DEVELOPMENT OF MICROCONTROLLER-BASED ENERGY MANAGEMENT SYSTEMS FOR MEDICAL FACILITY

Ugwu Kenneth Ukachukwu [1], Damian Obioma Dike [2], Lazarus Okechukwu Uzoechi [3], and Nkwachukwu Chukwuchekwa [4].

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING, FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI, NIGERIA.

E-mail addresses: [1] kenugwu48@gmail.com, [2] damian.dike@futo.edu.ng, [3]lazarus.uzoechi@futo.edu.ng, [4] nkwachukwu.chukwuchekwa@futo.edu.org

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ABSTRACT

To conserve energy and to prevent frequent power outages due to overload or partial loss of supply on medical facilities that require uninterrupted power, a microcontroller – based medical facility energy management system is developed. Smart energy management system (EMS) basically monitors and controls loads and energy supplies to connected facilities. In medical facilities, there are critical loads and non – critical loads depending on functionalities required. Critical loads should never be turned off or loose supply while non – critical loads may be turned on or off depending on the power consumption and supply pattern. In practice, various combinations of load management and conservation measures are targeted at energy efficiency such as power factor corrections, rescheduling and combination of energy storage mechanisms. The functionalities implemented for electrical load management in this work are load prioritization, load scheduling, load add, and load shed. In addition, an algorithm for the determination of system loading condition such as normal load, under load and overload as well as automated load adding, and load scheduling schemes based on the operating conditions and customer's priority are developed. A C++ program is developed to achieve this algorithm. Furthermore, this thesis explores the potential cost savings associated with integrating an Arduino, a current sensor, and an Automatic Transfer System (ATS) into energy management, as seen in Figure 3.3. This is one of the most reliable and economical ways to improve the reliability and quality of the power supply. The University of Nigeria Teaching Hospital, Enugu was used as a case study. The result of this practical experiment shows that this scheme can improve distributional load management by reducing power change over time, loss of lives and great saving in cost of operation.

Keywords: Automatic Transfer System (ATS), Energy Conservation, Energy Management Systems (EMS), Load Prioritization and Microcontroller

1.1 INTRODUCTION

Many critical shutdowns occur in power networks across a wide range of industries. The health-care sector is no different. However, the health effects of power disruptions are not well recognized. Greater awareness is required to prevent and/or reduce negative health effects. Numerous nations throughout the universe are recently experiencing a severe energy crisis characterized by load shedding of natural gas and electricity. This not only interferes with people's daily life but also seriously hinders the social and economic development of nations. This is in addition to a lack of institutional and political support for harnessing the vast renewable energy resources that are already available.[9]

According to a 2009 study, households in the United States can save up to 48 percent on an annual basis in the best-case scenario, emphasizing the need to decrease costs and improve technology once more.[69]. Practically, in every example studied, the energy peaks are lowered by 42 percent to 49 percent. As a result, energy conservation leads to financial savings. In China, questionnaires were used to test the reliability and validity of the results on January 1, 2018. Individual actions on energy consumption and conservation are influenced by external factors such as energy conservation legislation, other people's behaviour, and the provision of knowledge regarding energy practices, according to the findings. In the literature, the usage of a battery energy storage system (BESS) in conjunction with renewable energy systems, known as hybrid systems, has been investigated and developed. A case study employing lithium-ion batteries and photovoltaic modules is carried out. For one of the situations considered, the outcome is only profitable in the long run. As a result, battery costs and battery ageing, as well as the constraint of charging and discharging cycles, which is an essential issue in practice, are found to be significant elements that must be overcome in order for such projects to be profitable.[33]

In 2010, another ground-breaking study was conducted, combining the concept of Behind the Meter Energy Storage (BMES) with a battery energy storage system and on-site PV power. Demand charges are decreased by designing consistently valid algorithms for both small scale and big scale values of independent system peaks. This system is critical because it compensates for losses caused by PV system energy losses or fluctuations. If interconnected at a critical load panel, the energy storage system is technically capable of providing emergency backup power during a utility outage. [75]

As a result, a microcontroller-based medical facility energy management is built to handle this problem, which is the major purpose of this work, to conserve and prevent power failures due to overload or extra-load on the system during peak time. This entails employing an automated transfer system (ATS) to monitor and control energy flow activities such as lighting, heating, ventilation, and air conditioning, as well as electrical appliances, and/or defining time schedules for their operation.

