Home Energy Management System for Demand Response Applications

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***Abstract*— Now a days, energy saving is one of the most important issue for development of smart grid. The utility companies have higher electric charge during peak periods, so smart grid emphasizes off-peak energy consumption. The Home Energy Management system shall play a very important role in realizing residential demand response in smart grid environment. Therefore, the HEM system with Demand Response (DR) is proposed, in which different loads are used and corresponding priority is adjusted based on priority of user. The controller board is used, which makes a decision to switch ON/OFF action of the selected end use appliances based on utility signal as well as home owners load priority and preference setting. It also demonstrates that how each appliance will perform when it will be controlled by HEM. The proposed system is also responsible for collecting electrical consumption data from all loads and provides an interface for homeowner to retrieve appliances status. It provides user to know the status of appliances wirelessly through sms.**

Keywords—Energy management; HEM; demand response; smartgrid; home automation

I. Introduction

Nowadays, Utility companies across the world have taken various steps for efficient consumption of electricity. The process of observing, controlling and conserving electricity usage in an organization/ building is known as energy management or home energy management [1]. It has been reported that 40% of the global power consumption takes place inside residential buildings [2]. Home Energy Management systems are usually called smart grid systems. This allows for direct communication between the utility company and the consumer. The energy management system optimizes the energy usage by informing the customer on a live basis of their corresponding consumption rates. Utility companies have higher electric charges during peak periods, so the smart grid emphasizes off peak energy consumption. The employment of HEM systems in a residential area reduces energy bills for consumers and peak demands. A HEM system in smart grid enables Demand Response (DR) and Demand Side Management (DSM) programs. Demand response (DR) is defined as “changes in electricity use by demand-side resources from their normal consumption patterns in response to changes in the price of electricity, or to incentive payments designed to induce lower electricity use are at times of high wholesale market prices` or when system reliability is jeopardized”. The DR action can be either incentive-based (e.g., direct load control) or time-based (e.g., dynamic pricing, critical peak pricing) program. The concept of proposed HEM system is based on this topic while taking into account homeowner’s load priority and comfort preference. DR programs help in managing and varying electricity consumption on electricity supply basis.

The maximum consumption of energy is caused by inefficient use on consumer side. In recent years many HEM systems are proposed to reduce energy wastage, however, with limitation in monitoring and control functionalities for home owner. Also in existing HEM systems the load controllers are incapable to gather electrical consumption data from selected appliances and perform local control based on demand response signal sent by controller board. The Home Energy Management system shall play a very important role in realizing residential demand response in smart grid environment.

A. Motivation

This dissertation is motivated by several rising applications of smart grid. Traditionally, over the past several decades, electric power systems have encountered more frequent stress condition due to ever increasing electricity demand, inefficient use of electric power generation and transmission resources. Transmission line outages have been a common cause of system stress conditions, which are possible to occur during critical peak hours. Such events will cause a supply limit situation where cascading failures and large area blackouts are possible. These problems have partially tackled by demand side management. Demand Response (DR) has been envisioned to deal with such unexpected supply limit events by selectively reducing system loads. DR also plays an important role in load shifting from peak hours to off peak hours that can help to increase reliability and efficiency in operation.

B. Objectives

- To monitor appliance power consumption
- Controlling and monitoring the Electronic Appliances Remotely
- To measure electrical factors of the loads.
- To analyze the communication time delay
- To evaluate the HEM operation performance, Interoperability, scalability
- Wireless Home Automation
- Home Disaster Management
- To Design a system which is easy to use and deploy.

II. RELATED RESEARCH

Today, the interests in Home Energy Management systems have been increasing extensively. Various HEM systems are designed based on different communication schemes, such as Zig-Bee, Power-line Carriers etc. Inclusion of Wireless Sensor Networks (WSNs) will play a important role in the extension of the smart grid towards residential places, and enable various demand and energy management applications. Efficient demand-supply balance, reducing electricity expenses and reducing carbon emissions will be the immediate benefits of these applications.

To realize the features of DR, the deployment of fully automated DR solution is necessary called auto-DR. In 2007, Piette and Watson described the Automated Demand Response strategies [3] which can be made possible through the use of a Home Energy Management (HEM) system. It shows that automated DR will be most successful if the building commissioning industry improves the operational effectiveness of building control. Critical peak pricing and even real time pricing are important trends in electricity pricing.

D. Han and J. Lim in the year 2010, proposed a Smart Home Energy Management System (SHEMS) [4] based on an IEEE802.15.4 and ZigBee (called as a "ZigBee sensor network"). This smart home energy management system divides and assigns various home network tasks to appropriate components. It can integrate diversified physical sensing information and control various consumer home devices, with the support of active sensor networks having both sensor and actuator components. They developed a new routing protocol DMPR (Disjoint Multi Path based Routing) to improve the performance of ZigBee sensor networks.

