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A Miniature Smart City Experimental Set for Engineering Education

Sibel ZORLU PARTAL
Yıldız Technical University, Electrical Engineering Department

Dogan Onur ARISOY
Yıldız Technical University, Control and Automation Engineering Department

Abstract: This paper introduces a miniature experimental set demonstrating a smart city and its components for engineering education. The model prototype simulates the real life loads and energy sources in a small lab scale, employing the ZigBee communications and power control modules for many use cases in a typical smart city. The grids become smarter with the increase of renewable energy systems' usage, distributed energy production, and the availability of control and communication technologies on power grids. Therefore the education institutions take actions to educate the students on the state of the art smart grid components. As a part of this goal, the miniature smart city model was developed and some interactive software applications have been embedded to mimic the real smart city applications for engineering education.

Keywords: Smart city, Smart grid, ZigBee, Wireless control, Laboratory equipment

Introduction

Emerging technology, economical structure and modern daily life require us to use resources more efficiently, organized and controlled. An important part of this advancement which has become a basic need of human life in the last century, is production, distribution and consumption of energy with high efficiency. International researches have been done on this topic and technology is being developed to shows us the fact that, the advancement is following a path to "Smart City" concept, where energy is produced by renewable resources, all the energy flow is monitored though the "Smart Grid" infrastructure and energy consumption is made efficient by controlled usage and efficient equipment (Fang, Misra, Xue, & Yang, 2012). Smart grid components need to be studied in detail. In this paper, communication component will be highlighted and a short range communication standard will be employed in a model prototype. Brown (2008), defines a successful smart grid by its aspects which are, self-healing, high reliability and power quality, resistance to cyber-attacks, accommodating a wide variety of distributed generation and storage options, optimizing asset utilization, minimizing operations and maintenance expenses. These all are essential for smart grid system and making these able to synchronize themselves and inform results and problems.

Smart grid systems are in need of an advanced communication infrastructure with safe and reliable information exchange. Gungor et al. (2012) survey different types of communication technologies and methods in a smart grid system and discuss their effectiveness and usage areas. In this paper the ZigBee protocol was implemented for smart city communications in this experimental education set. As known ZigBee protocol is one of the most appropriate communication infrastructure for home automation, its low range and low data transfer rate make it less favorable in extensive use. Even though ZigBee has these down sides, its ability of mesh networking, low energy consumption and low price makes it advantageous (Masica, 2007). As ZigBee is convenient for home automation systems and applications, Han and Lim (2010) and Grill, Yang, Yao and Lu (2009) have also studied this concept.

As summarized above, there are several research and demonstration studies in literature. In this work, it is intended to cover most of these important items for a Smart City and demonstrate a simulation platform for higher education. The idea of using this type of experimental set is very useful in education since the students can visualize and understand the concepts better, as also demonstrated by Chowdhury et al. (2013). The smart city model presented here simulates real life loads such as residential houses, schools, industrial premises, social and cultural sites, and public parks. It employs solar energy panels and wind turbines as the energy sources to feed these loads. Wireless communication technologies and power electronics hardware were installed for smart energy management to monitor and control of renewable energy sources and loads. This demo simulation platform as seen in Figure 1 has been being used at a university in Istanbul for the engineering education, which helps students to learn many concepts in a Smart City.

Figure 1. Miniature smart city

Method

There is a big energy cycle with energy production, transmission, distribution, energy converters etc. The best way to increase the efficiency is to adapt new technologies to these systems, monitor their conditions and control. To control and monitor, there are three layers which are the controlled system, the communication layer and the controller, as described in the chart of Figure 2. In this paper, systems and methods which are used to build a miniature smart city are surveyed first, then the control and communication technologies are discussed.

