Hardware Demonstration of Home Energy Management System for Demand Response Applications Using ZIGBEE

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Abstract: ***Today's energy consumption and transmission are major factors in efficient utilization. A Home Energy Management (HEM) system plays acrucial role in realizing residential Demand Response (DR) programs in the smart grid environment. It provides a home owner the ability to automatically perform smart load controls based on utility signals, customer's preference and load priority. This paper presents the hardware demonstration of the proposed HEM system for managing end-use appliances. The HEM's communication time delay to perform load control is analyzed, along with its residual energy consumption.***

Keywords: home automation, demand response, microcontroller

1. Introduction

Smart grid is the integration of advanced information, communication and networking technologies in traditional electric grid to make it smarter and faster in making decisions. This integration will bring more automation, reliability of electrical services, safety of electrical equipment's and hence an increase in consumer comfort level. With the advent of smart grid several emerging techniques and technologies have been proposed in past decade by researchers across the globe. Smart meters, bidirectional communication, advanced metering infrastructure (AMI), home automation and home area networks (HAN,s) are the techniques and technologies addressed by various researchers [1]. Traditional electric power grid has been serving humanity for the last one century. Population has increased, the traditional grid has worn out thus addition of more and more electric equipment bring instability to the traditional electric power grid [2].

Smart grid has applications in generation, transmission, distribution, and consumption of electrical energy. Smart grid technology enables distributed power generation, where power can be generated locally, use the required energy and sale extra power back to utility. In [3] a power quality monitoring strategy has been enabled by using sensor networks in smart grid (transmission & distribution application). Smart grid can also enhance the electricity usage efficiency. Consuming electrical energy efficiently has proved to be beneficial both economically and socially. By employing home energy management systems, a consumer can reduce his energy bill, reduce peak demand and hence contributes less towards environmental pollution by reducing emission of Green House Gases (GHG).

The demand curve in traditional power grid and flat pricing rates scenario shows that load demand is very high during peak periods as compared to off-peak periods. The result is that utility companies bring their peaker plants online which results in higher generation costs and emission of GHG,s. The originally inelastic demand curve needs to be changed to reduce energy cost and peak load demand. Home energy management (HEM) systems in smart grid enable Demand Side Management (DSM) and Demand Response (DR) programs. DSM is more related to planning, implementing and evaluating techniques and policies which are designed to modify the electricity consumption of consumers. Whereas DR programs are used to manage and alter energy consumption based on supply. Continuous efforts from research community are underway to design new protocols, standards and optimization methods to coordinate Distribution Energy Generation (DER) and residential appliances efficiently in order to reduce peak demand and energy consumption charges of consumers.

Energy management is a broader term, which applies differently in different scenarios, but we are concerned about the one which is related with energy saving in homes, public sector/ government organizations or business. In this scenario the process of monitoring, controlling and conserving energy in an organization/ building may be termed as energy management [2]. In smart grid where the consumers can generate local energy from several distributive generation units and where there is a plenty of space for different pricing schemes, the need for energy management programs has been pointed out by many researchers. Demand side management can contribute in reduced emissions, reliable supply of power and lowering the energy cost. Current grid has demand side management programs for consumers like commercial buildings and industrial plants; however it does not have any such scheme for domestic consumers due to the reasons of lack of effective communication, efficient automation tools and sensors. Secondly implementation costs of various demand response programs are higher when compared with its impact. However in smart grid, smart loads, low cost sensors, smart meters and the information and communication technology open a window for domestic energy management programs [1]. Previous literature employs different techniques for energy management in smart grid.

2. System Design Model

In any HEM systems, two types of communication modules are needed. One is integrated with the HEM unit and the other is built-in in each load controller. The type of communication modules selected will impact the overall system's data communication rate, range, cost, and its residual power consumption. Under a typical home area network/smart-device platform, one or a combination of the following communication technologies maybe deployed: Wi-Fi (802.11/n), Bluetooth (802.15.1), ZigBee (802.15.4), and Power Line Carrier (PLC). According to the evaluation study of various communication technologies [15], we select ZigBee to demonstrate the proposed HEM system. This is because ZigBee is a low-cost, low-power consumption option, and does not require an extensive new infrastructure.

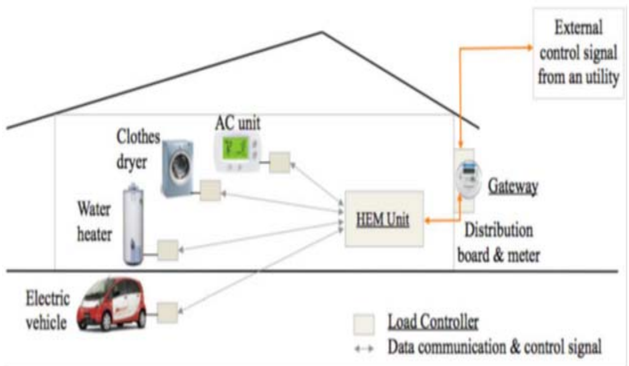

Figure 1: Overview of the proposed HEM system

As shown in Fig. 1, we focus on controlling power-intensive household appliances, namely water heaters, air conditioners, clothes dryers, and electric vehicles. Other household loads, such as lights, TVs, computers, and other plug loads, will not be controlled because turning OFF these loads will result in noticeable impacts on customer's lifestyle.