Y. S. Son, T. Pulkkinen, K. Y. Moon, and C. Kim in the year 2010 developed a Home Energy Management System (HEMS) [5] based on power line communication which can provide easy-to-access information on home energy consumption in real time, intelligent planning for controlling appliances and optimization of power consumption at home. This system reduces the cost of power consumption by about 10%.

J. Li, J. Y. Chung, J. Xiao, J.W. Hong, and R. Boutaba presented design and implementation of a smart home system using task scheduling approach [6]. This system is open, extensible, integrated, intelligent, and usage-centric. They have shown that how convergence system designs is a capable methodology for enabling an integrated and multi-faceted home management system that encompasses energy management, home appliance control, environment management, u-health, and living support functionalities under a single unified design.

J. Han, C. S. Choi, W. K. Park, and I. Lee in the year 2011 proposed a green HEMS [7] based on energy comparison. The feedback on energy consumption to energy users was used to reduce total energy use. This HEM system figures out the efficiency of a home appliance as compared to the others by displaying energy usage information of individual appliances. So it is necessary to collect the energy usage data of home appliances in this system.

For residential energy management, M. Erol-Kantarci and H. T. Mouftah in year 2011 proposed an in-Home Energy Management (iHEM) system [8] to reduce energy expenses and contribution of the consumers to the peak load. They evaluated the performance of an in-Home Energy Management (iHEM) application. The performance of iHEM is compared with an Optimization-based Residential Energy Management (OREM) scheme whose objective is to minimize the energy expenses of the consumers. This iHEM also reduces the carbon emissions of the household and its savings are close to OREM. They have showed that the iHEM application is more flexible as it allows communication between the controller and the consumer utilizing the Wireless Sensor Home Area Network (WSHAN). They evaluated the performance of iHEM under the presence of local energy generation capability, prioritized appliances, and for real-time pricing which reduces the expenses of the consumers for each case.

M. A. A. Pedrasa, T. D. Spooner, and I. F. MacGill in described the Co-ordinated scheduling in-home appliances to optimize smart home energy services [9]. They described the algorithmic enhancements to a decision-support tool that residential consumers can utilize to optimize their acquisition of electrical energy services. The decision-support tool optimizes energy services provision by enabling end users to first assign values to desired energy services, and then scheduling their available Distributed Energy Resources (DER) to maximize net benefits.

A. H. Mohsenian-Rad and A. Leon-Garcia tackled two major barriers of the lack of knowledge among users about how to respond to time-varying prices as well as the lack of effective building automation systems for fully utilizing the potential benefits of real-time pricing tariffs by proposing an optimal and automatic residential energy consumption scheduling framework [10] which attempts to achieve a desired trade-off between minimizing the electricity payment and minimizing the waiting time for the operation of each appliance in household in presence of a real-time pricing tariff combined with inclining block rates. Simulation results show that the combination of the proposed energy consumption scheduling design and the price predictor filter leads to significant reduction not only in users' payments but also in the resulting peak-to-average ratio in load demand for various load scenarios. Therefore, the deployment of the proposed optimal energy consumption scheduling schemes is beneficial for both end users and utility companies.

A. H. Mohsenian-Rad, V. W. S. Wong, J. Jatskevich, and R. Schober proposed an optimal and autonomous incentive-based energy consumption scheduling algorithm for smart grid [11] to significantly reduce the peak-to-average-ratio (PAR) and the cost of the system. They considered the deployment of energy consumption scheduling (ECS) devices in smart meters for autonomous demand side management within a neighborhood, where several buildings share an energy source. Smart meters with built in ECS devices were used and connected to the power grid and to a local area network which is essential for handling two-way communications in a smart grid infrastructure. They interact automatically by running a distributed algorithm to find the optimal energy consumption schedule for each subscriber.

III. Proposed System

Fig. 1 shows an overview of the proposed energy management system. The concept of the proposed system is to design and developed the intelligent home energy management system with userfriendly interface, and wireless communication interface including monitoring and control functionalities for the home owner and load controllers that gather electrical consumption data from the appliances and perform local control based on Demand Response by using controller board.

