigbee, Bluetooth, WiFi, GPRS and RFID, however, it appears that the 802.15.4-based low-power protocols such as Zigbee appear to hold the maximum promise. Other protocols such as WiMax and Rubee are being added. The Edgeware allows the creation, setup, management, control and utilization of a two-way hierarchical and low-power network.

The Middleware is the “Cyberware” sits between the Edgeware and the Decision making web service or Centralware. The Middleware provides functionality such as data filtration, aggregation and messaging on the raw data from the Edgeware, extract meaningful information, and route it appropriately to the correct destination / web service.

The Centralware is the “Central Cyberware” that receives real-time price feeds and other data from the utilities, has a basic set of knowledge-based rules on control decisions, and makes the control decisions that need to be executed. The WINSmartGrid Centralware also has the capability to connect to other Intelligent Web services to collaborate on decision making about the control decisions – currently it is a structural interface, with a basic set of rules only. This structural web service will eventually be connected to the external intelligent services as they come on-line.

Once the Centralware makes the decisions, the Middleware is informed about the control decisions via actions, which then maps and routes these control decisions to the Edgeware, which in turn converts those decisions to low-level control signals for the appropriate controller (e.g. X10 controller connected to a Plug-In car).

Characteristics of importance

The following are key characteristics of the technology which present opportunities of research due to their need for constant improvement:

- Low Power technology
- Standards-based hardware adapted to fit the problem resulting in lower overall cost
- Wireless infrastructure for monitoring
- Wireless infrastructure for control
- Service architecture with three layers – Edgeware, Middleware and Centralware
- Open architecture for easy integration
- Plug-and-Play approach to the network installation.
- Reconfigurability – The capability of the technology to be reconfigurable allows OTA (over the air) upgrade of the firmware to be able to handle different and devices, applications, sensors, controllers, thermostats, etc.

Research Issues on Cyberphysical Energy Systems

The following are key research issues of importance to our work

- Data Modeling
- Network Modeling
- Zigbee – Low Power Networks
- Open architecture – So as to allow multiple smart meters to integrate with the HAN, we prefer to go with an open architecture for WinSmartGrid.
- Wireless Debate – Since UCLA’s Wireless Internet for Mobile Enterprise Consortium(WINMEC) is a neutral meeting ground and promotes thought leadership, best of breed and standards, we will encourage open debate on which wireless protocol to use including 801.15.4 (Zigbee, IPv6LoPAN), 802.11 (Wi-Fi), Bluetooth, and even look at WANs such as WiMax, LTE, CDMA, EDGE, etc.

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- Home Area Networking (HAN) architecture – Looking at architectures that are available today for AMI systems such as iTron, Cellnet, Elster, etc., and being compatible with the major providers, where possible.

Other Research Projects Proposed discussed with WinSmartGrid Partners at UCLA-WINMEC Center

- Monitoring of infrastructure to report to control center for rapid decision making
- Millisecond delay wireless networks for the field
- Quick reporting of Use of RFID to track smart meters for asset management
- Use of Wireless-integrated temperature monitors for field applications
- To determine distance between cables and trees in the field.
- Bring intelligence to condition of equipment by monitoring temperature.
- Monitoring sparking wirelessly and bring this information to the Central station
- Monitoring condition of underground power lines where oil line is in close proximity of the power line to prevent explosions
- Remote monitoring of conductor temperature Benefits of above - Reduction of labor costs and ability to monitor the above variables more frequently, automatically, accurately, and with less human intervention

Thought Leadership

To discuss the 40,000 foot view of the Smart Grid, a thought leadership meeting for the UCLA based WINSmartGrid Connection project hosted by the UCLA WINMEC Center was held on March 18, 2009, in UCLA moderated by Dr. Gadh, and the next one is being held on June 18, 2009 - http://winmec.ucla.edu/smartgrid/2009/. The following organizations participated in the first meeting: UCLA WINSmartGrid Connection, 3Di Systems, A2Insights, BC Hydro, Capgemini, CSULB/TMAssociates, Current Group LLC, Electric Power Group, H2scan Corporation, Lawrence Berkeley National Laboratory>, Los Angeles Dept Water & Power, Litton Consulting Group, Inc., NERC Cyber Security CIP Program, On-Ramp Wireless, Inc., Oracle Corporation, OPUS Consulting Group, Qualcomm Incorporated, Qualcomm Ventures, Sempra Energy/The Gas Company, Siemens, Utility Consulting Group, and, University of California, San Diego.

Recent Seminars, Panels and Keynotes

- Dr. Gadh has been actively researching and promoting the notion of Wireless Internet and Wireless Sensor Interfaces for Smart Grid needs. His seminars on the Smart Grid recently include:
- Keynote address - SmartGrid at Raytheon, Feb 19, 2009
- Seminar - NIST, Gaithersburg, MD, March 30, 2009
- On-line Lecture, BrightCove, http://www.brighttalk.com/webcasts/search/gadh , March 24, 2009
- Panelist - Connectivity Week, Santa Clara, Jun 9
- Participation - DOE Workshop Technical Workshop on Computational Issues and Challenges of the 21st Century Power System
- Chair - panel discussion on Industry-Government Participation on Smart Grid at the Southern California Edison Smart Grid Forum on 4/7/2009

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