Wireless Sensor Network Based Power Management for Intelligent Buildings

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Abstract— **The proposed system aims the implementation of smart monitoring and controlled consumption at residential and commercial buildings. The rise in demand of power is increasing as compared to transmission capacity, due to increase in population growth also fuel and coal prices. The major challenge is to reduce the power consumption by optimizing the operation of several loads without causing any impact in the customer's comfort. Intelligent Power Management system is the combination of smart sensors and actuators. The development and design of an intelligent monitoring and controlling system for home, residential and commercial building appliances in real time system is implemented. The system implements the load prioritization and facilitates the real time monitoring of the connected loads based on the predefined maximum load value. The system also shut down all loads when there is no person available in the vicinity. It monitors electrical parameters like voltage and current and subsequently calculates the power consumption. A Visual Basic application is included in the system which will be controlling all activities of the system in user controlled mode (manual mode) or system controlled mode (intelligent mode). This will improvise the savings of the energy which will provide better efficiency and power management in the buildings.**

Keywords— Load prioritization, overall consumption, maximum demand, optimum cost of consumption, Zigbee, Serial Communication

I. INTRODUCTION

Now days it seems to be important to use wireless mechatronics system that provides service and personal care which will become more ubiquitous at home in future. It will be very useful in assistive healthcare especially for elderly and disable people [1]. Wireless mechatronics system includes various spatially distributed sensors that collects data and has processing capability to monitor the environmental situation. In the Intelligent Building or for various intelligent services, wireless sensor networks (WSNs) have become important because of their ability to monitor and manage their situational information. Hence WSNs has been applied in various fields like military, industries, and healthcare, commercial and residential buildings. There can be many solutions but the financially viable solution to this problem is implementation of Peak load pricing (PLP). The main factor considered for PLP is Maximum Demand which is the instantaneous power consumed over a defined period of time. By implementing this solution, the consumer is billed based on maximum demand so it has gained prime importance in the electricity bill. In majority countries, maximum demand is predetermined by the time slot of 15 minutes or 8-30 minutes, whereas power is calculated by KW demand meter to record highest kW value. The WSNs are mainly being used in the buildings for energy controlling services. Various household appliances which are used regularly are monitored and controlled by WSNs installed in the home [5].

For efficient load management the consumption at each appliance is measured, and then the monthly energy consumption against demand for load is calculated. It is done by considering the rate schedules available in the system for low cost with applicable operational charges. Simultaneously load priority is considered as per customer's requirements and accordingly the off-peak loads curtailment is performed by the system. Monitoring of connected loads is carried out continuously using current and voltage sensors to measure consumed power over a specified period. The loads which are non prioritized are being turned OFF by maintaining the high priority loads kept ON within predetermined demand and time window of 15 minutes slot. In this research, we have designed and implemented a ZigBee based intelligent building energy management and control service. We have used the ZigBee (IEEE 802.154 standard) technology for communication and networking because of its features. It has low-power and low-cost characteristics which enables it to be used widely in home and building environment [10].

Software system enables real time monitoring of the current, voltage and power values with dynamic characteristic display. Switching section of the system prevents the damage due to overload conditions of the devices.

II. RELATED WORK

This section discusses about some of the existing work done in smart building systems, which depend on the wireless communication technology. Initial real time smart monitoring and controlling system for household appliances was proposed maintaining the integrity of the specifications by Nagendra Kumar Suryadevara, Subhash Chandra Mukhopadhyay[1]. This system was based on ZigBee which helps in reducing the standby power. The electrical parameters such as voltage and current are measured by sensors and their output is fed to the ZigBee module. The central hub server provides the real-time information to the users, at the same time allowing them to control and manage the appliances. The system proposed by Yentai Huang,Tian,Wang [2] stipulates the implementation of demand response (DR) for the Home Energy management system (HEMS). This system enables the scheduling and control of electrical appliances as per the user convenience. It also helps in reducing the overall cost of consumption. The implementation of this system tries to overcome the limitations of computational power and low memory size. All the household electrical appliances under consideration are grouped together and controlled by HEMS. The optimization schedule is determined by the DR program, and accordingly the control logic sends the signals to control the interruptible load. The main shortcoming of the system is building mathematical model and the demand response program implementation is only applicable exclusively for resource limited embedded devices like smart meter. Zhou, Wu, Li and Zhang [3] in their proposed system considered real time energy control for heterogeneous system. The system is based on half hour ahead planning through optimization and online strategy to manage with the dynamic changes and fuzzy logic based storage system is implemented.

