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Smart Home Energy Management System for Monitoring and Scheduling of Home Appliances Using Zigbee

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ABSTRACT

Energy management system for efficient load management is presented in this paper. Proposed method consists of the two main parts. One is the energy management center (EMC) consisting of graphical user interface. EMC shows the runtime data and also maintains the data log for the user along with control of the appliances. Second part of the method is load scheduling which is performed using the single knapsack problem. Results of the EMC are shown using LABVIEW while MATLAB simulations are used to show the results of load scheduling. Hardware model is implemented using human machine interface (HMI). HMI consists of PIC18f4520 of microchip family and zigbee transceiver of MC12311 by Freescale. The microcontroller interface with the zigbee transceiver is on standard RS232 interface.

INDEX TERMS—Smart Grid, Energy Management, Zigbee.

1. INTRODUCTION

Installation of new generating units, especially thermal power plants, to meet ever increasing demand of electricity has threatened our environmental sustainability along with the increasing cost of electricity. This steep increase in demand of electricity has posed a serious challenge to electricity distribution systems and most of utility companies have to follow a trend of load shedding; is the art of managing the load demand by shedding it in critical situations where demand is increased than total generation to avoid system failure or major breakdown. Common practice is to trip feeders originating from a substation. Integration of renewable energy resources and application of efficient load management schemes will avoid the blackout caused by the conventional load shedding. Load management scheme deals with demand side management operated by utility or energy management system run by consumer.

Electricity distribution system in Pakistan faces a lot of technical, financial and managerial problems. Aging infrastructure and inability of utilities to meet the demand have increased the severity of the problems. Recent developments in information technology may help in overcoming these problems. Concept of smart grid with energy management system may help to overcome problem of peak demand. Smart grid for power system refers to electricity networks that incorporate requirements and actions of all stake holders to provide reliable, cheap and safe electricity supplies [1]. The utilities around the globe are working hard for realization of dream of smart grid a reality. Smart grid refers to integrating the latest information, communication, control and digital technologies to the current grid system.

Smart grid enables utility and user to operate their load management schemes. Dynamic pricing is a key component of load management schemes in which utilities create time varying rate structure [12, 14, 15]. Consumer has given more responsibility to manage his appliances in accordance to time of use rates. Different techniques have been introduced for reducing residential cost either reducing power consumption or by shifting load to off peak times [19]. Proposed method in this paper does not reduce power consumption of user but shifts the load to cheaper times when it is possible using dynamic programming load scheduling. There are several ways of dynamic pricing and some of these are listed as following [2].

- Time pricing, a variable is established for peak hour, shoulder and off-peak pricing
- Real-time pricing based on market demand which allows change of pricing on hourly basis
- Hybrid of above two is called variable peak pricing and it forms variable pricing

This paper presents energy management system by providing an optimized solution to monitor and control his appliances through user friendly software developed in LABVIEW and based upon the appliances network input. Goal of this research is to optimize the scheduling time of appliances to reduce power consumption and electricity bill by shifting load to off time [16]. Proposed model contains hardware and GUI (Graphical User Interface) for users to view their consumption and manage load accordingly.

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2. RELATED WORK

Smart power management system for smart grid system is presented in [3] consisting of five single steps: smart power system modeling, monitoring, database collection and management, grid condition check & maintenance and smart grid power system fault analysis. Smart power management system makes use of engineering data and provides a visualization which is to be effective in smart grid system.

In [4] a system for demand side management with a hardware solution for laboratory demonstration is proposed. Load of the consumer is divided into three categories: very critical, critical and non-critical. Power to the loads is fed through the microcontroller which is installed at home. System is proposed to control the load from the substation containing iPac 9302 single board computer and micro controller in the consumer premises using Zigbee technology i.e. IEEE 802.15.4 standard communication protocol. The method proposed does not take priorities from consumer as the load is controlled from substation on the bases of optimum load management and the critical conditions.

In [5] a system is proposed for scheduling home appliances using mix integer linear programming to shift load to off peaks for reducing electricity cost. Peak power consumption and operational characteristics of smart appliances which can be controlled by power signal profile. Optimal profile minimizes the consumption and reduces the cost.

[6] Presents a model for electricity load management in smart home control. The given control method consists of three parts for electrical load management: user must define the load type which is load definition, control of standby loads and usage of informative panel for load management.

Shaalan *et al* proposed a system of dynamic pricing using multiple knapsack method [7]. Consumer appliances are scheduled on a day ahead variable peak pricing to reduce electricity cost. Several other algorithms have been developed on the basis of load scheduling. Vázquez, Felix Iglesias *et al* in [8] used a co-evolutionary particle swarm optimization method. The method is defined for households to coordinate with each other to operate for maximum benefits. [9] Used a linear programming for the scheduling of electricity for industrial consumer for product manufacturing.