2.1 LITERATURE REVIEW

To maintain competition, the quality/cost ratio of the items given to the customers must continue to improve. This necessitates, among other things, a tight control of production costs. A closer look at how these costs are incurred reveals that taking benefit of utility incentives and favourable pricing to encourage consumers to use energy in such a way and at such times as to allow the utility to manage load patterns and achieve significant cost savings without sacrificing efficiency can be fruitful.[24]

In recent years, as the earth's resources have depleted quicker, various countries throughout the world have worked to find ways to save energy and limit the impact of carbon on the environment to avoid resource waste and seek a sustainable livelihood to extend the earth's resources. Energy monitoring has become an important undertaking for maximizing energy efficiency by taking cognizance of energy efficiency in the current trend of saving energy and reducing carbon emissions. Energy management and monitoring is a game-changing overall energy-saving solution. Previously, the most logical first step in implementing the concept of peak shaving would have been to encourage consumers to change their habits regarding electrical energy demand, or to go one step further, to use automatic load scheduling to optimize consumption; this application is also known as Demand Response (DR). It is regarded as a crucial tool in energy management since it allows utility companies to meet the electricity needs of additional customers with little or no increase in power generation.[25]. There are various research in this sector, such as [54], that address the load shifting issue by modelling a discrete time open-loop control system with the present state of charge of the storage as the beginning condition. When compared to the traditional case, in which the load starts when the consumer demands it, the calculated savings in this study are larger than 19 percent. The algorithm for stochastic energy consumption scheduling is created. The goal of microgrid control is to achieve a real-time balance between power generation and consumption. Variations in local weather settings may cause a big increase or decrease in renewable power generation when renewable energy sources are added to a microgrid. Microgrid stability may be jeopardized by the unpredictability of renewable energy output. To improve system stability, one idea is to integrate stochastic modelling and optimization techniques into microgrid control [47]. The utility companies' time-varying pricing are used as inputs to this algorithm. The simulation results suggest that this methodology can achieve significant operational/economic benefits for the customer [70]. It is observed that the system leads to considerable savings in consumers' invoices and encourages the significant deployment of smart meters. By performing short-time predictions, the burden of the algorithm is reduced.

3. MATERIALS AND METHODS

The research involved both software and hardware for developing microcontroller-based energy management systems in medical facilities. Software tools used included Arduino IDE, Proteus, and C++ programming language. The hardware comprised components like the Arduino Microcontroller (ATmega 328p), current sensor (ACS 712), Arduino Nano, ADC Converter, LCD display, signal diode, voltage sensor, energy meter, relay drive module, transformerless voltage converter, PIR sensor, LDR, diodes, resistors, voltage regulators, capacitors, lamps, SMPS, and a laptop.

3.1: Determination of Energy Sources and Capacities through Surveys

To determine energy sources and capacities, interviews with the chief engineer and laboratory technologist were conducted, supplemented by a walk-through energy audit. The audit revealed that UNTH is powered by a 750MVA transformer, six 500kVA sublets, and various generators (500KVA, 100KVA, 1000KVA, and 700KVA). Specifically, a 500KVA transformer and generator feed critical units like the Cardio Thoracic Centre, Theatre, X-Ray/Radiology Units, Cardiac Catheterization Lab, and Main Laboratory. Essential energy services include lighting, ventilation, communication, water pumping, and medical equipment, classified

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as unmanageable loads due to their necessity. Manageable loads like air conditioners and refrigerators can be paused. Experts from various departments provided detailed energy usage data, summarized in Tables 3, 3.1, 3.2, 3.3, and 3.4.