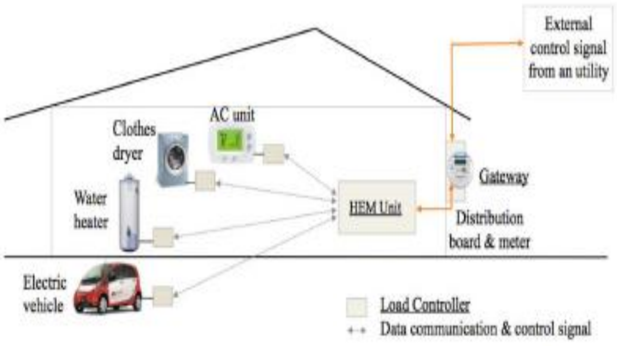

Fig. 1. Overview of the Proposed System

An HEM system plays a fundamental role in implementing the automated DR within a house, as most residential customers do not have time, nor practical enough to perform DR manually. A DR event is defined as a period during which the customer demand needs to be curtailed to improve a system stress condition. Customers who participate in a DR program can be informed of a DR event by an external signal from a utility via their smart meters. Different loads are used in this project and the corresponding priority is adjusted based on the priority of the loads and user preferences. As mentioned in Fig.1, a distribution board and meter can be used to provide an interface between utility and home owner in a real life environment. HEM receives external signal, which includes demand reduction request and duration, for implementing this concept the algorithm is designed to guarantee the total power consumption below the specified demand limit level during the specified duration. The proposed HEM algorithm allows the home owner to operate their appliances when needed as long as the total household consumption remains below the specified limit during a DR event. In earlier, the system proposed would make use of GSM module, hand based gesture which took into limited working of project. Hence in proposed system, the GUI view will be used to monitor and control appliances status and power consumption.

A. Block Diagram

The block diagram for the proposed system is shown in Fig.2. There are two modes of operation manual mode and auto mode. In manual mode each appliances is operated directly according to user requirement. Ones the user gets touch on any device it sends that command to controller board and also produces sound along with the SMS to user. Manual mode will play important role during any disaster. In auto mode, board receives a DR (Demand Response) signal from a utility, which is used as an input for our controller unit. The controller board makes a decision to switch ON/OFF selected end-use appliances based on the utility signal received, as well as homeowner‘s load priority and preference settings. Here the HEM unit is the PC/laptop with GUI. The GUI image contains the buttons to control and monitor the appliances status and power consumption. The input provided by the user is processed on backend.

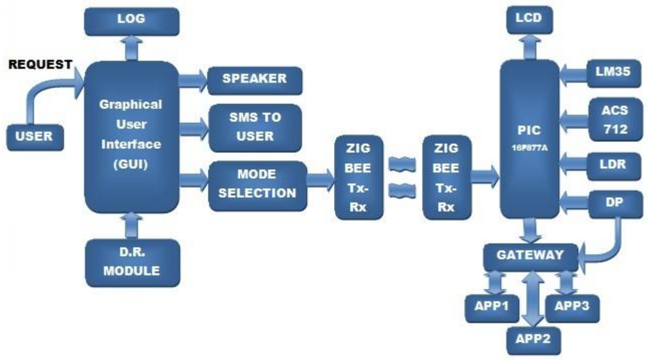

Fig. 2. Block diagram of Proposed System

1) HEM Unit

In general, an HEM unit comprises a laptop computer with a ZigBee-enabled communication Module.

a) An embedded PC running a GUI software application. It is also responsible for collecting electrical consumption data from all load controllers and providing an interface for homeowners to retrieve appliances' status and review their power consumption.

b) 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.

2) Load Controller

A load controller provides an interface between the HEM unit and a selected appliance. It also includes a algorithm developed for implementation of Auto-DR that serves as the brain of the HEM system It makes a decision to switch ON/OFF selected end-use appliances based on demand response signal, as well as homeowner's load priority and preference settings. It provides basic power management functions (i.e., monitor, control, and communicate). It contains:

a) A data capturing and processing module, which collects and calculates real-time electrical consumption data from appliances

b) A control module(gateway), which is simply an electronic relay circuit that provides the capability to switch a selected appliance ON/OFF, depending on the command sent by the HEM unit or user.

c) A communication module, which is responsible for providing communication paths between a load controller and the HEM unit. This is to allow the collected electrical consumption data from a load controller to be sent to the HEM unit; commands from the HEM unit to be received by a load controller; and response signals from a load controller to be sent to the HEM unit.

B. Features

Two manual and automatic modes are available to user to change the status of end use appliances. The user request signal from user is send through communication module. It is also responsible for collecting electrical consumption data from all load controllers and providing an interface for homeowners to retrieve appliances status and review their power consumption. The status of each appliance is provided to user wirelessly through SMS. The main features of this product are:

- Autonomous control based on brightness and temperature of the room.
- ON/OFF of the load based on the priority of the load controllers
- The status information transfer of appliances wirelessly.
- Saving of unwanted energy consumption due to lack of user awareness.
- Peak load reduction potential

Thus the proposed system can reduce energy consumption via interaction with the information about surroundings (e.g. brightness of a room), DR signal and control the load using controller. The proposed HEM system is more user friendly and easy to deploy.

IV. CONCLUSION

Home Energy Management system with demand response plays a most important role for effectively managing the wastage of energy caused by the inefficient use of the consumer electronics. This project presents a new design to control the appliances at home. The proposed Home Energy Management system for demand response applications which can proactively and effectively control and manage the appliance operation to keep the total household consumption below a specified demand limit by managing selected power-intensive loads according to their priority and user requirements. The proposed energy management system takes into account both load priority and user preferences. The changes in status of appliances will be notified to user through SMS. The system also provides for scalability by allowing addition of new devices within the network. Thus the project provides a low-cost, flexible, user-friendly, and very secure architecture for implementing a Home Energy Management System.

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