[10] Proposed a system for advanced remote control infrastructure and intelligent home management system, which is implemented on hardware using PIC18LF4620 and a zigbee transceiver MRF24j40. Firmware, is designed to control each home appliance and manage a communication network with handheld control and management device. [11] is about a new smart home control system based on intelligent sensor network to make home network more intelligent and automatic. The system contains multiple smart sensor network which senses the presence of consumer, sense the day lighting and humidity. C++ simulation are used to implement a novel real-time, error control, low energy utilization scheme in [18] using redundant residue number system to enhance the wireless sensor network's lifetime and reliability. In [19] a heuristic model called imperialist competition algorithm is proposed for improvement of voltage reliability of distribution networks. The algorithm minimizes the cost of the active losses.

3. PROPOSED METHOD

Aim of this work is to propose a model for EMS (Energy Management System) and home appliances control. Fig. 1 shows schematic diagram of the EMS and home appliances control. Energy Management System is the main part of this model. It provides user visual interface to its consumption. System contains all the information regarding load consumption and maintains the data in a txt file. GUI is developed in Labview and runs on any system containing OS (operating system). Scheduler which is also a part of this application schedules the appliances and home appliances control is used to remotely control the appliances. So the proposed system helps the user to effectively use the electricity for reduction of electricity bills. The home appliances control and information (current, voltage) from different loads in home is sent using zigbee. The zigbee makes life easier for appliances to talk each other and to send their data to EMS. Two appliances controls are provided: one is through remote and second by using EMS software interface. EMS controls appliances directly by communicating with them using the commands given in Table 1.

TABLE I

Commands to Control Appliances

EMS Commands for appliances Control	
Main Switch On	"MainSon"
Main Switch Off	"MainSoff"
Light Room 1 on	"LightR1on"
Light Room 1 off	"LightR1off"
Fan Room 2 on	"FanR2on"
Fan Room 2 off	"FanR2off"
Washing machine on	"WashingMon"
Washing machine off	"WashingMoff"

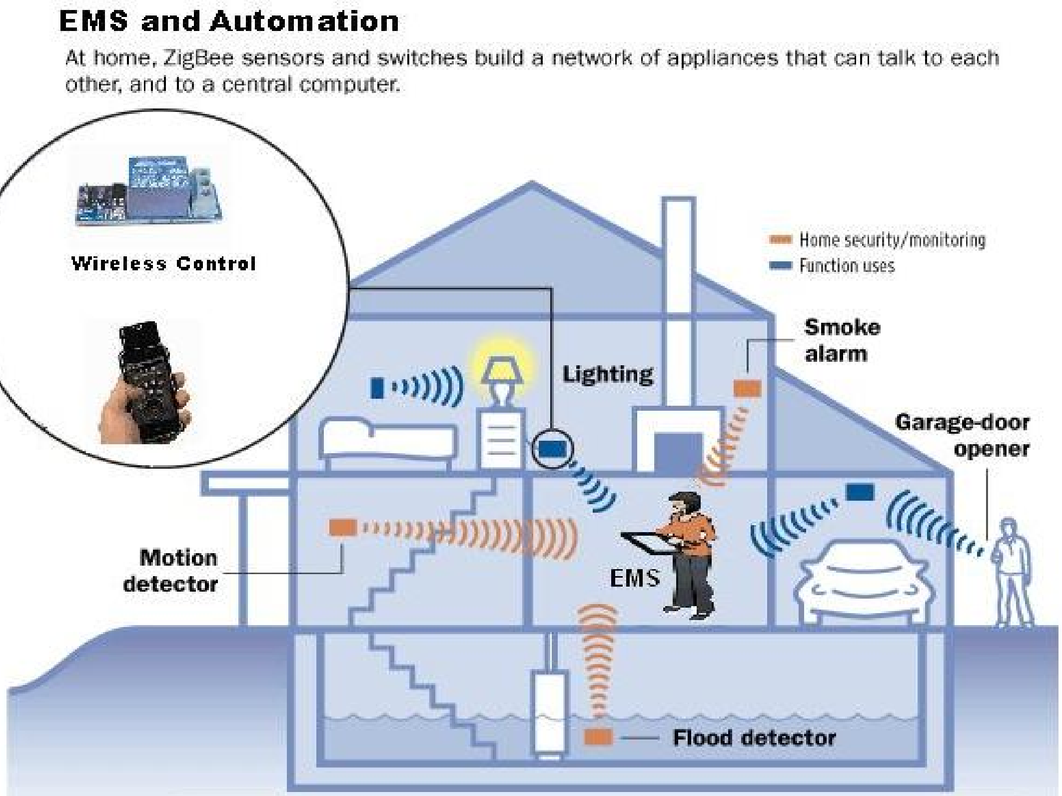

Fig.1. Schematic Diagram of EMS (Energy Management System)

A. EMS SOFTWARE

EMS (energy management system) for the proposed method consists of 'EMC' (energy management center) and 'Scheduler'. EMC (energy management center) provides a graphical user interface to the consumer through which the user can monitor and control its appliances. Load scheduler is to schedule appliances according to priorities of consumer and dynamic pricing.