3.2 System block diagram

In this phase, an actual prototype is designed based on the information gathered from quick design. It is a small working model of the required system.

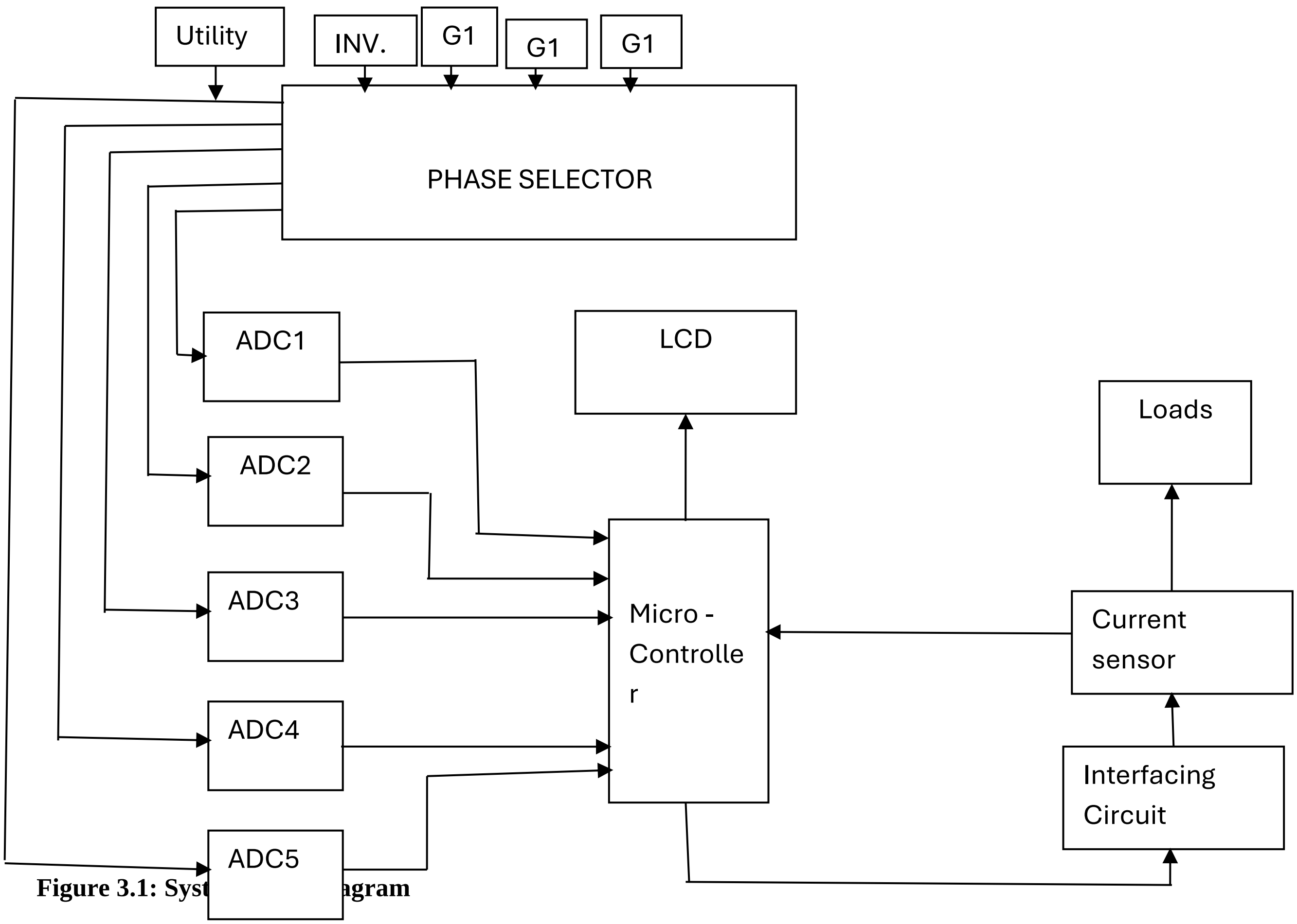

Figure 3.1: Syst agram

Figure 3.1 shows the block diagram of the Energy Management System and how each load connects to the Microcontroller. The entire system is powered by the AC main which could be the generator, the inverter, or the national grid. A rectifier circuit converts the AC to DC since the circuit needs only 5V. The DC output is also fed into other sensing unit connected to the system. The System is powered by an Arduino Switched Mode Powered Supply (SMPS). Arduino input or output pins get initialized and the loads connected at the Controller terminals are now ready for operation. Each load has a current sensor which calculates the amount of current drawn by each load in comparisons with the threshold value. If the current a load draws are higher than the threshold value, the controller automatically disengages the relay supplying power to that load. The UPS minimizes the down time and hold the current for some seconds before switching takes place. After 10 seconds, it checks again to ascertain the present current of the load, if another load relates to lower current capacity, it switches on the relay, connecting the load to the mains.