In the Electrical load management approaches for peak load reduction by Guido Benetti [4] the review of various load management techniques such as demand side management, demand response, Electrical load management is discussed. A systematic literature survey of various technical papers based on peak load management is done and the evaluation states that the most widely used technique is Electrical Load management. Real time energy control suggests the various loads such as HVAC, dryers etc. are controlled with the half hour ahead planning through optimization. The modeling and management scheme for residential consumer's called as prosumers who can procures and consumes the power using the various renewable energy sources like roof top solar generation, micro grids have also been discussed in this paper which will contribute to moderate cost reduction. The new economic model for energy market that keeps into account the storage capacity and selling energy is proposed in this paper. The study also indicates that the tradeoff between the computational complexity and scalability needs to be established to overcome the various structural limitations.

Ilze Laince, Blumberga,Rosa proposed a case study on household energy consumption the appliances were selected for assessing the potential for load shifting[5]. Some percent of load reduction is possible due to washing machine and dish washer load shifting. Appliance load shifting is reasonable way for reducing peak consumption. The main challenge is the user awareness about demand side management. An event driven smart home controller by Alessandro Di Giorgio,Laura Pimipinella [6] is a smart home controller (SHC) that dynamically manages the household loads to provide economic savings and overload management. Load monitoring and control is maintained by a Zigbee connection with smart appliances, smart plugs and smart meters. Loads are classified as plan able, controllable, monitor able loads and detectable loads; the DMS triggers the controller which results in event driven load shifting. K. Costcova,L. Omelina,P.Kycina, P.Jamrich [7] has done a comprehensive study of load management methods, technologies and programs used in various countries. In this study, they have presented an overview of load management techniques that are tested in the real world applications and theoretically proven to work effectively irrespective of the geographical representation. The utility controls the customer appliances based on contract for peak load reduction in case of direct approach, whereas in case of indirect approach the customers are informed by the utility about peak hours when there is a need for load reduction and provide incentives to the customers to participate on load reduction techniques. B.T. Ramkrishna Rao,Anand Daga,Ajay Kumar [8] proposed the 8051 microcontroller based maximum load control system, predefined maximum demand is set first and when the system instantaneous demand crosses over the value then load shedding is initiated by the controller and the loads are automatically being tripped. As the load prioritization is not maintained there are chances of tripping the priority loads. The user control is not provided so the real time monitoring may not be possible in this system. A WSN-based intelligent light control system for indoor environment such as a home for reduced paper was proposed by M. S. Pan et al.[9]. In this paper, wireless sensors are responsible for measuring current illuminations and the lights are controlled by applying the model of user’s actions and profiles.

J. Han et al. [10] discussed Home Energy Management System using ZigBee technology. The system consists of automatic standby power cutoff outlet, a ZigBee hub and a server. Whenever the consumption of power by the device is below a certain threshold, the power outlet along with the ZigBee module cuts off the power from AC mains. The information from the power channels is gathered by the central hub, and these power channels are controlled by ZigBee module. It also sends the present state information to a server so user can monitor or control the present energy usage using the HEMS user inter-face. This may create some difficulties for user. For example, if the users may want low intensity of light, for some situation but the system will cut the power off leading to darkness.

These references mentioned above for home monitoring and controlling systems have some disadvantages such as:
1) Energy consumption control mechanism can be applied to several house-hold appliances that can be controlled but is limited to only certain devices like light illuminations;
2) Controlling the home appliances through network management functions, in practice inhabitant requirements may vary according to their behavior but not with network characteristics.
3) Variable tariff of electricity has not taken into consideration, which is consumed throughout day and night by any of the systems.
Hence, a low-cost, flexible, and real-time smart power management system, which can easily integrate and operate with the intelligent building monitoring system, is presented.

III. PROBLEM STATEMENT AND OBJECTIVE

The demand of power is increasing as compared to transmission capacity, due to increase in population growth also fuel & coal prices. If peak demand exceeds available supply blackout can occur throughout a region. It has been observed that a lot of energy is wasted due to unnecessary use of electrical appliances. Hence, without affecting comfort, there is need to eliminate energy waste; this would reduce the overall energy consumption in buildings. The design and development of an intelligent power management system, monitors and controls electrical appliances for intelligent building in real time system. The purpose is to reduce maximum demand during the peak period of consumption of electricity. Hence, demand response tariffs are applicable here. It also protects the electrical appliances from damages & improves the equipment efficiency.

A. Objective

- To study the demand and supply gap
- To reduce the maximum demand during the peak period of consumption of electricity.
- To provide real time monitoring of the connected loads in order to achieve considerable savings.
- To protect the electrical appliances from any damage and improve the equipment efficiency.
- To sense and control the appliances or devices at the point of wireless sensor network using Zigbee communication module.