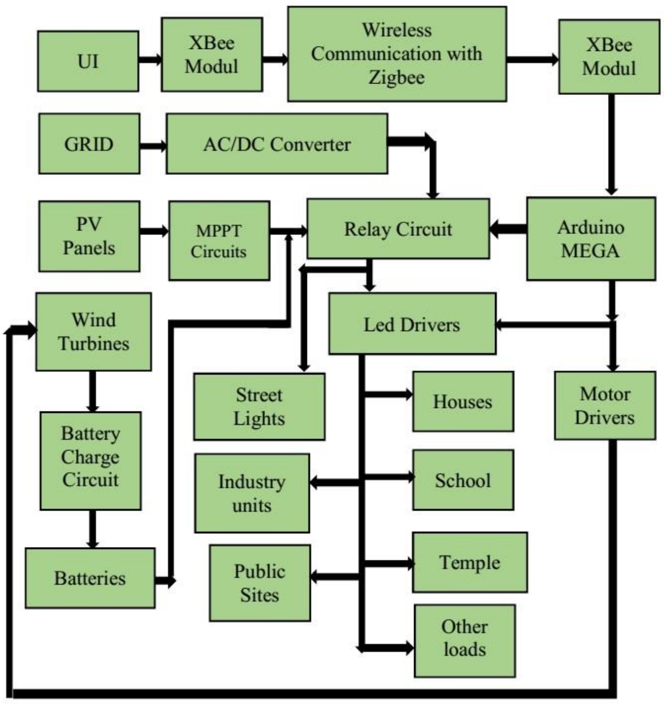

Figure 2. Energy management flow chart

Energy Cycle in the Smart City

In order to mimic a smart city, our miniature model needs energy sources. For this purpose two most common renewable energy sources are chosen as solar and wind. For solar power, four of 5W PV (photovoltaic) units are used with florescent luminaries over them and MPPT (maximum power point tracking) circuits are placed after PV panels to regulate output voltage and to limit output current. As the second means of energy production, five wind turbines are simulated via coupled motor-generator groups. Each of these groups are consisted of two 12V, 8W brushed DC (direct current) electrical machines. Motors in the groups are driven via PWM (pulse width modulation) controlled motor driver circuits and outputs of the generators are routed to battery charge circuits for voltage regulation and current limiting then used to charge battery groups. Also an additional 12V, 280W power supply is used to supply circuits, wind turbine motors and other parts of the system.

The energy efficiency is vitally important and it is best achieved at the consumer level. Using efficient end devices, monitoring and control of energy consumption are the key components for this purpose. In the miniature model, thirteen 12V, 1W power LEDs (light emitting diodes) are used as home and industrial loads. LEDs are powered via PWM controlled LED drivers to simulate different loads in different times of a day under different weather conditions.

The fundamental component of monitoring and control is measurement. In the model voltage and current of both production and consumption are measured via sensors, and then converted to digital data via ADCs (analog to digital converters). These values of voltages and currents are used to calculate instantaneous power values of all production and consumption components.

Communication, Monitoring and Control of the Smart City

In this prototype, wireless communication modules have been used for monitoring and control purposes. As this paper is about a miniature *Smart City* with a miniature *Smart Gird* infrastructure; all measurements, monitoring, control and communications are designed in a small scale demonstration test bench. The real life loads are scaled down on this test platform, maintaining the ratio of load profiles relatively.