The passive infrared (PIR) monitors the motion around its vicinity and automatically switches on the inside light or fan when the motion of the enclosure is disturbed and switches off whenever there is no disturbance. Then the light intensity sensor takes care of the outside lights, by switching on and off during the night and day respectively. All these features are coordinated to achieve a better EMS in any hospital.

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3.2.1 System Circuit Diagram

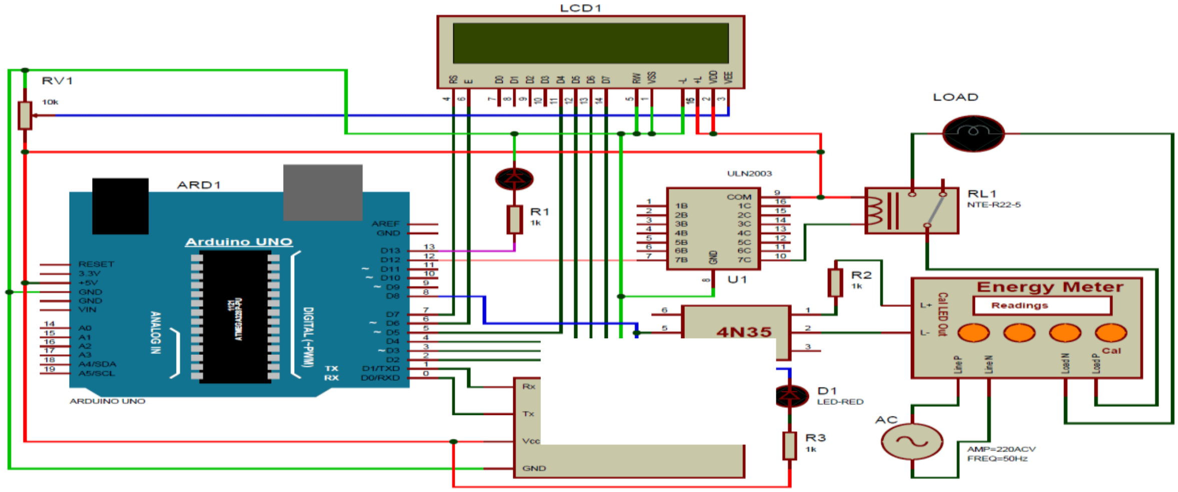

Figure 3.2: System Circuit Diagram

Figure 3.2 shows the the circuit diagram of the system where Arduino UNO has been interfaced with ACS712 current sensor, Autointensity unit and Liquid Crystal Display. It checks for the current of the connnected load and cuts off any load that draws more Current higher than the system rating. The Arduino UNO is a microcontroller board based on the AT mega 328. It supports the microcontroller simply by linking it to the computer with a USB cable or power it with an AC – to – DC adapter or battery to get started. It supplies different sensors through a 5V and a ground pin. The analogue pin of the Arduino is connected to different sensors to allow monitoring and control the appliance.

