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FPGA based Smart Home Energy Management System for Demand Response Applications

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Abstract: Energy Management System (EMS) plays an essential part in realizing Demand Response (DR) in smart homes in the smart grid environment. Based on load priority, utility control signals and customer's preference, EMS enables smart load control. This paper describes the hardware prototype of the Home Energy Management System that automatically switches the loads between the battery and electric grid thereby reduces the energy consumption from grid. The EMS is implemented in SPARTAN 6 FPGA board, which in turn sends control signals to the relays connecting the loads to the supply.

Keywords: Home Energy Management System; Demand Response; Smart home; FPGA.

I. INTRODUCTION

India is one of the world's largest producers of electricity. Today, the electric grid operation consists of a vertical structure consisting of generation, transmission and distribution with the necessary infrastructure to ensure reliability, stability, and efficiency [1]. With the revolution in the information and communications technologies, Smart Grid provides an opportunity to revolutionize the electrical power system. Smart Grids communicates between all grid generators, operators, consumers and other electricity market stakeholders to meet their needs and fully utilize their capabilities. When compared to legacy systems, it has included new technologies such as renewable energy sources, energy storage, and instrumentation such as consumer metering and grid performance analysis. Smart grid relieves any congestion in the grid caused by an unexpected peak demand by distributing the available electric energy intelligently thereby reducing the peak load and flattening the load profile [2]. Implementation of this intelligence to manage demand response is the main aim of smart grids. It would also reduce the electricity costs at home or business as the smart grid would enable optimized energy usage by appropriate scheduling of device operation by any automated control systems.

Demand Response is a strategy that is used to reduce or shift power consumption at peak hours to leaner demand hours [7].

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This will help the consumers to reduce their electricity costs by receiving certain incentives for consuming low power during peak hours. This strategy will also remove the need for any further expensive infrastructure for electricity generation, transmission and distribution [9][13]. It is a system where in the consumer of electricity can interact with the grid to control how and when electricity is distributed. Demand response could forecast daily load profile by making it more stable which would enable efficient consumption of energy resources.

Smart Homes are integral part of Demand Response implemented in Smart Grid [3]. It provides controllable devices which are energy efficient with access to real-time energy usage data [9]. This integration of home appliances and smart grid enables consumers to manage their energy usage cost effective and environment friendly manner.

In this paper, an FPGA is used as the local controller in a smart home to control the energy supplied to the load based on the type and number of loads connected to the electrical system. FPGA allows the smart home energy management system to incorporate many loads into the system without increasing the size of the hardware deployed. It also allows on-field modifications to be done remotely thereby reducing the maintenance costs. FPGAs are best suited for real-time applications owing to its concurrent nature thereby providing high speed processing capabilities.

The paper is organized into five sections. The first section provides a brief introduction into the concepts of smart grid, demand response and smart homes. The second section deals with the related work in the concepts introduced in the first section. Section 3 deal with the methodology employed to implement a home energy management system with the help of an FPGA as the central controller and provides the hardware implementation details. Section 4 concludes the paper.

II. BACKGROUND STUDY

With the development of new technologies, a necessity has risen to transform conventional grids into smart grids that uses sensors, monitoring, communications, automation, and controllers to improve flexibility, efficiency, stability, reliability, and safety of the electrical system. Energy management thus becomes an integral part of this transformation and it should primarily start from homes.

Home Energy Management Systems (HEMS) is one of the approaches that can be employed in a smart grid environment

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using smart plugs along with a controller to optimize the overall power consumption of any ordinary house transforming it into a smart house [3]. Another approach to reduce the power consumption from the grid is by efficiently switching the loads between renewable energy in local storage based on its charge-discharge cycles and availability of the grid [4]. Fuzzy logic can be used for load management and local storage or battery management [5]. Certain communication protocols involving power scheduling have also been developed to coordinate power usage to minimize the total demand from an individual household [6]. Scheduling load usage can be done using algorithm like game theory to create multiple schedule vectors in such a way that the demand is never raised [7]. In a demand response scenario, priorities can be assigned to various loads dynamically based on time constraints and context evaluation to ensure better resource management [8]. Prototypes have also been developed to study the effect of demand response system and demand side management system in a smart home with the help of controllers like Arduino or PIC [9][10].

Demand Response (DR) is one of the approaches in smart grid adopted by utilities to reduce the amount of power consumed by the consumer. It can significantly reduce the electricity bills for consumers by altering their energy usage pattern in response to the variations in electricity price. In real time pricing scheme, the utility can set the price high during high demand period and a lower price for when the demand is low [9].