IV. SYSTEM DESCRIPTION

The system architecture which is designed and implemented is composed of two subsystems the monitoring and the control subsystems. The monitoring system acquires at predetermined time intervals that measures the energy consumption of the analyzed electrical appliances and some other environmental information for eg. temperature, electrical parameters and presence of persons. The controlling system exploits the data collected by the monitoring system and to control the behavior of each appliance some energy conservation strategy is applied. In the following we will observe the two subsystems in detail:-

A. Monitoring Subsystem:

This system implements a number of electricity and environment sensors to measure the power consumption of every electrical appliance in the commercial and residential buildings. It also monitors parameters such as temperature, current and human presence. Data collected by these three types of sensors are communicated wirelessly to a base station which is located on the same floor and then conveyed to a central server. The communication between base stations and the server occurs wirelessly through ZigBee module. Then the server processes the data and provides user the power consumption of every electrical appliance.

B. Controling Subsystem:

This system manages the behavior and working of every single electrical appliance. According to energy conservation rules which are specified by the user, so as to minimize electricity wastage in the building. It employs current sensor for each appliance which are controlled by the microcontroller. This microcontroller is connected to central server wirelessly through Zigbee technology. Then the server generates switching commands such as “ON” and “OFF” for specific appliance in the building. Commands are then sent by the microcontroller to every sensor.

C. System Block Diagram:

The figure shows the functional block diagram of the system developed. This will monitor all electrical parameters and control appliances depending on its requirements. As the block diagram shows, current sensors are used in the system that measures current and calculates proportional voltage. The sensors output signals are integrated which are connected to XBee module. This module is used as serial communication port for transmitting data wirelessly.

The overall operations of the circuit is controlled with the AVR microcontroller. ACS712 based current sensors are used which are having linear relationship with input

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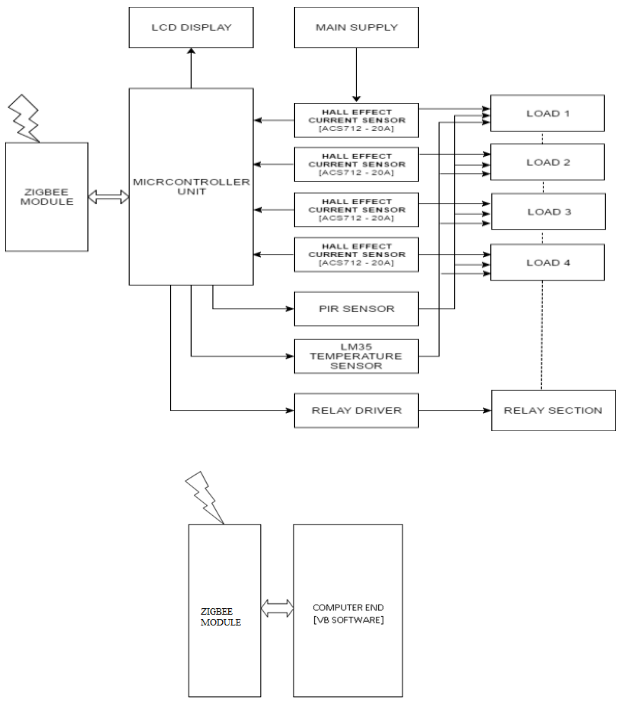


Fig.1. System block diagram of Intelligent power management system

AC/DC current. RMS value of the current is calculated using the controller. All the parameters from each load is combined in one packet frame and combined with network address to be sent by the wireless transmitter. At receiver end wireless receiver, receives the packet and decode it for extraction of the required data for processing at computer end. Depends up on the data received from the sensing node, visual basic software distinguish between power consumption values of each load and assigned them to corresponding fields. Then the server of the system will check for load priorities and maximum demand limit assigned by the user. To explain this, if current demand value decrease of the limit window, then system will turn off the load according to priority to maintain the limit. For performing the task of switching the loads, server will send switching commands to the relay. For time limit or peak time selection control option is included to enable automatic demand control on time basis for auto start functionality. Manual mode is also provided in the software to manually turn OFF & ON remotely.

By analyzing the power from the system, energy consumption can be controlled. In this system we have set an electricity tariff plan to run various appliances at peak and off-peak tariff rates. The appliances are controlled either automatically or manually (local/remotely). The smart power metering circuit is connected to mains 240 V/50 Hz supply.
The system prevents the unwanted wastage of power by two different ways.

1. The electrical appliances get switched off when the human is not detected. The human detection sensor i.e PIR sensor serves this purpose.
2. The electrical appliances gets automated when the sensing values exceeds the preset threshold value.

V. MEASUREMENT OF ELECTRICAL PARAMETERS

To measure the electrical parameters, mathematical analysis is performed. Mathematical analysis of the relay driver circuit and the current sensor has been considered to calculate the voltage and current requirement of the circuitry.