The 4N35 is a general purpose optocoupler which consists of LED and NPN phototransistors. It breaks the links between signal source and signal receiver to stop electrical interference. Pin 1 and 2 are connected to the energy meter. When the power comes into the circuit it emits infrared rays. To protect the energy meter from damage, usually a resistor (about 1K) is connected to pin 1. Hence the energy meter can be powered on when receiving signals. This can be done to control the loads connected to the phototransistors. Even when the loads short circuit occurs thus realizing good electrical isolation.

P4 of Arduino is connected via a resistor to the GND of the Arduino. This prevents any leakage in the 4N35 output transistor from pulling the Arduino input pin up. This Arduino calculates, measures, and collects the relative measurements and sets the state of the devices, sends them to our system that identifies and processes data. If these devises consume too much, the Arduino will automatically react and cut off region or underload or overload.

3.2.2 ACS712 Current Sensor Working and Applications

ACS 712 Current Sensor provides accurate measurement of AC/DC current. Different devices need a different amount of current based on their functional requirements. Some devices are so sensitive that they get damaged when a high amount of current is delivered to them. So, to save such a situation and monitor the amount of current required or being used in an application, measurement of current is necessary. This is where the Current Sensor comes into play. One such sensor is the ACS712 Current Sensor. Figure 3.3 elaborates more on the internal circuitry of ACS 712 current sensing unit.

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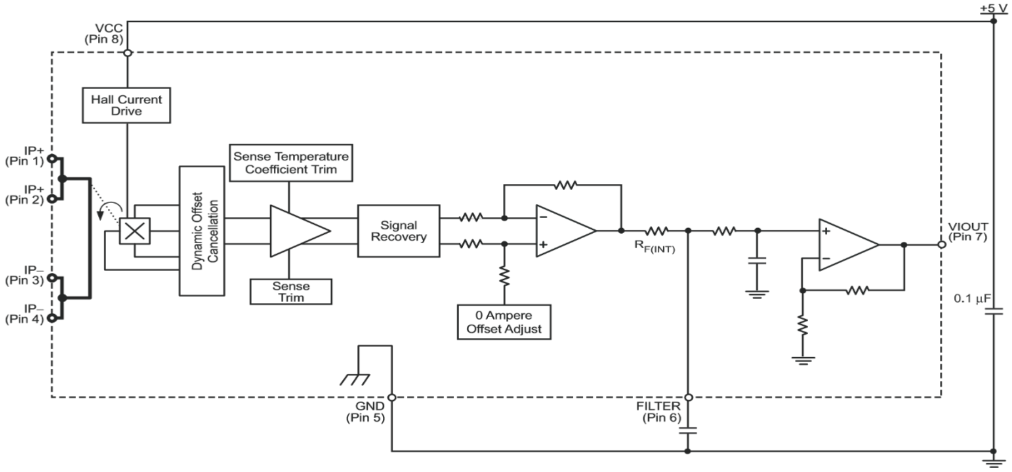

Figure 3.3: Circuit diagram of Current sensor module

3.3 System flow chat

In this stage, a simple design of the system is created. It gives a brief idea of the system to the user. The quick design helps in developing the prototype.

The following is the simplified system algorithm of the entire system:

i. the system first turns on.

ii. the system initializes the input/output pins of the Arduino controller.

iii. the system scans for available load connected to the controller ports.

iv. now ready to respond to the current sensing from each of the loads.

v. responds to the loads according to the current drawn by each load.

vi. turns on the gadgets under control.

vii. toggles the state of the load if current exceeds the setpoint of current sensing unit.

The flowchart of the proposed Microcontroller-based Energy Management System in Medical Facility was designed from the algorithm as shown in Figure 3.4.