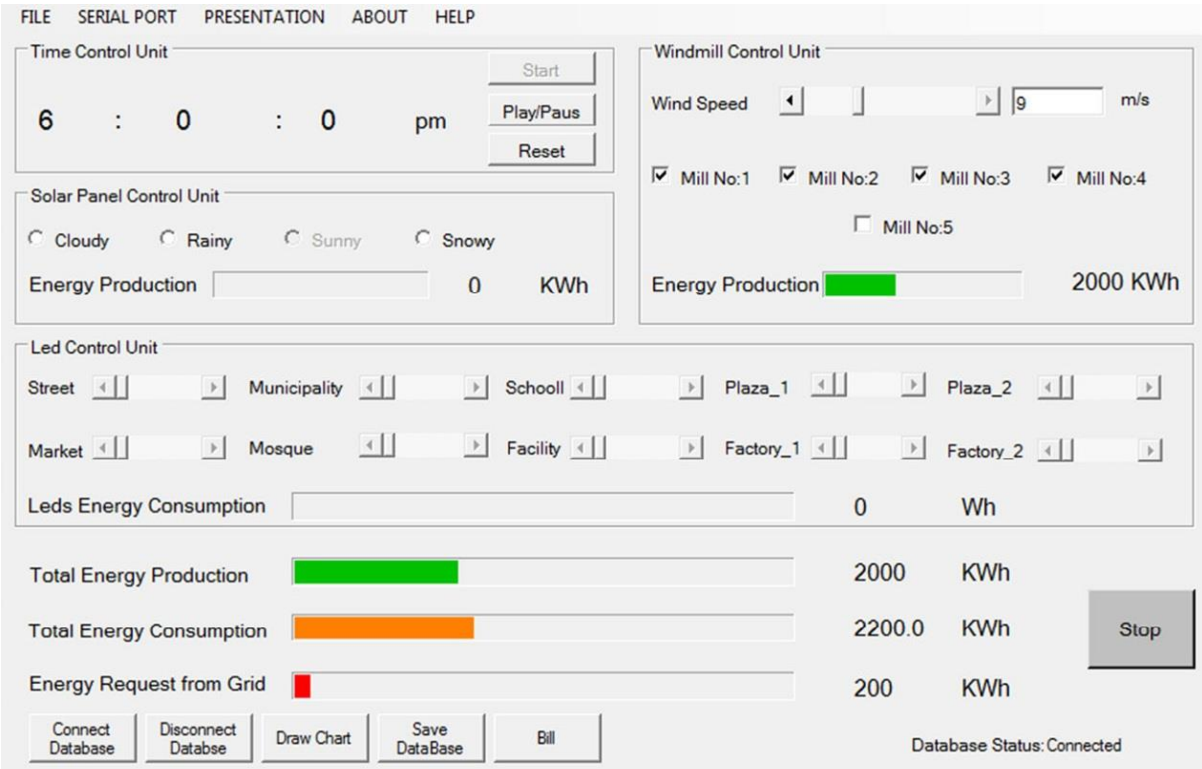

Figure 3. User interface for monitoring and control

ZigBee Protocol and Xbee Modules

ZigBee is a wireless network protocol standardized with IEEE 802.15.4 which supports different network topologies. ZigBee is mostly used for home or building features. A commercial module in market, XBee, is a low power consuming, short ranged, low data rated and low cost wireless network module which operating with ZigBee protocol. Its typical line-of-sight (LoS) range is up to 100 meters. It supports mesh network infrastructure which allows XBee modules to communicate over each other (Masica, 2007). In this project XBee modules are used to establish communication between the miniature city components and computer which enables monitoring and control of the system.

Monitoring and Control via User Interface, Computer and Arduino

For monitoring and control purposes a computer which has a UI (user interface) as shown in Figure 3 is used. Through this UI instantaneous power values can be monitored and different parts of the miniature city can be manipulated. Infrastructure of the miniature city is controlled by Arduino Mega 2560. With XBee modules a communication layer between computer and Arduino is established. Manipulation through the user interface is translated into sub-protocols which then sent to Arduino for execution. Execution is done as opening or closing relays, or setting PWM values for drivers. Arduino also collects information from the infrastructure of the miniature city via sensors. These are instantaneous voltage and current values from different parts of the system such as solar energy production, wind turbine production and different consumption data. Then Arduino sends these data to the computer via wireless communication for computing. Data received by the computer are used to calculate instantaneous power values of the system, and can be monitored from the UI.

Wireless Energy Transfer from Charging Station to Truck

To demonstrate the wireless energy transfer technology a model truck, that follows a preset path on the road of the miniature smart city, is used. In each lap, truck stops in front of the charging station for a while. During that time wireless energy transmitter circuit in the charging station is activated, which, in turn, enables the wireless energy transmission via the coils that are both in the station and the truck. Energy is received by the truck and regulated by the wireless energy receiver circuit and used to light an LED on top as shown in Figure 4. Due to circuits and energies being small actual charging is not possible, however this application is quite satisfactory for teaching the fundamentals of wireless energy transfer.

Figure 4. Wireless energy transfer from charging station to truck

Results and Discussion

A miniature smart city simulation platform, which monitors and controls the integrated energy resources and loads, is developed and made ready for engineering education. It stores the power consumption of the loads real-time for future reference.

The experimental set is made for students by the students to increase the understanding of fundamental subjects via applied demonstrations. The set is open for students to observe during working hours in Yıldız Technical University, Electrical Engineering Department's general laboratory. Students may get informed about the set by laboratory assistants and lecturers may use the set with student groups to reinforce theoretical topics they cover during lectures with applied demonstrations. Lectures that are planned to incorporate this experimental set are given in Table 1.

Table 1. Lectures that experimental set planned to be used in

Lecture Names
Introduction to Electrical Engineering
Electromechanical Energy Conversion
Electric Machinery
Electricity Generation
Renewable Energy System
Introduction to Smart Grids
Smart Home and Energy Management
Alternative Energy Sources and Modelling
Planning Feasibility of Renewable Energy Sources
Grid Integration of Alternative Energy Systems
Hybrid Alternative Energy Systems

Conclusion

The goal for building this miniature smart city model is to train the engineering students on the trending technologies in market and teach new topics such as smart city and smart grids, to create awareness on smart energy management, and to present the technologies and technics for communication design in a smart city environment. The model demonstrates many concepts for Smart City, including generation, monitoring, and control of power, embedded software, and communications. It is expected to help students with the smart city education in a laboratory environment.

The current experimental set is mainly in demo mode with certain capabilities. Enhanced features can be embedded. For example, a more interactive UI could be introduced for students to run in different configurations. Furthermore, the system may be augmented with cameras, remote control, and monitoring infrastructures.

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Author Information

Sibel Zorlu Partal
Yıldız Technical University, Electrical Engineering Department
Yıldız Technical University, Davutpaşa Campus, 34220, Esenler, Istanbul / Turkey
Contact e-mail: *zorlu@yildiz.edu.tr*

Dogan Onur ARISOY
Yıldız Technical University, Control and Automation Engineering Department
Yıldız Technical University, Davutpaşa Campus, 34220, Esenler, Istanbul / Turkey