Volume 2, Issue 7, July 2017 ISSN (online): 2456-0006

International Journal of Science Technology Management and Research

Available online at: www.ijstmr.com

WSN Based Power Management for Intelligent Building

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Abstract*: The proposed system aims the implementation of smart monitoring and controlled consumption at residential and commercial buildings. This in turn will support capacity building and will reduce the overall cost of consumption. The system will manage the demand supply gap arising out of increase in population growth and rise in fuel cost and coal prices. Load prioritization and real time monitoring at individual appliances will render the system design cost effective. The predefined loads are prioritized based on the requirements and the microcontroller based system monitors electrical parameters such as voltage and current and subsequently calculates the power consumption during peak period and maintains it below the predefined maximum load value. Implementation in automatic as well as manual mode using visual basic (VB.) based software makes the system user friendly, flexible in operation and delivers the real time load monitoring.*

***Keywords:* - Load prioritization; overall consumption; maximum demand; optimum cost of consumption; Zigbee; visual basic (VB.)**

I. INTRODUCTION

Currently the major drawback in the power industry is demand supply gap arising out of rising cost and limited available resources, focusing upon the various ways to control the consumed units during peak consumption periods. Peak load pricing (PLP) implementation serves to be the financially viable solution to this problem. Maximum Demand is the instantaneous power consumed over a specific period of time. The consumer is billed by the supplier based on maximum demand so it has gained prime importance in the electricity bill. Maximum Demand in majority countries is predetermined time slot of 15 minutes or 8-30 minutes, wherein power is calculated by KW demand meter to record highest kW value. For effective load management the consumption at each appliance is measured, and then the monthly energy consumption vs. demand for load is calculated by considering the rate schedules available in the system for lowest cost with applicable operational charges. At the same time load priority is considered as per user requirements and accordingly the off-peak loads curtailment is performed by the system. Continuous monitoring of connected loads (priority or non priority) is done using current and voltage sensors to measure consumed power over a specific period. The non priority loads are being turned OFF maintaining the high priority loads kept ON within predetermined demand and time window of 15 minutes slot. 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. For communication and data transfer Zigbee is implemented among the sensor nodes so that V.B. application can query particular node for current energy consumption.

II. RELATED WORK

In this section, we discuss the existing works about smart building system that depends on the wireless communication technology. Nagendra Kumar Suryadevara,Subhash Chandra Mukhopadhyay[1] proposed the real time smart monitoring and controlling system for household appliances. The system is based on Zigbee that reduces the standby power. Sensors used monitor the electrical parameters like voltage and current whose output is sent to the Zigbee module. The real time information is provided to the user by means of the central hub server and they can monitor and control the appliances. J. Han *et al*. [10] discussed Home Energy Management System using Zigbee technology. It consists of an automatic standby power cutoff outlet, a ZigBee hub and a server. When the energy consumption of the device connected to the power outlet is below a fixed value the power outlet with a ZigBee module cuts off the ac power. The central hub gathers information from the power channels and the ZigBee module controls these power channels. 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.

Yentai Huang,Tian,Wang [2] the proposed system stipulates the implementation of demand response (DR) for the Home Energy management system (HEMS). The system will enable scheduling and control of the electrical appliances as per user convenience and aims to reduce the cost of consumption. It is suitable for embedded system application like smart meter. The system implementation aims to overcome limitation of low memory size and computational power. Household electrical appliances under consideration are networked together and controlled by HEMS. The DR program determines the optimization schedule and the control logic accordingly sends the

signals to directly control the interruptible loads. The key limitations of the system are complexity in building mathematical model and the demand response program implementation is only applicable exclusively for resource limited embedded devices like smart meter. M. S. Pan *et al*.[9] recommended a WSN-based intelligent light control system for indoor environments, such as a home for a reduction in energy consumption. 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.
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. Overview of load management techniques tested in real world application & theoretically proven to work efficiently irrespective of the geographical location has been stipulated. In case of direct approach utility controls the customer appliances based on contract for peak load reduction and in case of indirect approach utility informs the customers about peak time when the load reduction is needed and customers in turn are incentivized to participate in load reduction. 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. 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. 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.