Nowadays conventional sources of energy are not enough to meet the ever-growing energy demand of the consumers. This has forced the utilities to look at other small-scale renewable energy generation units such as solar panels on rooftops or small wind turbines to enable the consumers to be self-sufficient. This energy is usually stored in battery banks for future use. Effective management of these energy sources mainly, the grid and the battery, will ensure proper Demand Response is employed at the consumer side by the utility which in turn will minimize power wastage and reduce the consumer's electricity bill [11][12].

III. FPGA BASED SMART HOME

The electrical system consists two sources of ac supply. AC supply is obtained from either the electric grid or from an inverter connected to a battery. An DPDT relay is used to switch between these two sources of ac supply. This relay is activated only if the loads are switched ON from the switch

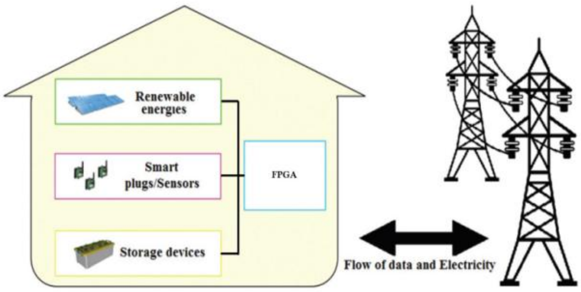

Fig. 1 System Overview

panel. The loads are switched ON\OFF with input from capacitive switch panel. These inputs from the switch panel are first send to the local controller, SPARTAN 6 FPGA board, which in turn sends control signals to the SPDT relays connecting the loads to the ac supply.

Switching of AC sources is based on the status of the battery charge and the amount of load it can drive. The battery state is obtained by measuring the voltage across its terminals with the help of a voltage transducer. The analog voltage input is converted to digital 12-bit value with the help of an onboard ADC. Based on this voltage value the battery state is classified into high, medium or low charged state. For light loads, the supply is drawn from the battery with the help of an inverter. For heavy loads, electric grid is used as the energy source. Also, if the charge of the battery is low, load is always connected to the grid.

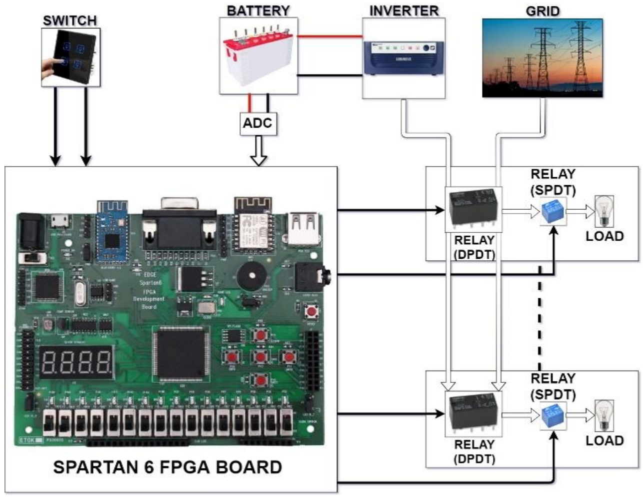

Fig. 2 FPGA based Smart Home Implementation

Hardware prototype of the Load Management System and Battery Management System are tested for its operation and evaluated for different cases. The Load Management system is implemented for two rooms considering different loads i.e. light, medium, heavy etc. Various loads used for hardware prototype are tabulated in Table. I. LED lamp of 10W is considered as light load. 40W incandescent lamp is considered equivalent to fan and 60W incandescent lamps is considered to be equivalent to TV which are medium loads. 100 W incandescent lamps are considered as heavy loads.

Table. 1 Load Size Assumptions In Hardware Implementation

Household loads	Actual loads in prototype	Type of load
LED lamp 10W	LED lamp 10W	Light load
Fan 60W	Incandescent lamp 40W	Medium load
TV 150 W	Incandescent lamp 60W	
Fridge 1200W	Incandescent lamp 100W	Heavy load
Mixer 750W	Incandescent lamp 100W	
Heater 1500W	Incandescent lamp 100W	

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The load management system integrated with the battery management system forms Smart Home Energy Management system. The developed system is tested for various cases such as: 1.Grid Available, Two Batteries are full; 2.Grid Available, One Battery is full; 3.Grid Not available, Both Batteries are full. Decision taken by FPGA based smart home energy management system was noted, Results were obtained as in Table I. The Load Management System is tested for one day and energy savings for one day is estimated.