B. EMC

EMC software is developed in LABVIEW and it communicates with the external world using standard RS232 protocol to gather the required information. It has two tabs:

1. MAIN
2. DATALOG

MAIN tab contains information about line voltage and load current, and some additional control such as alarm and on/off control. The on/off control is used to switch on or off the EMC application software while alarm control is used for any false operation of the device or malfunction of hardware. MAIN tab is shown in Fig. 2 below.

DATALOG tab shown in Fig. 3 contains data log for the voltage and current with specified date and time in a file and also plot the result of XY graph sheet.

C. SCHEDULER

Working principle of load Scheduler is Single Knapsack method, which is solved dynamically to reduce consumption time and to have optimized results. Consumers in smart grid community are charged with peak pricing model. Peak pricing model is set on day ahead peak pricing model. So with forecasted cost curve a consumer is able to schedule its appliances according to curve to shift the load run time of off peak hours. Normally two kind of appliances schedule are found in home which are [10]:

- Full run schedules for appliances which controls full time running appliances like refrigerators, lights and heating systems winter
- Flexible schedules which control to part time run appliances

Fig.2. EMC (Energy Management Center) MAIN Tab

Households normally contains two kind of appliances, one with inbuilt intelligence and other is manually operated but this work focuses on how to minimize the electricity bill for the household by optimally scheduling the operating times of all appliances so that list of the constraints is met. Mathematical expressions for key terms and notations are given as following: [10].

Cost function (C_{ij}): Cost calculation is based on 24-hour based day ahead electricity tariff. The cost curve is discrete in nature and with piece wise jumps as shown in figure 4.

From figure 4 the cost function represent cost consumption at the given time. Normally cost of electricity is high at peak-hours and is low for off peak hours.

Scheduling problem is mapped by discretizing the multiple knapsack method to single knapsack. The (single) knapsack problem is a problem with number of objects having weights/values and which must be packed in a single knapsack of the specified capacity to achieve maximum profit and to fill him with maximum number of items. A number of efficient optimization algorithms are reported in literature for optimal solutions.

The multiple knapsack method is the generalization of single knapsack problem. In multiple knapsack we have (k knapsack) and a set of 'i' objects. Every resources of knapsack have a capacity ($Capacity_i$) [10]. Mapping Problem to knapsack consists of the following:

- k knapsack the maximum energy required to be utilized
- Weights of the function is power required by appliances $\boldsymbol{P_i}$
- Values of the function is the required time interval for the given problem
- Capacity of the knapsack shows maximum energy that can be utilized by the appliances

Constraints applicable to the problem are briefed as [10]: first the energy constraint defined as: From figure 4 the cost function represent cost consumption at the given time. Normally cost of electricity is high at peak-hours and is low for off peak hours.

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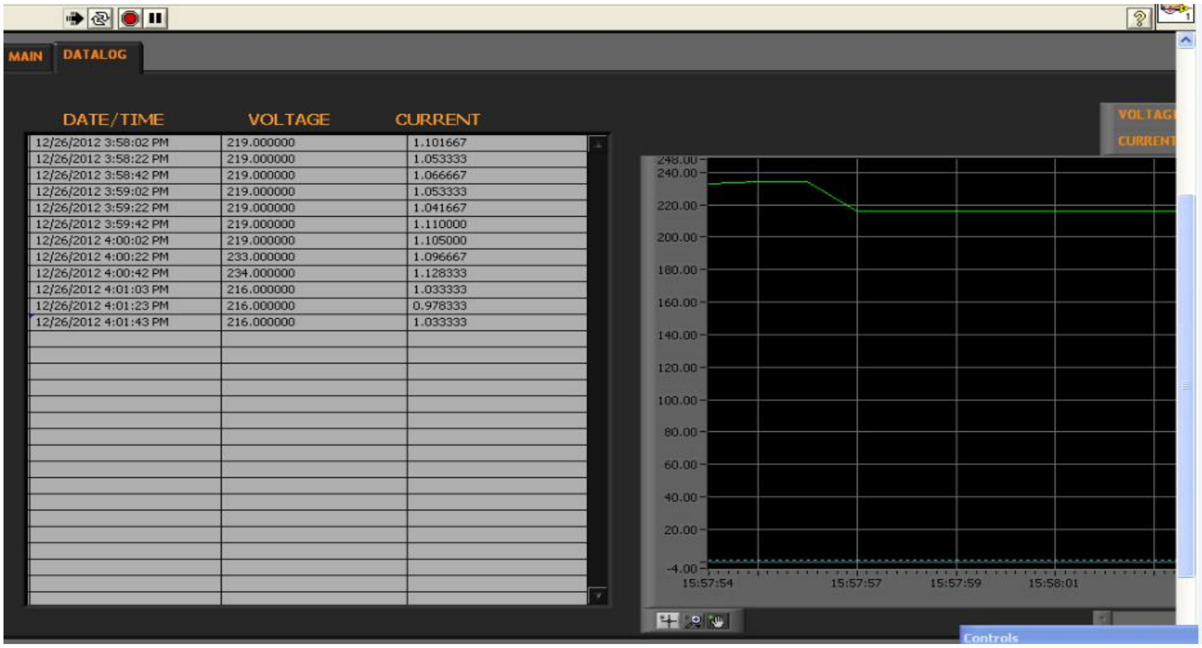