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. SYSTEM DESCRIPTION

Monitoring and controlling of the electrical appliances used in buildings is the main goal for designing this system. In this system we measure the electrical parameters of appliances. This system is very cost efficient, ease of modeling, setup and use. Considering the consumer point of view, electrical power consumption of various devices with supply voltage and current are the important factors. The consumer can switch off the electrical appliances whenever necessary either automatically or manually.

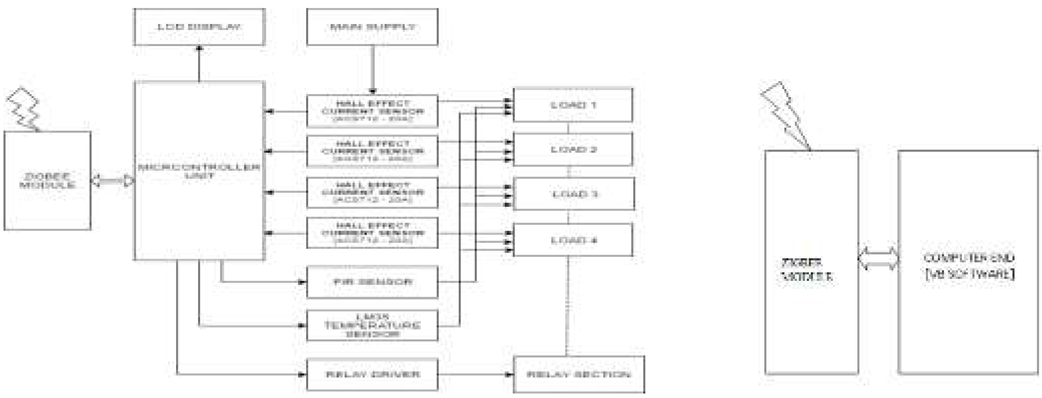

Fig.1. System block diagram of intelligent power management system

The above fig.1 shows the functional block diagram of the developed system which will monitor electrical parameters and control appliances on basis of requirements. As the system block shows, current sensors i.e. it measures current and propportional voltage are used. The measurement is done by interfacing appliances with fabricated sensing modules.The output signals from the sensors are integrated and connected to XBee module i.e. used as serial communication port for transmitting data wirelessly. They are interfaced with various sensing devices and interconnected in the form of mesh topology so that it will have reliable data reception at a centralized ZigBee coordinator. The adjacent ZigBee nodes covers maximum distance of 10m and through hopping technique of mesh topology, reliable sensor fusion data is performed. The ZigBee coordinator is connected to the host computer through USB cable, which stores the data into a database of computer system.
Whole operation of the circuit is controlled with the AVR microcontroller. ACS712 based current sensors are used which are having linear relationship with input 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 system will check for the user assigned load priorities and maximum demand limit, if current demand value fall of the limit window then system will turn off the load according to priority to maintain the limit. For switching of the loads computer software will send relay switching commands on reverse channel to the sensor node. 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. An electricity tariff plan has been set up 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.

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.

B. Mathematical Analysis

Mathematical analysis of the Relay driver circuit and the current sensor has been considered to calculate the voltage and current requirement of the circuitry. The current sensor IC 712 is expected to provide the linear output.

1) 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'.

$$Imin = 5/150$$
$$Imin = 33 \text{ mA}$$

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.

2) 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)

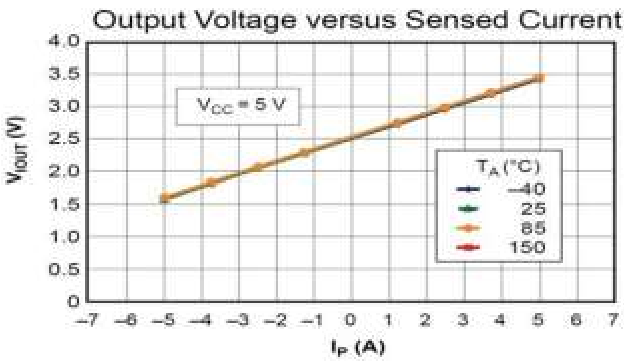

Fig.2. Output Voltage vs. Sensed Current

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 (0-1023), 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. Similarly, the sensitivity value will also be lowered by a factor of 4.5/5 = 0.9, which means 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.