1) Current and voltage calculation through current Sensor:

The ACS712 current sensor is based on the principle of Hall-effect. According to this principle, when a current carrying conductor is placed into a magnetic field, a voltage is generated across its edges perpendicular to the directions of both the current and the magnetic field.
The supply voltage across the analog to digital converter is the same as supply voltage Vcc. (Vcc = 5.0V) The analog output of the ACS712 will be digitized through the ADC chip. When there is zero current through the current sensor, the output voltage is Vcc/2 = 2.5V. If the ADC chip is 10-bit (01023), it will convert the analog output from the ACS712 sensor into digital value of 512 count. If the supply voltage drifts and changes Vice = 4.5V, the new output will be 4.5/2 = 2.25 V, due to the radiometric nature. As the reference voltage is lowered to 4.5V, its output will still be digitized to 512 by the ADC. The sensitivity value will also be lowered by a factor of 4.5/5 = 0.9, this means that if the ACS712-05B is powered with a 4.5V supply, the sensitivity is reduced to 166.5 mV/A, instead of 185mV, A. Hence it concludes that any changes in the reference voltage will not be a source of error in the analog-to-digital conversion of the ACS712 output signals. The linear and proportionate voltage and current is shown in the figure.

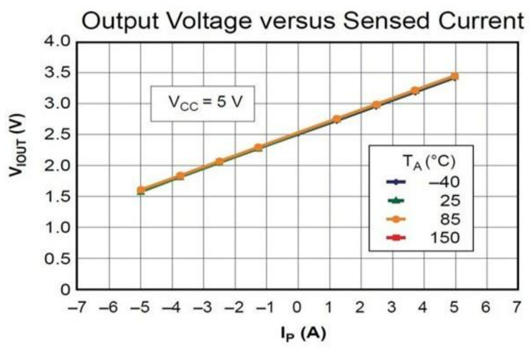


Fig.2. Output Voltage vs. Sensed Current

2) Current and voltage calculation through Relay driver: Relays are devices which allow low power circuits to switch a relatively high Current/Voltage ON/OFF or a relay to operate a suitable pull-in and holding current should be passed through its coil. Relay coils are designed to operate from voltage 5V or 12V. Relay driver circuit function is to supply the necessary current (typically 25 to 70ma) to energize the relay coil.

Consider supplied voltage across the circuit be 'V' and V=5V the input resistance value of 'R.' and R=150W the minimum current required to operate the circuit be 'Imin'.

$$I_{min} = 5/150$$

$$I_{min} = 33\text{ mA}$$

The collector current across the transistor is Ic and it is calculated as follows

$$I_C = I_B * \beta$$

$$I_B = 33/100$$

The input resistance across the transistor be calculated as follows, according to the ohms law

$$V = IR$$

$$R = V/I$$

$$R = 5/3330$$

$$R = 15\text{ kW}$$

It is the maximum resistance that can be operated across the transistor.

VI. HARDWARE DEVELOPMENT

A. Atmega328P microcontroller:

Atmega328P microcontroller is based on Arduino that is single board which consists of an open-source hardware board designed around it. This type of microcontroller requires low power, and its performance is high. Also it is 8 bit microcontroller which is based on the AVR enhanced with RISC architecture. The operating voltage ranges from 1.8V to 5V and it runs up to 20MHz. Arduino comes with simple integrated development environment (IDE) which is applicable on personal computers and allows users to write programs using C and C++.

B. ACS712 current sensor

The Allergo ACS712 current sensor works on the principle of Hall Effect. This means, when a current carrying conductor is placed into a magnetic field, a proportional voltage is generated across sensors edges which are perpendicular to the directions of the current and the magnetic field. This sensor is an accurate sensor to measure AC/DC current ranging from 5A to 20A and it operates at voltage of 5V.

C. Relay Driver Circuit

A Relay driver IC is a switch that will be used when we require low voltage circuit to switch ON or OFF a light bulb, which is connected to 220V mains supply. Important and unique features of relays are high current capacities, capability to stand ESD and drive circuit isolation.
ULN2803 is an IC which requires high voltage, high current, used especially with Microcontrollers where we need to drive high power loads. These loads which this IC can widely use are Lamps, relays, motors etc. It is rated at 50v/500mA.

D. ZigBee

ZigBee Alliance has defined ZigBee which is a low rate wireless network standard and is based on the IEEE 802.15.4.
It aims to be a low-cost, low power solution for systems which consists devices used in houses, factories and offices. It operates at 2.4 GHz frequencies and 868 MHz, 902-928MHz and data rate 250 kbps which are best suited for periodic and also intermediate two way transmission of data between sensors and controllers. It covers the area that ranges within 10-100 meters.