Fig.3. DATALOG Tab

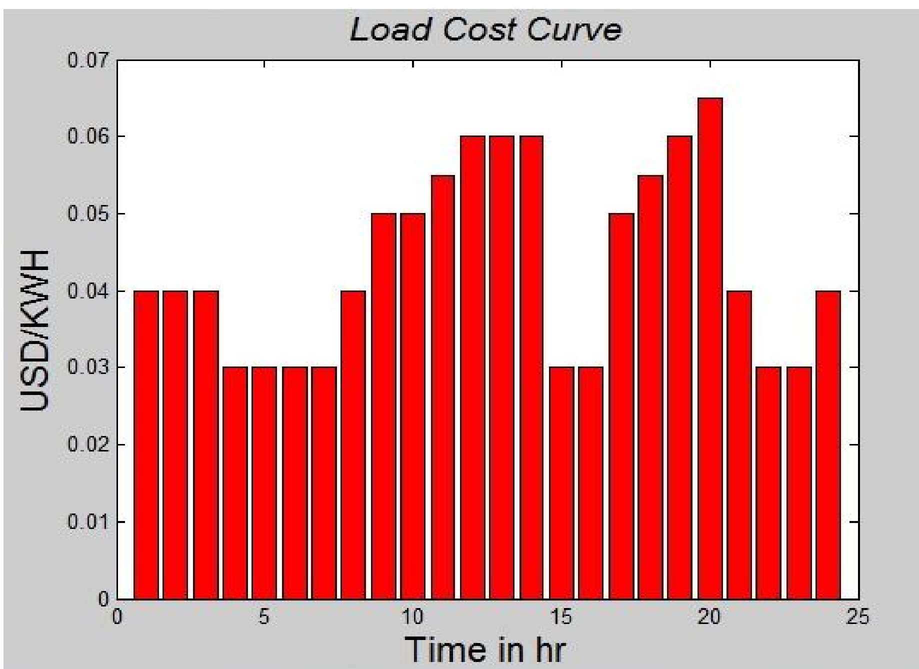

Fig.4. Forecasted Cost Graph

The multiple knapsack method is the generalization of single knapsack problem. In multiple knapsack we have (k knapsack) and a set of 'i' objects. Every resources of knapsack have a capacity ($Capacity_i$) [10]. Mapping Problem to knapsack consists of the following:

- k knapsack the maximum energy required to be utilized

- Weights of the function is power required by appliances P_i
- Values of the function is the required time interval for the given problem
- Capacity of the knapsack shows maximum energy that can be utilized by the appliances

Constraints applicable to the problem are briefed as [10]: first the energy constraint defined as:

$$\sum_{i=1}^{k} P_{ij} = E_{ij} \qquad (1)$$

Where E_{ij} is the energy required for appliance i in phase j. Time Constraint is designed to make sure that each task is completed within its time slot.

$$\sum_{j=1}^{j} X_{ij} = T_j \qquad (2)$$

X_{ij} is a Boolean variable which is defined as [10]:

$$X_{ij} = \begin{cases} 1 \; if\ appliance\ is\ 'on'\ in\ time\ slot\ j \\ 0 \; if\ the\ appliance\ is\ 'off'\ in\ time\ solt\ j \end{cases}$$

and T_j is the given time slot.

Capacity constraint controls the total energy usage of home for each time slot j

$$\sum_{i=1}^{k} P_{ij} X_{ij} = Capacity_{\ j} \qquad (3)$$

Problem is described with the help of example: For instance we have three appliances AP1, AP2, AP3 having the following parameters.

Values: [3 2 3]

Capacity of each slot: 1000

Energy consumed by appliances: [500 300 200]

Cost of each slot: [20 30 20 20 30]

TABLE II

Example Data

Cost function	**20**	**30**	**20**	**20**	**30**
AP1	500	0	500	500	0
AP2	300	0	300	0	0
AP3	200	0	200	200	0
Total	1000	0	1000	700	0

4. PROPOSED HARDWARE

The proposed hardware for the above system consists of HMI (human machine interface) and appliances network. Both of these parts are described in the subsequent sub sections.

A. HMI: (human machine interface)

Heart of this hardware part is HMI, because it provides a link of communication between the EMS (energy management system) software and the appliances network. HMI, shown in Fig. 5, mainly consists of PIC18f4520 of microchip family and zigbee transceiver of MC12311 by Freescale [17]. Microcontroller interface with the zigbee transceiver is on standard RS232 interface. This module receives the data from the appliances network and displays the status of the appliances on a custom LCD of lines 16x2. The software used for HMI interface is MPLAB IDE by microchip.