IV. HARDWARE DEVELOPMENT

High-tension (HT) consumers have to pay a maximum demand charge in addition to the usual charge for the number of units consumed. This charge is usually based on the highest amount of power used during some period (say 30 minutes) during the metering month. The maximum demand charge often represents a large proportion of the total bill and may be based on only one isolated 30 minute episode of high power use. Considerable savings can be realized by monitoring power use and turning off or reducing non-essential loads during such periods of high power use. Maximum Demand Controller is a device designed to meet the need of industries conscious of the value of load management. Alarm is sounded when demand approaches a preset value. If corrective action is not taken, the controller switches off non-essential loads in a logical sequence. This sequence is predetermined by the user and is programmed jointly by the user and the supplier of the device. The equipment's selected for the load management are stopped and restarted as per the desired load profile Maximum Demand is the power consumed over a predetermined period of time, which is usually between 8 — 30 minutes. This power is calculated and billed by a kW demand meter, which records the highest kW value in one 15 minute period, over a month's time.

A. List of Components

- Atmega328P microcontroller
- ACS712 current sensor IC
- Relay driver circuit ULN2803
- ZigBee
- Passive Infrared Sensor
- LM35 Temperature Sensor

B. Atmega328P microcontroller:

It is a low power; high performance 8 bit microcontroller based on the AVR enhanced RISC architecture. The Atmega328P has 32kB of flash memory for storing code; it also has 2kB of SRAM and 1kB of EEPROM. It has 23 I/O lines, 6 of which are channels for the 10-bit ADC. This microcontroller runs up to 20MHz with external crystal. Its operating voltage ranges from 1.8V to 5V.
Arduino is a single board microcontroller which consists of an open-source hardware board designed around an 8-bit Atmel AVR microcontroller. It comes with a simple integrated development environment (IDE) that runs on regular personal computers and allows users to write programs for Arduino using C or C++. An Arduino's microcontroller is also pre-programmed with a boot loader that simplifies uploading of programs to the on chip flash memory, compared with other devices that typically need an external programmer. This makes using an Arduino more straightforward by allowing the use of an ordinary computer as the programmer.

C. ACS712 current sensor IC

ACS712 current sensor is an accurate sensor to measure AC/DC current up to 20A. It can even measure high AC mains current and is still isolated from the measuring part due to integrated hall sensor. Its operating voltage is 5V. The Allergo 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. It is a device that eliminates the risk of damaging the current monitoring circuit due to the high voltage on the conduction side. The electrical isolation between the conduction current and the sensor circuit also minimizes the safety concerns while dealing with high voltage systems.

D. Relay Driver Circuit

A Relay driver IC is an electro-magnetic switch that will be used whenever we want to use a low voltage circuit to switch a light bulb ON and OFF which is connected to 220V mains supply. The required current to run the relay coil is more than can be supplied by various integrated circuits like Op-Amp, etc. Relays have unique properties and are replaced with solid state switches that are strong than solid-state devices. High current capacities, capability to stand ESD and drive circuit isolation are the unique properties of Relays.
ULN2803 is a High voltage, high current Transistor Array IC used especially with Microcontrollers where we need to drive high power loads. This IC consists of a eight NPN Darlington connected transistors with common Clamp diodes for switching the loads connected to the output. This IC is widely used to drive high loads such Lamps, relays, motors etc. It is usually rated at 50v/500mA.

E. ZigBee

ZigBee is a low rate wireless network standard defined by the ZigBee Alliance and based on the IEEE 802.15.4. The standard is aiming to be a low-cost, low power solution for systems consisting of unsupervised groups of devices in houses, factories and offices. Expected applications for the ZigBee are building automation, security systems, remote control, remote meter reading and computer peripherals. The IEEE defines only the Physical (PHY) and Medium Access Control (MAC) layers in its standards. For ZigBee alliances of companies worked to develop specifications covering the network/link, security and application profile layers so that the commercial potential of the standards could be realized. It operates at 868 MHz, 902-928MHz and 2.4 GHz frequencies and data rate 250 kbps is best

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suited for periodic as well as intermediate two way transmission of data between sensors and controllers. ZigBee covers the range within 10-100 meters.

F. Passive Infrared Sensor

PIR(Passive Infrared Sensor) allows to sense motion, almost always used to detect whether a human has moved in or out of the sensors range. They are small, inexpensive, low-power, easy to use and don't wear out. For that reason they are commonly found in appliances and gadgets used in homes or businesses. They are often referred to as PIR, "Passive Infrared", "Pyroelectric", or "IR motion" sensor.