E. Passive Infrared Sensor

Passive Infrared Sensor (PIR) is used to detect motion of a human around its range. It allows to sense motion and finds whether a human has moved in or out of the sensors range. Its features are small, inexpensive, low-power, easy to use and don't wear out.

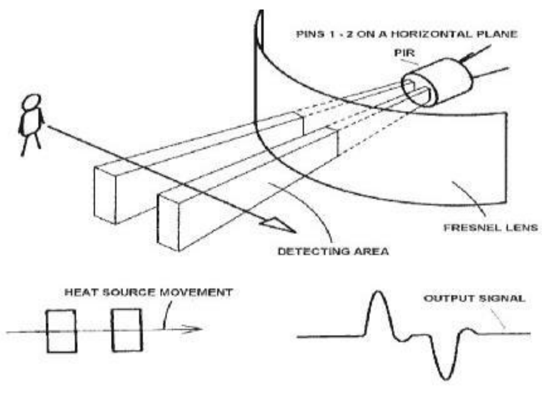


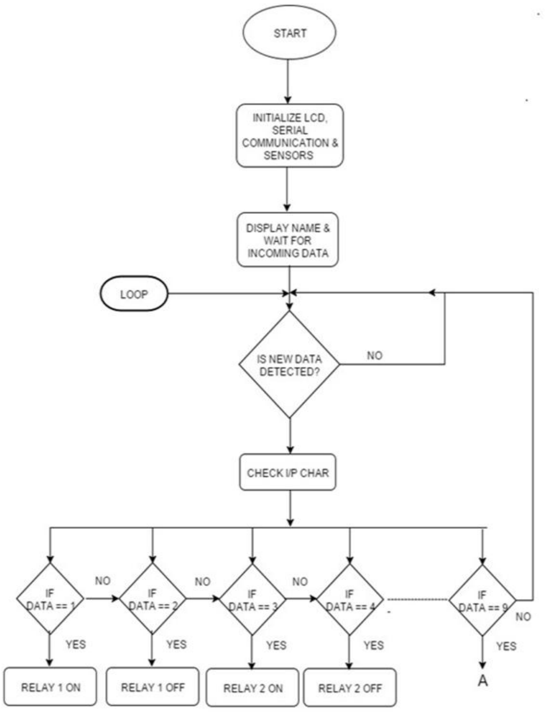
Fig.3. PIR Sensor Working

F. LM35 temperature sensor

It is a precision integrated-circuit centigrade temperature sensor whose output voltage is linearly proportional to the Celsius temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in degree Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. For every change in temperature by degree Celsius, the sensor output changes by10mV. The sensor can measure temperature in the range of 0 to 100°C, i.e., the output of the sensor varies from 0 to 1000 mV.