Algorithm for HMI is shown in Fig 6. It first initializes all the modules and then checks their status. Communicates with the modules and receives data from different appliances. It maintains the log of the energy consumption

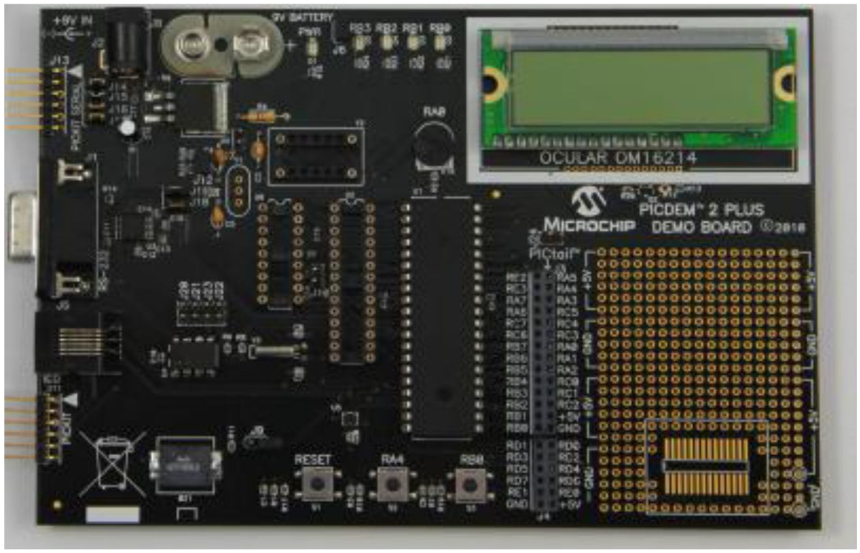

Fig.5. HMI (Human Machine Interface)

B. APPLIANCES NETWORK

By using term appliances network we mean the number of home appliances that are distributed in home and bound to a zone. Each zone consists of multiple appliances, and is responsible for controlling and monitoring operation [13]. Each zone is in communication with HMI. A brief overview of appliances network and hardware is shown in Fig 7 and 8. Algorithm for appliances control is shown in Fig. 9.

The appliances network consists of: Voltage and current sensor, Zigbee interface and appliances control circuit. Voltage and current sensor ACS712 is used to convert the line voltage to a low voltage; it is done by a conventional method using potential transformer. After potential transformer converting the line voltage to a lower voltage level we apply the given output to a bridge rectifier which convert the given AC (alternating current) voltage in to DC (Direct current) voltage. After this it is fed to the PIC16f877A microcontroller from microchip which converts the given voltage into digital format.

Similarly we convert load current into DC current using ACS712. The Allegro® ACS712 provides cheap and accurate solutions for AC or DC current sensing in electrical systems. The package of device is designed to provide easy installation. As load current for light and other home appliances is too small so it cannot be directly applied to the PIC16f877A for conversion to digital format. To overcome this difficulty we designed a precision rectifier which converts the low voltage alternating current signal to direct current signal. Circuit of precision rectifier is shown in Fig. 10.

After conversion of voltage and current data in digital format, it is ready to be transmitted to HMI (human machine interface). Zigbee interface shown in Fig. 11, MC13211 of Freescale, is used for this purpose.

The microcontroller PIC16f877A uses standard RS232 interface to communicate with zigbee. Data from the controller is sent to the zigbee and zigbee transceiver further transmits the data to HMI (human machine interface).

The appliances control circuit is used to control the appliances. It is directly connected to the microcontroller PIC16f877A which is used to control the home appliances; this is done to provide control operation to the user. The appliances control circuit uses SRD relay module to control high-voltage electrical devices. (Maximum 250V)

5. RESULTS AND DISCUSSION

Proposed system consists of two parts: Graphical user interface which is energy management center which provides the user wireless energy metering and control. Data from different zones of their consumption is processed to HMI (human machine interface) and then transferred to the energy management center where user can visualize its power consumption with date and time. The second part of the work consists of Load scheduler with dynamic programming using single knapsack method. The scheduling is done on day ahead tariff basis and user specifies the load which needs to be scheduled or which can be run at any time of the day. Results for the appliances given in Table 3 are shown in Fig. 12 and 13. Difference of the cost may be observed by comparing the scheduled and non scheduled curves.