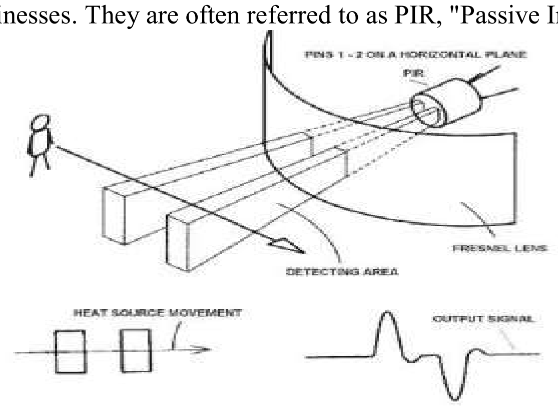


Fig.3. PIR Sensor Working

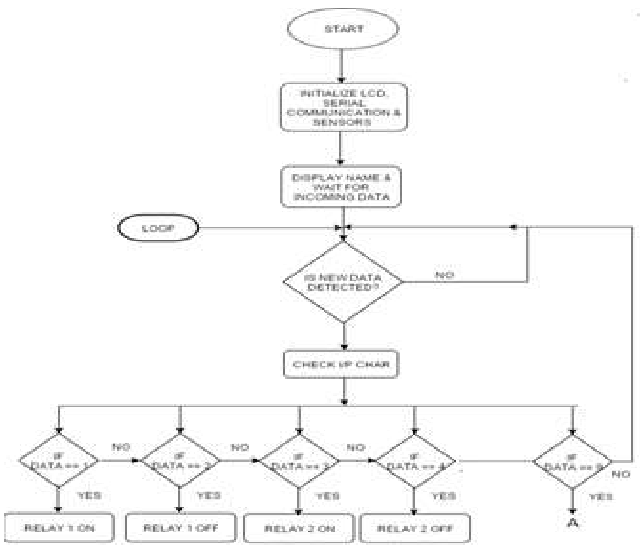
To explain how basic PIR sensor work we will refer the above diagram. It itself has two slots each slot is made of a special material that is sensitive to IR. The lens used here is not really doing much and so we see that the two slots can 'see' out past some distance (basically the sensitivity of the sensor). When the sensor is idle, both slots detect the same amount of IR, the ambient amount radiated from the room or walls or outdoors. When a warm body like a human or animal passes by, it first intercepts one half of the PIR sensor which causes a positive differential change between the two halves. When the warm body leaves the sensing area, the reverse happens, whereby the sensor generates a negative differential change. These change pulses are what is detected.

G. LM35 temperature sensor

It is a precision integrated-circuit centigrade temperature sensor whose output voltage is linearly proportional to the Celsius (Centigrade) 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 each degree Celsius change in temperature, the sensor output changesby10mV.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. The LM35 operates over the temperature range of -55° to +150°C, while the LM35C is rated for a -40°C to +110°C range (-10°C with improved accuracy). It has an output voltage that is proportional to the Celsius temperature. The scale factor is .01V/°C. The LM35 does not require any external calibration or trimming and maintains an accuracy of +/-0.4°C at room temperature and +/- 0.8°C over a range of 0°C to +100°C. Another important characteristic of the LM35DZ is that it draws only 60 micro amps from its supply and possesses a low self-heating capability. The sensor self-heating causes less than 0.1°C temperature rise in still air.

V. METHODOLOGY AND IMPLEMENTATION

A. Proposed system flowchart



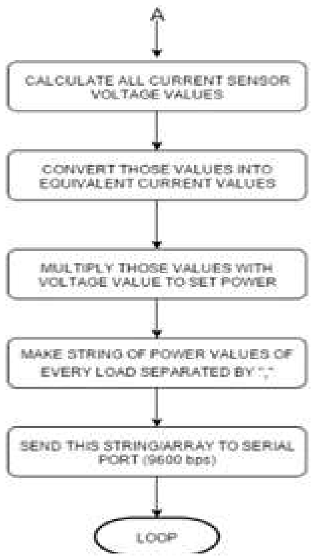


Fig.4. Hardware Flowchart

B. Prototype Implementation

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

Fig.5. System Prototype Hardware

Working:

The loads are interconnected and equally distributed. The power supply of 230V is given to the system and all four loads are switched ON. This will initialize 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.6. 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.