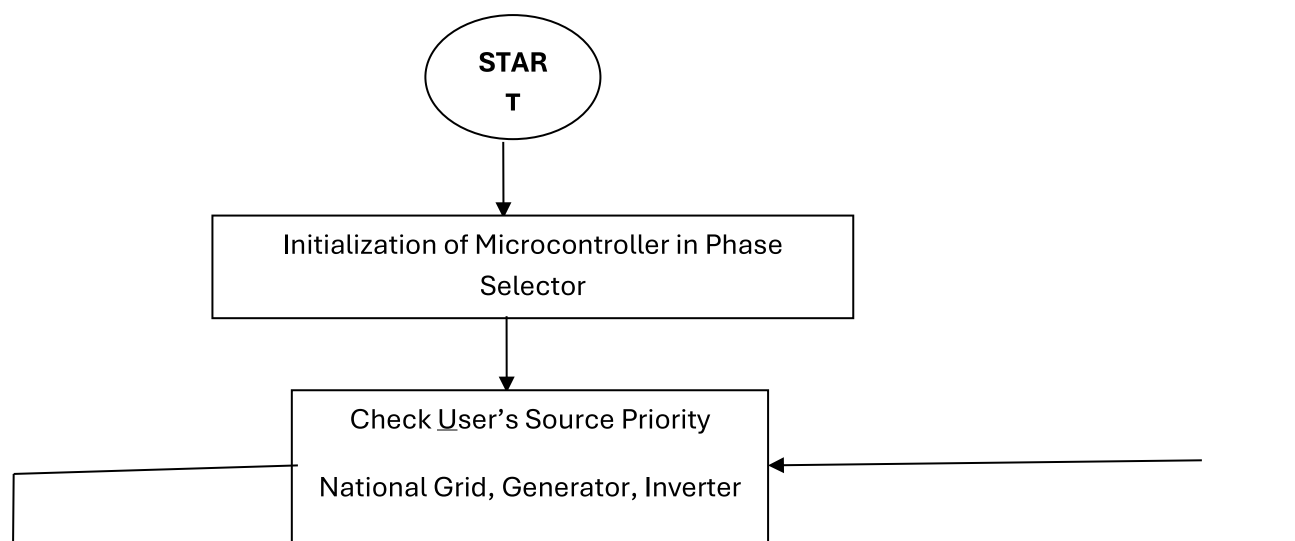

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Figure 3.4: The System Flowchart

The system consists of the following power sources which include the public power utility (EEDC), the generators and the PV system. Based on the proposed algorithm of the user's source priority according to the program commands in the microcontroller, the power from the public utility comes first in preference to the generators and the PV system in as much as the input power is within the required power range. Anything outside this voltage range(120V-240V), the system will automatically switch to the generator (G1, G2, G3) in that order. It is expected that the generators to be used are electronic chocked generator which can automatically switch ON/OFF. The PV system was designed to operate at night only if there's no power from the public power utility. As shown in the flowchart below, the system also monitors the input voltage (V_i) and the current demanded (I_d). If the $Vi\ and\ Id$ are Ok it will switch on the load but if they are not ok, let it switch to the next available power source. At the same time there must be uninterrupted power supply (UPS) to hold on the power up to 10 sec for the switching to take place.

3.3.1 Power Supply Design

This unit is responsible for power supply to the entire system. Figure 3.5 shows the block diagram of transformer-less power supply of 5V on Proteus Software. The values of the components used are 1N4007 Bridge Rectifier diode, 470$\boldsymbol{u}$F/25V Filtering capacitor, Zener diode IN4733A and connectors.