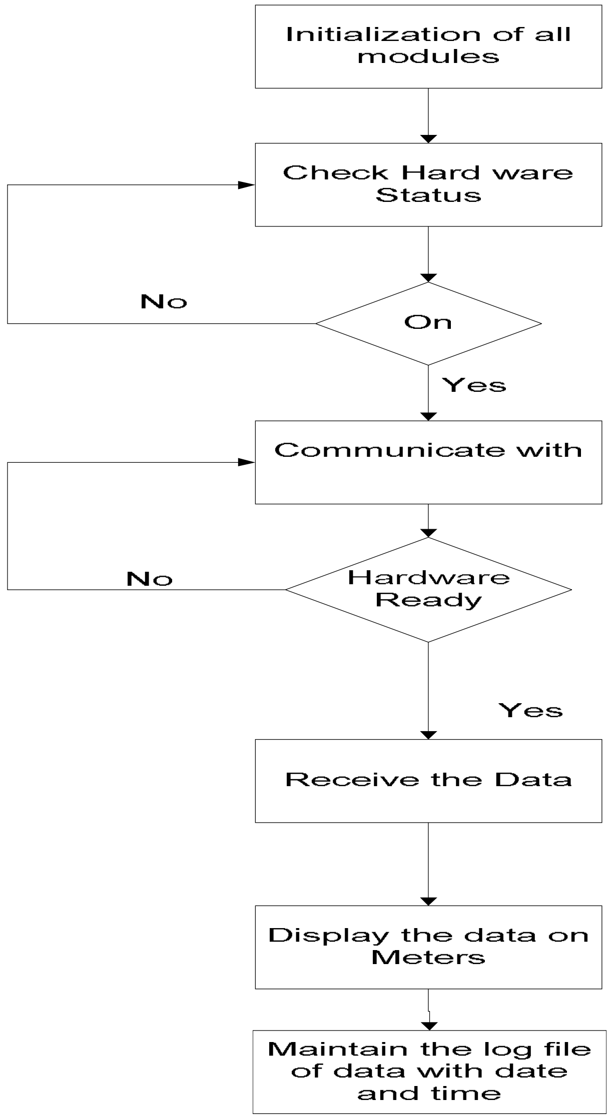

Fig.6.HMI Algorithm

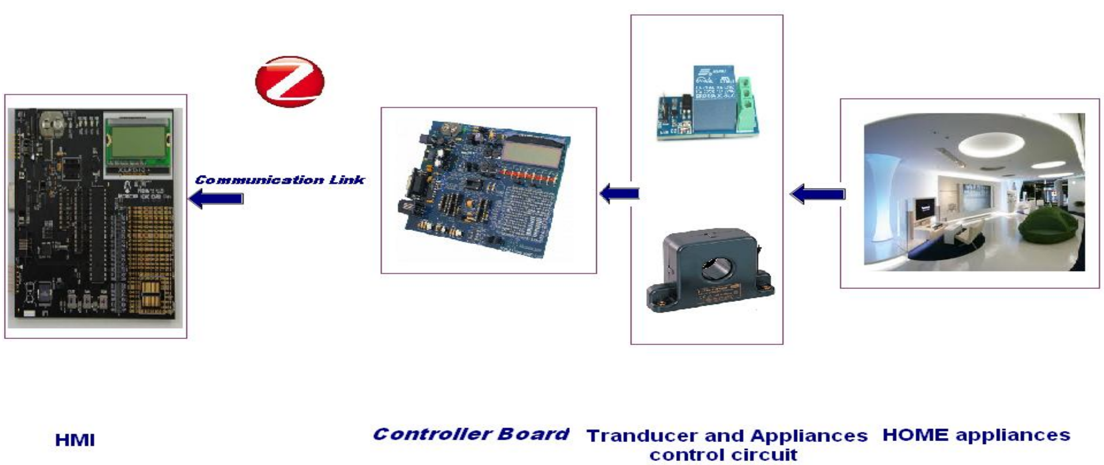

Fig.7. Dataflow from appliances network to HMI

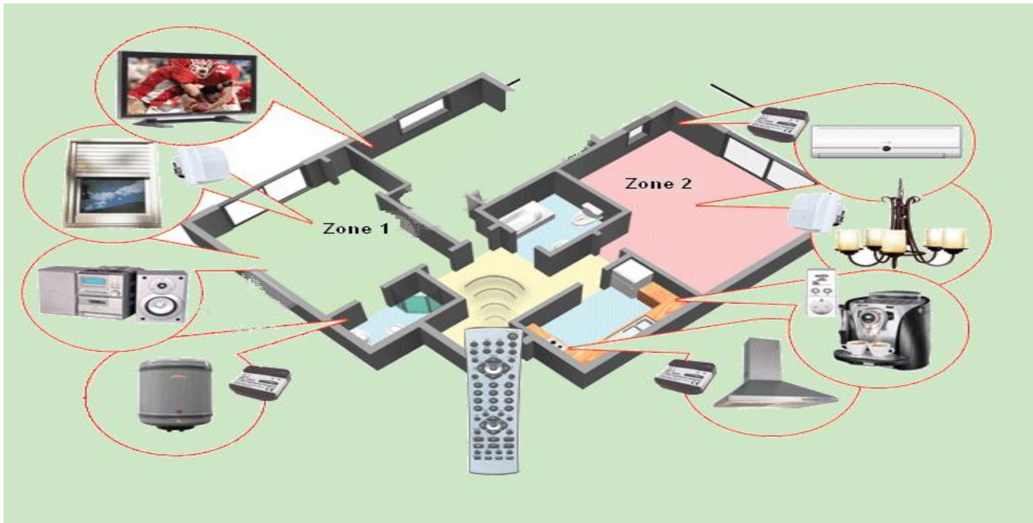

Fig.8. Appliances Network

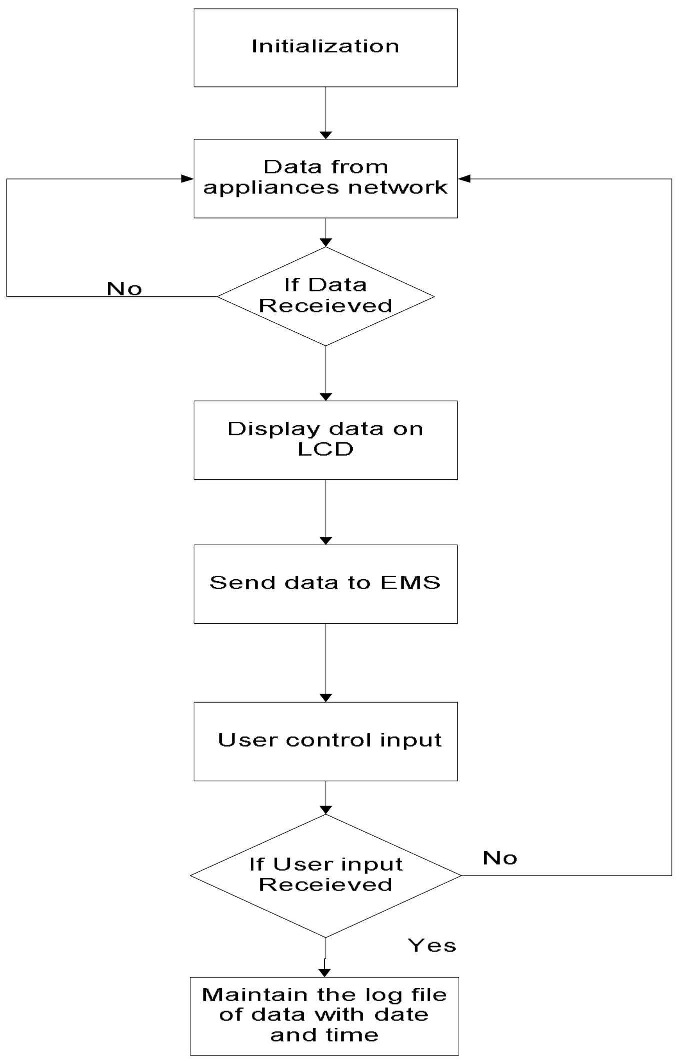

Fig.9. Algorithm for Appliances Network