A. Hardware Section

The HEM system installation in our laboratory environment is shown in Fig. 2 with four commercial load controllers and four actual loads: a hair dryer, a portable air conditioning unit, and two electric baseboard heaters. As discussed earlier, our DR algorithm focuses on controlling power-intensive loads, which are a water heater (WH), an AC unit, a clothes dryer, and an electric vehicle (EV).

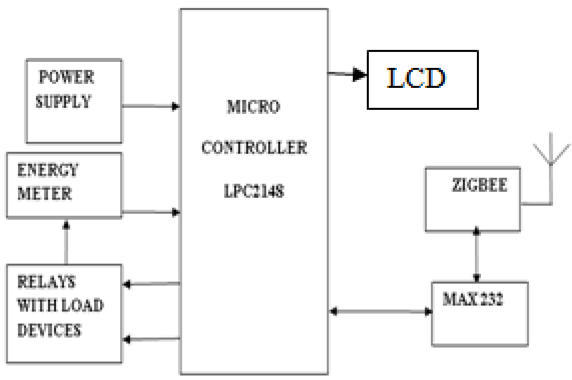

Figure 2: Transmitter Section

The overall system comprises an HEM unit that provides monitoring and control functionalities for a homeowner, and load controllers that gather electrical consumption data from selected appliances and perform local control based on command signals from the HEM system. A gateway, such as a smart meter, can be used to provide an interface between a utility and a homeowner in a real-life HEM deployment. In such a scenario, the gateway receives a DR signal from a utility, which is used as an input for our HEM unit.

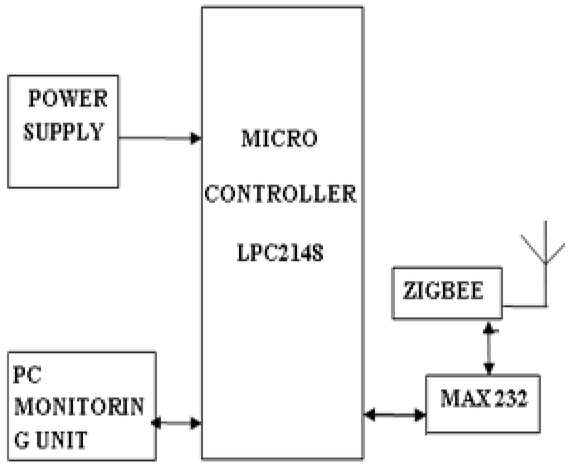

Figure 3: Monitoring Section

An HEM communication module, which provides communication paths between the HEM unit and its load controllers. This module is attached to the HEM unit and enables the HEM unit to send load control commands to all load controllers, and receive responses back. A laptop computer with a ZigBee-enabled communication module is used as the HEM unit for this demonstration.

B. Software Section

This is an Operating System (OS) on which all the software applications required for our design are going to be run. This OS is flexible to any user to operate and easy to understood. Accessing the software's and using them is very convenient to user. Or-CAD is a proprietary software tool suite used primarily for electronic design automation. The software is used mainly to create electronic prints for manufacturing of printed circuit boards, by electronic design engineers and electronic technicians to manufacture electronic schematics. The µVision development platform is easy-to-use and it helps you quickly create embedded programs that work. The µVision IDE (Integrated Development Environment) from Keil combines design management, source code editing, program debugging, and complete simulation in one powerful environment. Code written in 'EMBEDDED C'.

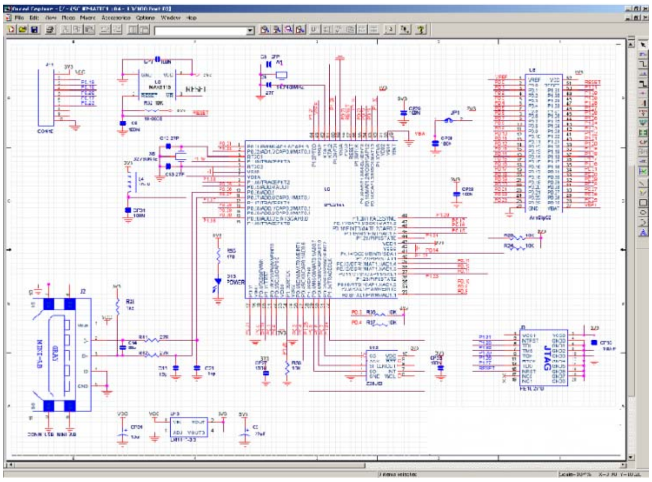

Figure 4: schematic design of the experiment by using ORCAD

The µVision3 IDE is a Windows-based software development platform that combines a robust editor, design manager, and makes facility. µVision3 integrates all tools including the C compiler, macro assembler, linker/locator, and HEX file generator.