The FPGA controller checks for both demand limit and comfort level violations of the user. For the demand limit violation, the FPGA checks if the total household consumption exceeds the specified demand limit level. To demonstrate demand response the FPGA measures the electrical quantities voltage and current, and the decision is taken based on the measured values which indicate the type of loads. The hardware and testing setup is shown in Fig.3 and Fig.4.

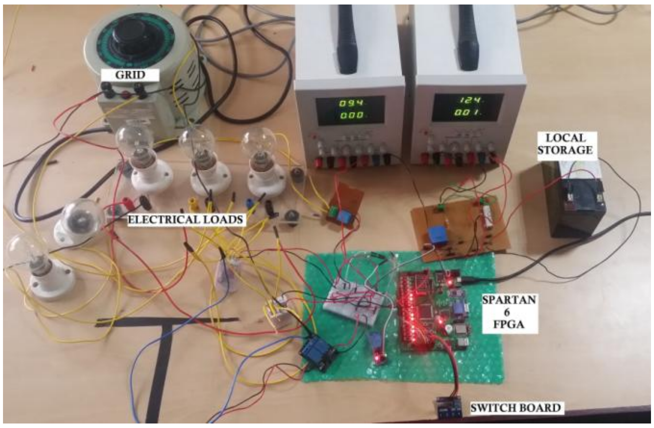

Fig. 3 Hardware Prototype of FPGA based Smart Home

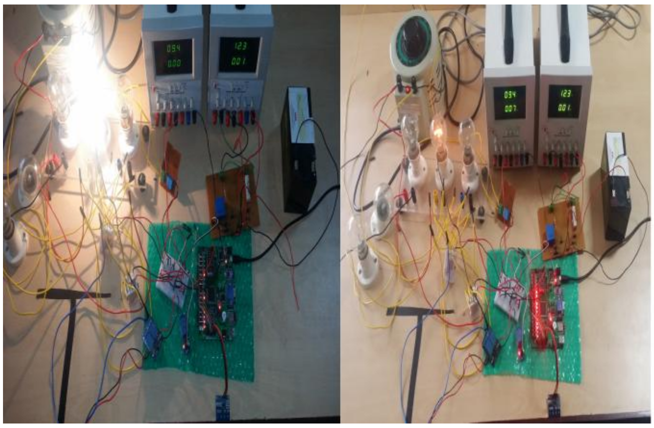

Fig. 4 Testing of hardware for different use cases (a) Loads are connected to the grid. (b) Loads are connected to the battery.

IV. CONCLUSION

A hardware prototype of the home Energy Management System (EMS) using Demand Response was implemented using Spartan 6 FPGA development board capable of switching between a battery source and electric grid based on the number and type of loads connected in the electrical system. This will reduce the energy consumed by each household from the grid which in turn reduces their electricity costs. It will also help the utility to monitor and control the loads operated at peak hours so that the power generated by their units meet the demand of the consumers and not lead to any power wastage during off-peak hours.

Table. 2 Testing and Evaluation of Hardware

Time	**Appliances turned on**	**Loads supplied by Battery**		
		Grid Available, Two Batteries Available	Grid Available, One Battery Available	Grid Not available, Both Batteries Available
8:00 am - 10:00 am	1 fan, 1 fridge	Fan	Fan	Fan
10:00 am - 12:00 noon	1 fridge, 1 fan	Fan	Fan	Fan
12:00 pm - 2:00 pm	1 fridge, 1 fan, 1 mixer	Fan	Fan	Fan
2:00 pm - 4:00 pm	1 fridge, 1 fan, 1 TV	Fan, TV	Fan, TV	Fan, TV
4:00 pm - 6:00 pm	1 fridge, 1 fan, 1 TV, 1 Light	Fan, TV	Fan, TV	Fan, TV
6:00 pm - 8:00 pm	1 fridge, 2 lights, 1 TV, 1 fan	Fan, TV, 2 lights	Fan, TV, 2 lights	Fan, TV, 2 lights
8:00 pm - 10:00 pm	1 fridge, 1 fan, 1 mixer, 1 TV, 2 lights	Fan, TV, 2 lights	2 lights	2 lights
10:00 pm - 12:00 am	1 fridge, 1 fan	Fan	Nil	Nil
12:00 am - 2:00 am	1 fridge, 1 fan	Fan	Nil	Nil
2:00 am - 4:00 am	1 fridge, 1 fan	Fan	Nil	Nil
4:00 am - 6:00 am	1 fridge, 1 fan, 1 light	Fan, light	Light	Light
6:00 am - 8:00 am	2 lights, 1 fan, 1 fridge, mixer, heater	Fan, 2 lights	2 Lights	2 Lights

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