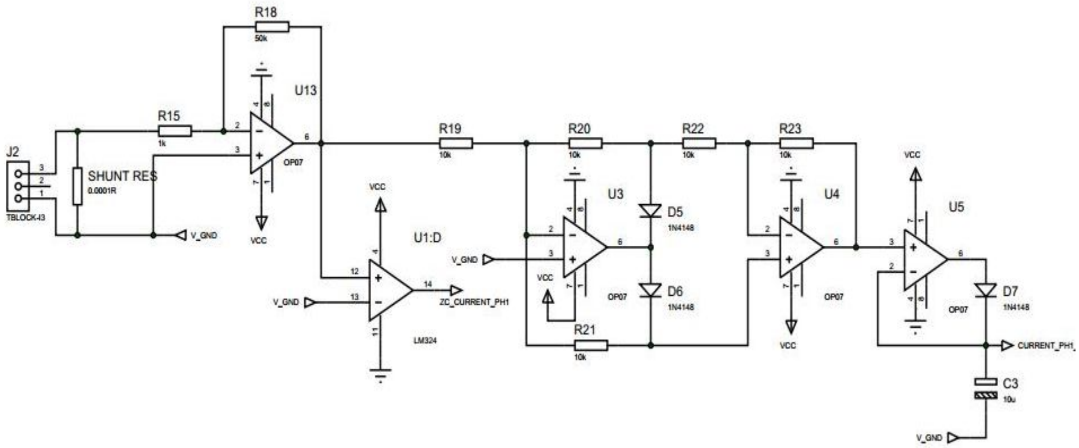

Fig.10. Precision Rectifier

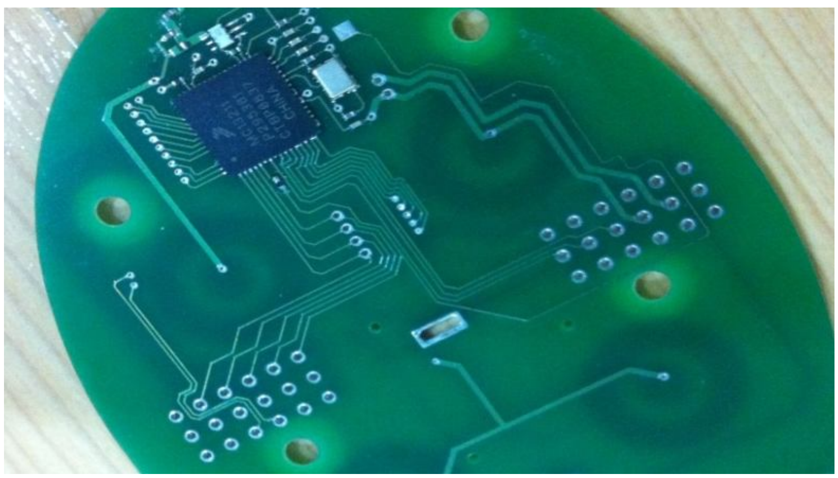

Fig.11. Zigbee Transceiver

TABLE III
Problem

Appliances	Required Time interval (Hrs)	Required Power (W)	Capacity
Ap1	2	200	1000
Ap2	1	200	1000
Ap3	1	400	1000
Ap4	3	300	1000
Ap5	1	1000	1000
Ap6	2	265	1000