VII. METHODOLOGY AND IMPLEMENTATION

A. Proposed system flowchart



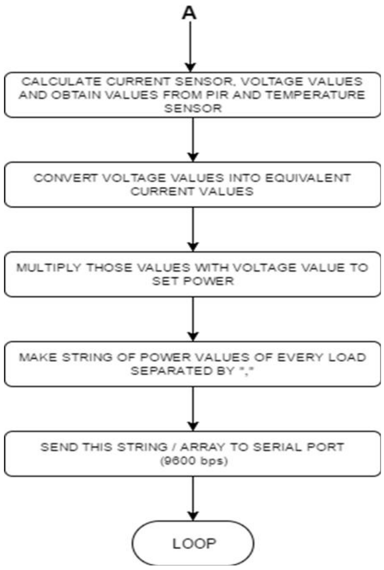
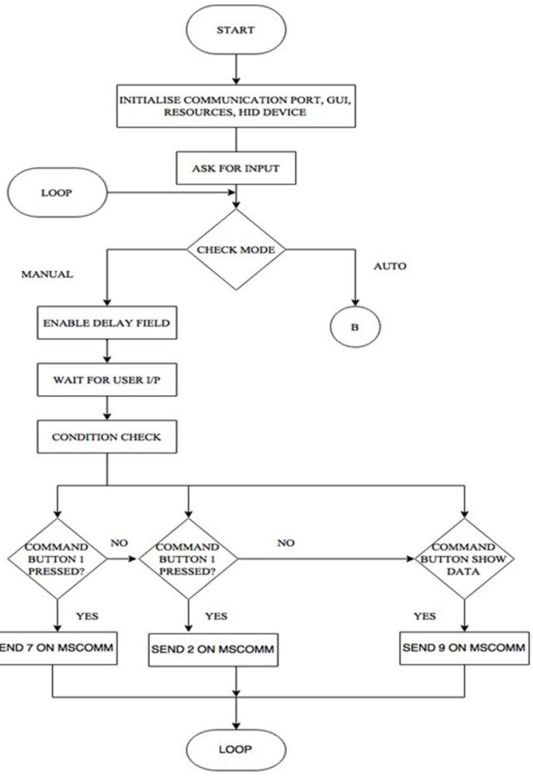
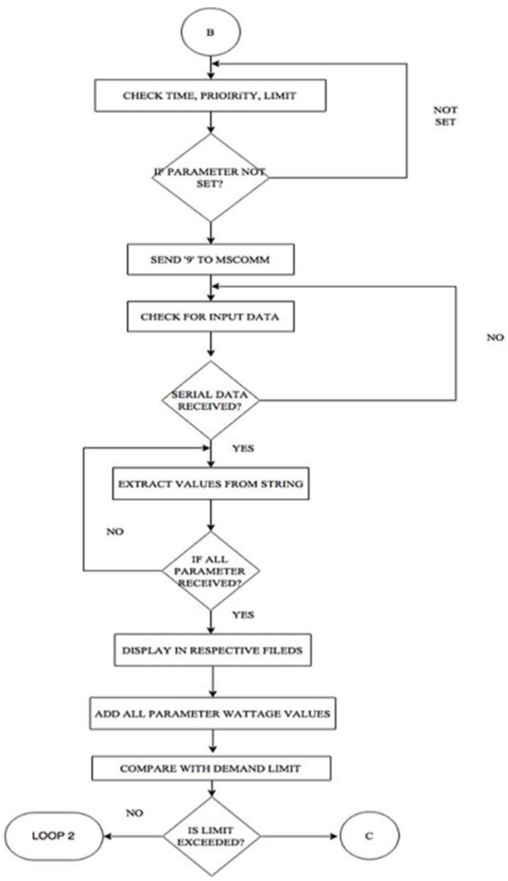


Fig.4. Proposed Hardware Flowchart





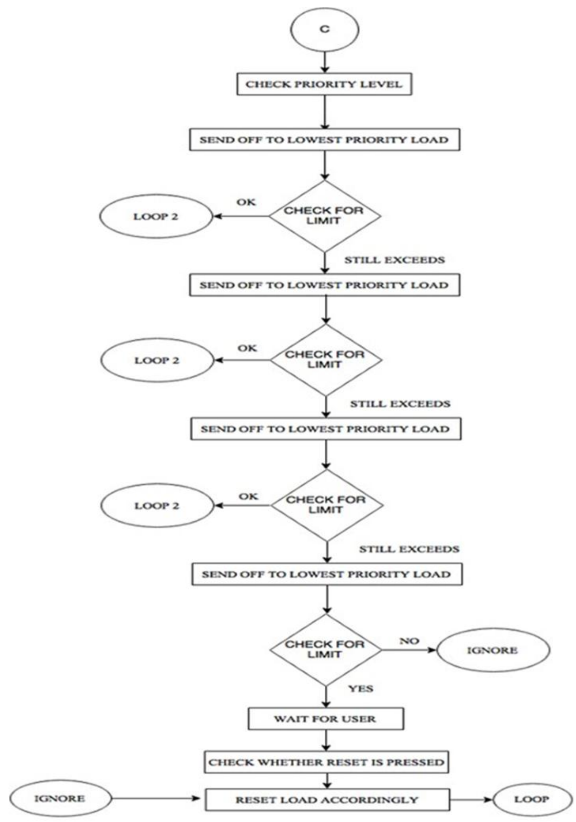


Fig.5. Proposed Software Flowchart

B. Prototype Implementation

The system has been designed for measurement of electrical parameters of household appliances in buildings. The prototype of the building energy management system is shown below which is considered for demonstration and result analysis. The maximum demand is already predefined for a time window set by the user which is generally 15 minutes time slot. According to real time pricing, the consumers are billed on the basis of this maximum demand by the utilities.

Fig.6. System Prototype Hardware

Working:

The loads are equally distributed and interconnected. The power supply of 230V is supplied to the system and all four loads are switched ON. This will operate the system as well as sensor modules. Meanwhile we are using Visual Basic software to control the systems operations. On the server side this software is programmed to be operated in automatic as well manual mode.

As the power supply is provided the LCD, Serial communication i.e ZigBee module, current sensors, PIR sensor and temperature sensor are initialized and the current sensors will continuously monitor the connected load. This will provide the data of how much current each load requires and simultaneously the proportionate voltages across the load. This data is displayed on the LCD screen and accordingly transmits data to the server wirelessly through XBee module.

Fig.7. Parameters status Display

On the server side by collecting the current and voltage data corresponding values of the power for individual loads are calculated and the string of power values is sent to the serial port.