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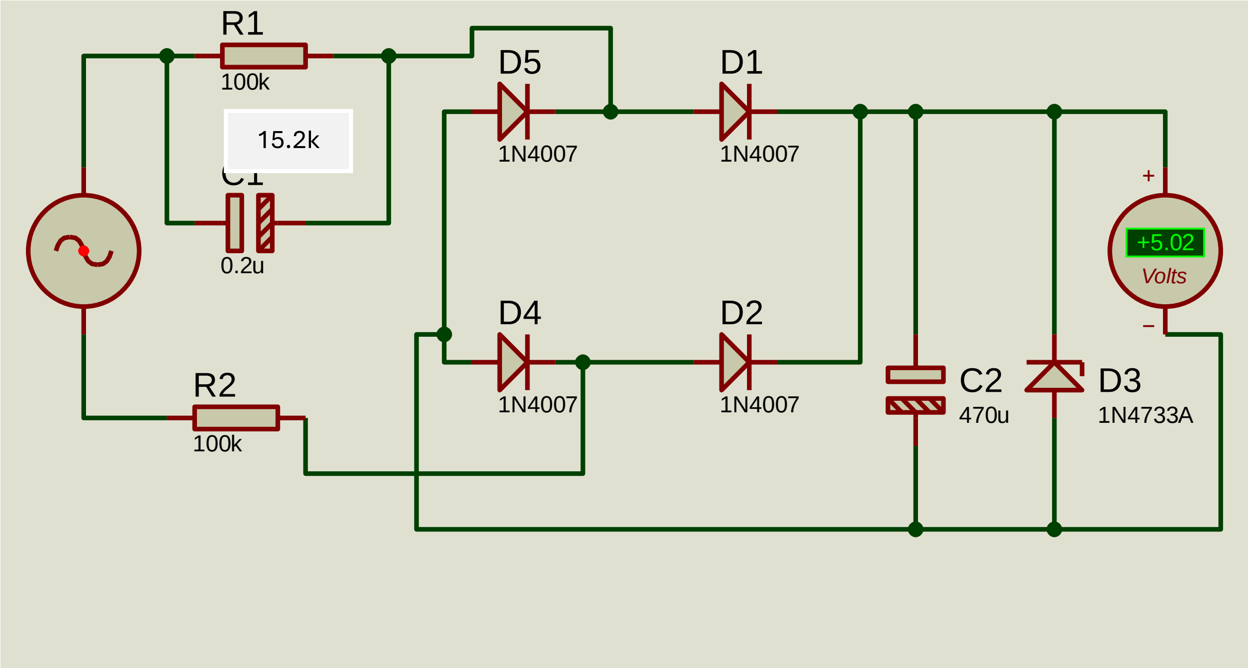

Figure 3.5: Power System Circuit Diagram

The following are the Power Supply component specifications.

i. Input AC voltage =220V

ii. Rectifier Diode DC Current Capacity=2A

iii. Filtering Capacitor voltage=470µF/25V

iv. Output DC voltage of Rectifier=5V

v. Output DC voltage of Rectifier=12V (for the Relay interface circuit)

Resistance (R_1); Capacitance C_1 can be calculated thus:

$$R_1 = \frac{V_{r.m.s} - V_o}{I} \qquad (1)$$

Where:

R_1 is the bleeder resistor which discharges a capacitor when the power is removed

$V_{r.m.s}$ = root mean square voltage (input voltage)

I = input current

Hence R_1 *and* C_1 of Figure 3.2 are calculated thus:

$$R_1 = \frac{220\sqrt{2} - 7}{20mA},$$

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$= \frac{311-7}{0.02}$; hence $R_1 = 15.2\text{k}\Omega$

$$C = \frac{1}{2\pi f X_c} \quad (2)$$

$$= \frac{1}{2 \times 3.142 \times 50 \times 15200};$$

$$c = 0.2uf$$

$$\text{Hence, } \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \quad (3)$$

$$R = \frac{R_1 R_2}{R_1 + R_2}$$

$$R = \frac{100 \times 15.2}{100 + 15.2} \quad ; R = 13.2\ k\Omega$$

3.3.2 Arduino UNO Microcontroller

Arduino Uno is a microcontroller board based on 8-bit ATmega328P microcontroller. Along with ATmega328P, it consists other components such as crystal oscillator, serial communication, voltage regulator, etc. to support the microcontroller. Arduino Uno has 14 digital input/output pins (out of which 6 can be used as PWM outputs), 6 analog input pins, a USB connection, a Power barrel jack, an ICSP header and a reset button.

For the Arduino environment, the following steps were deployed.