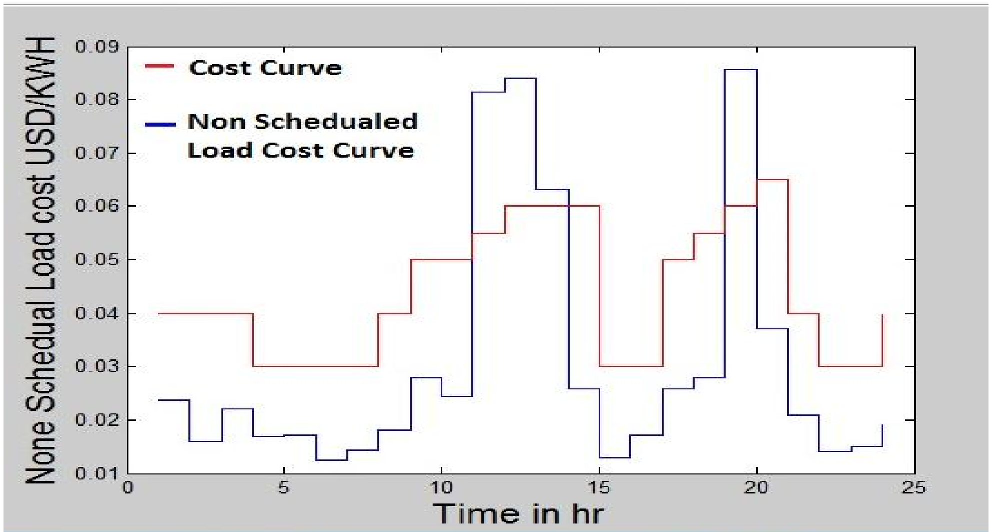

Fig.12. Non Scheduled Load Cost Curve

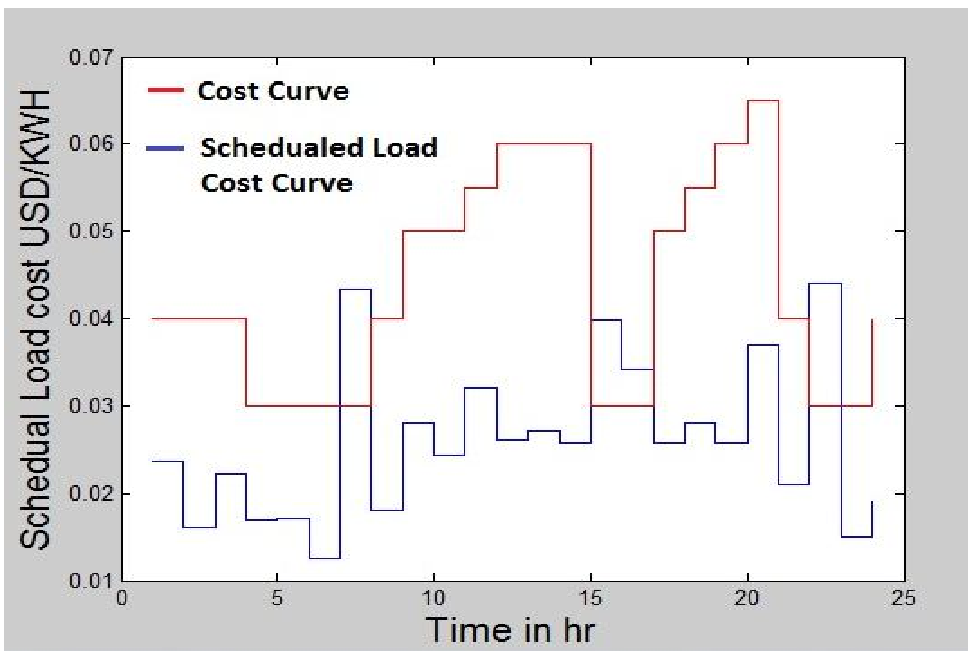

Fig.13. Scheduled Load cost curve

Economic benefit achieved by application of load scheduling is tabulated in Table 4.

TABLE IV
Economic Benefits Achieved

	Load / Day KWH	Cost USD/KWH / Day	Cost PKR/KWH /Day
Schedule	15.80	0.647	63.406
Non Schedule	15.80	0.75	73.5

CONCLUSIONS

Proposed method is encouraging and cost effective. It gives an incentive to consumer. Consumer can easily control its appliances remotely with click of a button. Graphical user interface is provided to the user where data of its consumption is stored in a file. So a user can view its consumption profile on day by day basis and make its on power profile for more reliable and effective. Scheduler tells user about the appliances commitment and its cost during the day time of usage. We can add additional control as the scheduler controls the scheduled appliances apart from user control.

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