When the PIR sensors are initialized they sense the presence of human in the vicinity and accordingly send data to the serial port. Similarly temperature sensor will continuously monitor the temperature of the system and send their data.

This system is based on priority scheduling; hence we need to set priority for each load on the server side. When the system will start, it will monitor the power consumed by each load and compare it with the maximum demand limit which is provided by the user.

In the first iteration if the total power exceeds maximum demand, the system will switch OFF the lowest priority load; whereas rest of the loads are still ON. This process will continue till time interval is complete. During this operation, if PIR sensor is active then it will sense the motion in the vicinity and will send 0 or 100 command to the system. If it is 0 means there is no motion and the system will switch OFF all 4 loads. If command is 100 system will continue its operation.

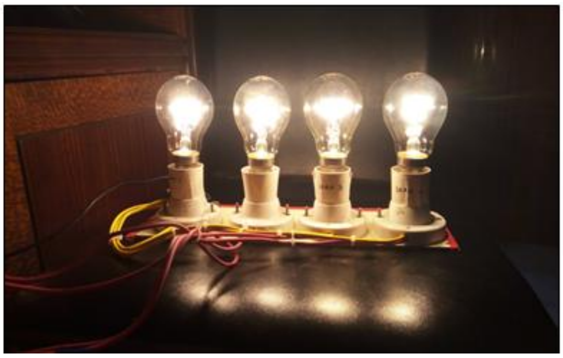


Fig.8. Loads connected to the system model

VIII. DISCUSSION OF RESULTS

The developed system has been tested for every energy management criteria and their results are presented in this section. The prototype is operated with various electrical appliances which are regularly used by inhabitants. Here we can compare results on the basis of switching time and maximum allowed load in peak time.

The collected and processed voltage, current and power values are displayed on the programmed Visual Basic software on a computer on server side. By monitoring the power consumption of each load, data is collected as shown in the table below.

TABLE 1

Observation Table for automatic mode of operation when PIR is inactive

Sr. No.	Loads				PIR	Temperature
	100 W	100 W	100 W	100 W		
1	139	159	119	114	NA	37.93
2	0.00	157	117	116	NA	37.92
3	0.00	0.00	133	118	NA	38.88
4	234	159	127	114	NA	37.92

TABLE II

Observation table for automatic mode of operation when PIR is active

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Sr. No.	Loads				PIR	Temperature
	100 W	100 W	100 W	100 W		
1	131.5	158	123.65	113	0	33.12
2	0.00	157	123.17	119	100	36.92
3	0.00	0.00	127	116.5	0	35.05
4	0.00	0.00	0.00	0.00	0	33.60

Where PIR sensor is not active, hence it shows NA value in TABLE I and it is active in TABLE II. Maximum demand limit is set to 200W and time interval of 15 min. On the server side, Visual Basic software that allows Graphic User Interface (GUI) applications is used. With help of this, the users have the options of switching loads ON/OFF in two different ways:

A. Manual Mode:-

The user can switch ON or OFF the loads without setting the maximum demand limit. This feature of developed software enables the user to have more flexibility by having manual control on the device usage. Fig below shows manual mode of operation when all the loads are in ON state as the system starts.

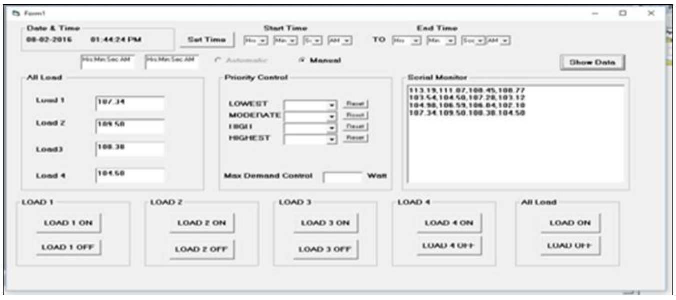

Fig.9. Manual Mode of Operation

B. AutomaticMode:-

In this mode load priority is set by the user according to their necessities and maximum demand limit is specified. Once the time window is preset the system will enter into automatic mode. This helps the user to have more cost savings by auto switch off the appliances during electricity peak hours.

If the connected loads exceed the threshold limit then the low and moderate priority loads will be switched off, whereas highest priority load is ON.

But incase if there is no human detection in the surrounding then PIR sensor sends 0 commands to the system and remaining loads also gets switched OFF. The loads are reset once the time window has elapsed. The fig below shows the system in automatic mode of operation during peak period.