3. Experimental Results

These results indicate that the total communication time delay between the HEM unit and load controllers is in milli second scale with ZigBee as the selected communication technology; and that a longer communication distance leads to a slight increase in the overall communication time delay. Note that the measurement results are experimental, and can change under different environments. The HEM operation is multiplexed. In other words, it has to transmit and receive a signal back from one appliance before it can ping the second appliance. The time required to complete one cycle is the sum of all transmit-receive signals for all appliances under control. This determines the frequency of measurements. Thus when there are more appliances to be monitored, the frequency of monitoring goes down.

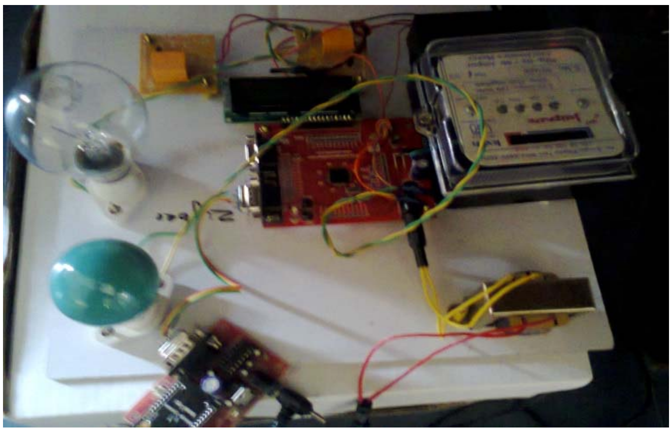

Figure 5: Transmitter section

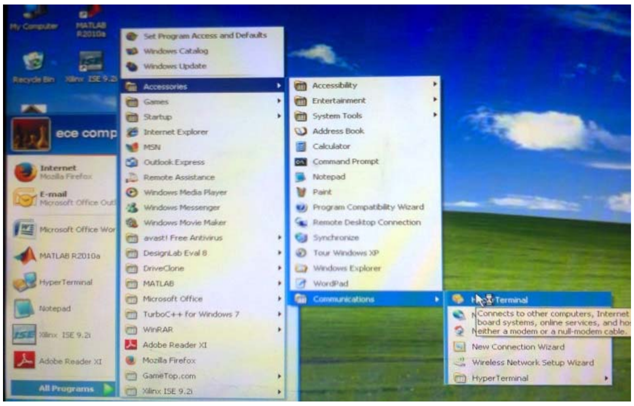

Figure 6: Controlling and monitoring PC unit

Transmitter section contains power supply arm lpc2148 controller, energy meter, relays, lcd, zigbee, appliances Controlling and monitoring PC unit contains power supply, pc receiver along with zigbee. By giving power supply to the project it will be activated and ready to process. In order to establish the serial communication between transmitter zigbee, receiver zigbee we need to set the baud rate as 9600 bps in PC.

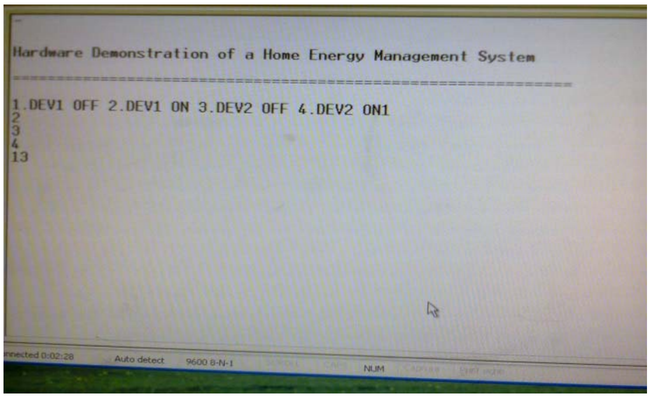

Figure 6: Reciever PC Editor

This PC receiver receives the data from transmitter and controls the appliances by entering the commands(1,2,3….) to the respective load devices. So that whenever load exceeds we can control the devices through the PC.

4. Conclusion

In this paper, the demonstration of the proposed HEM system based on ZigBee is presented for residential DR applications, along with the analysis of the communication time delay and the evaluation of the overall HEM system's residual power consumption. This demonstration indicates that the proposed HEM system can monitor and control actual loads according to the designed DR algorithm. The measured electrical measurements of the loads confirm that the system performed satisfactorily during the entire experiment. The average communication time delay between the HEM unit and load controllers is in millisecond scale and increases slightly with communication distances.

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