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Fig.7. Loads connected to the system model

VI. DISCUSSION OF RESULTS

The system has been tested for every energy management criteria and the results are presented in this section. 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 running on a computer. By monitoring the power consumption of each load, data is collected as shown in the table below.

TABLE I

Observation Table for automatic mode of operation when PIR is not active

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 III

Observation table for automatic mode of operation when PIR is active

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.

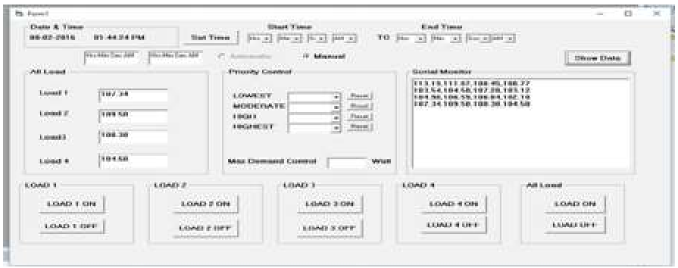

Fig.8. Manual Mode of Operation

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B. AutomaticMode:-

In this mode load priority is set by the user according to their requirements 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.9. Automatic mode of Operation

C. Simulations:-

Figure 10 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.

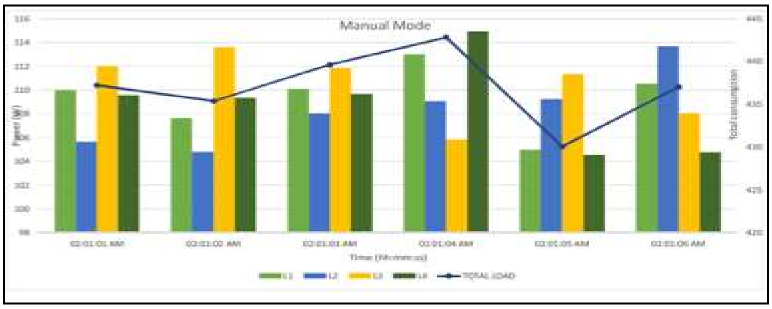

Fig.10. Result of Manual mode operation

Figure 11 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.

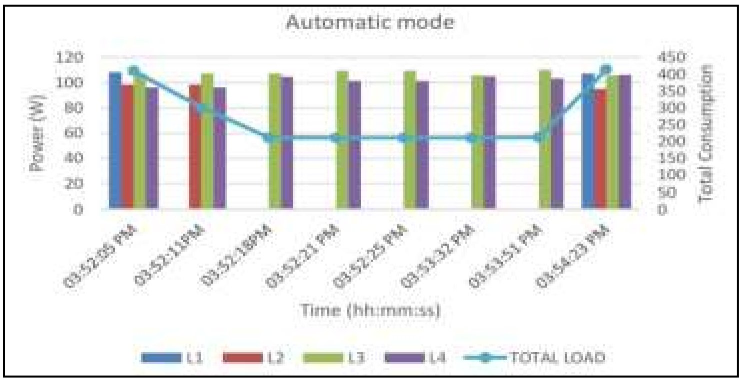

Fig.11. Result of Automatic mode of operation

CONCLUSION AND FUTURE SCOPE

A. Conclusion

The simulation result discovered that the maximum demand controller contributes to optimization of the cost of operation of the electric appliances. System maintains a constant demand value always lesser than the predefined maximum demand value for the peak period of consumption. The system demonstration provides the ease of measurement and eliminates any human errors. The role of energy management system 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 important factor is the design of the system, techniques used and the applicability of the system. By using localized switching it is possible to turn off artificial lighting in specific areas, while still operating it in other areas where it is required, a situation which is impossible if the lighting for an entire space is controlled from a single switch. The data obtained from the controller may be used for the design and development of 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 will be integrated with co-systems like smart home inhabitant behavior recognitions systems to determine the wellness of the inhabitant in terms of energy consumption.
- DSM in its various forms is an important tool for enabling a more efficient use of the energy resources available to a country. For example, DSM applied to electricity systems can mitigate electrical system emergencies, minimize blackouts and increase system reliability, reduce dependency on expensive imports in some countries, reduce energy prices, provide relief to the power grid and generation plants defer investments in generation, transmission and distribution networks and contribute to lower environmental emissions.
- Many other intelligent tools such as fuzzy logic, PSO, GA can be implemented for power management.

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