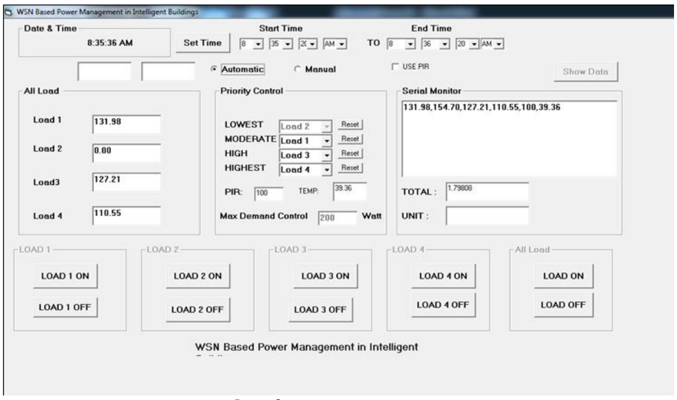

Fig.10. Automatic mode of Operation

C. Simulations:-

Figure shows the simulation result in manual mode of operation. The system is principally functioned without maximum demand controller in this case. The various power values within the preferred time span are plotted and the total power consumption for that particular period. The results verified that the system when operated in the manual mode without maximum demand controller shows the large variation in the consumption. This demonstrates that there is a demand supply gap when the system is implemented without maximum demand controller.

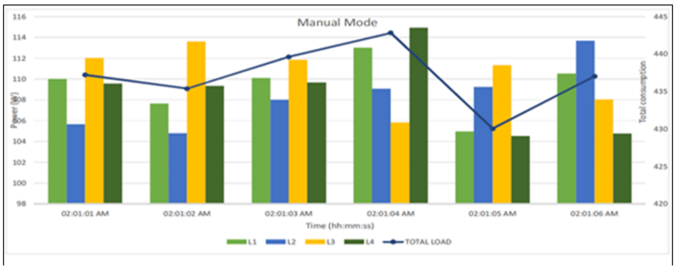

Fig.11. Result of Manual mode operation

Figure shows the simulation result in automatic mode of operation. The predefined demand limit is 250 W and all the connected loads are set in the desired priority the various power values within the desired time span are plotted and the total power consumption for a particular period. The simulation in automatic mode for a peak period time span indicates that the load curve is flat signifying that the consumption is within the demand limit. As the demand and supply gap is being met the considerable saving can be achieved which will in turn reduce the cost of consumption.

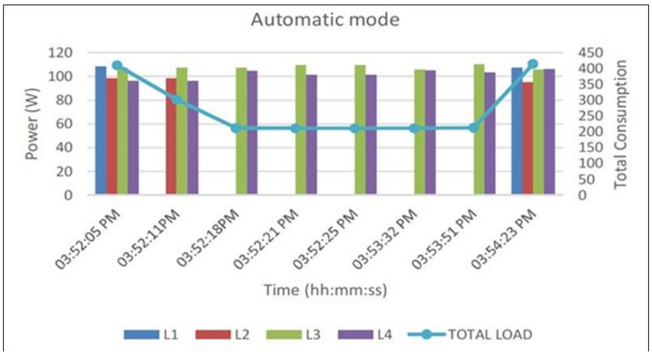

Fig.12. Result of Automatic mode of operation

IX. CONCLUSION AND FUTURE SCOPE

A. Conclusion

The results which were obtained from simulations performed shows that the maximum demand controller contributes to optimization of the cost of operation of the electric appliances. This system maintains a constant demand value always below the predefined maximum demand value for the peak period of consumption. The system demonstration provides the ease of measurement and eliminates any human errors. This system also benefits the user in reducing the energy consumption of households is constrained, if the factors such as characteristics of the user, dynamics, demand and supply gap or balance influence the use and effectiveness. Another key factor is the design of the system, techniques used and the applicability of the system.

Using the technique of localized switching it is possible to turn off lighting in specific areas, while still operating it in other areas where it is required. The data obtained from the microcontroller is used for the design and development of intelligent buildings, which can also be used for developing Smart grid. The detail contained in regulations can be quite comprehensive and designed to require architects, designers and constructors to adopt good energy efficiency practices and thus reduce energy consumed in the built environment. This will cause reductions in customer energy bills. Opportunities may exist to take advantage of special tariff rates by changing load profiles.

B. Future Scope

- The system when integrated with other co-systems like smart home inhabitant behavior recognitions systems to determine the wellness of the inhabitant in terms of energy consumption.
- Demand side management in its different forms is important for enabling a more efficient utilization of the energy resources available to a country. For example, DSM applied to electricity systems can remove electrical system emergencies, minimize blackouts and increase system reliability, reduce energy prices, provide relief to the power grid and generation plants.
- Also many other intelligent tools such as fuzzy logic, PSO, GA can be implemented for power management and ultimately energy conservation.

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