(a.) Connecting Arduino on the Breadboard

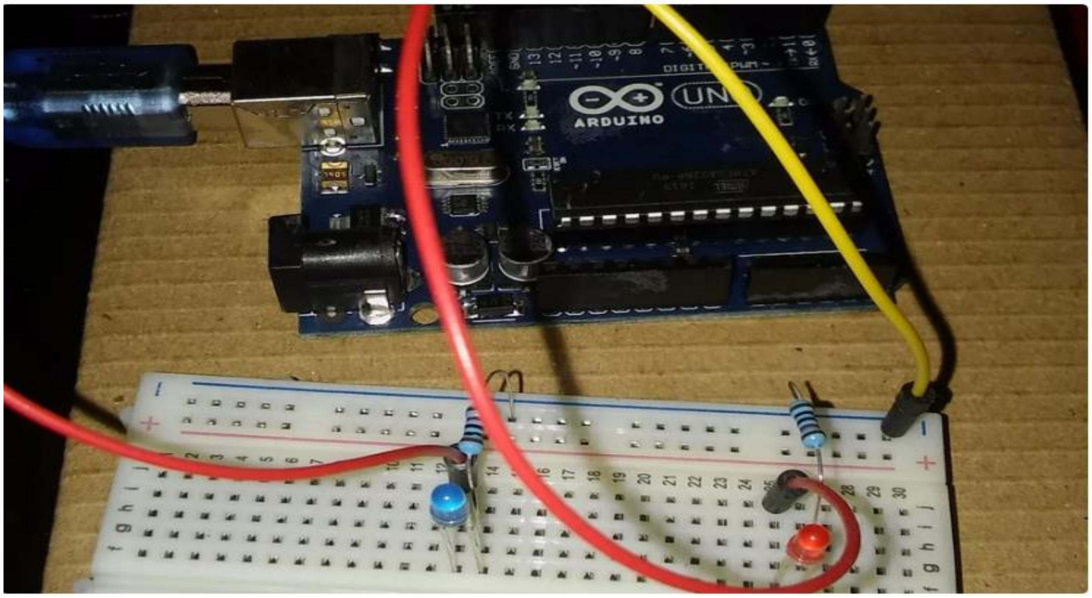

Plate I: Arduino on the Breadboard

Components Required: The components required for this project are listed below and all the parts were purchased at the local hardware store or on eBay. They are: Atmega328IC, 16Mhz Crystal, 22pf capacitor, L7805 voltage regulator, 10uf capacitor, LED, Breadboard, connecting wire, 6V or 9V or 12V power supply, Soldering Iron.

(b.) Atmega 328

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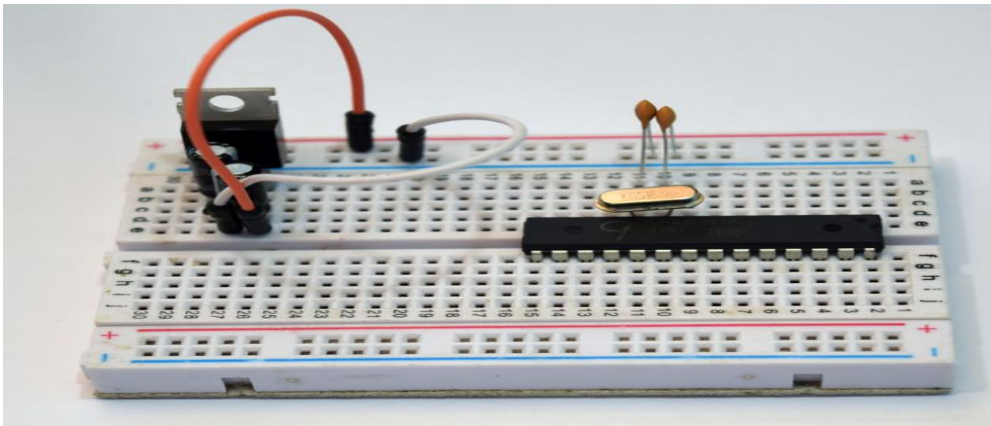

Plate II: Atmega328 on the Breadboard

The Arduino is based on the Atmega328IC and it is the brain of the circuit. All the processing is done by the IC. The Atmega328 has to have an Arduino boot loader flashed on to it to program it using Arduino IDE.

(c.) The voltage regulator

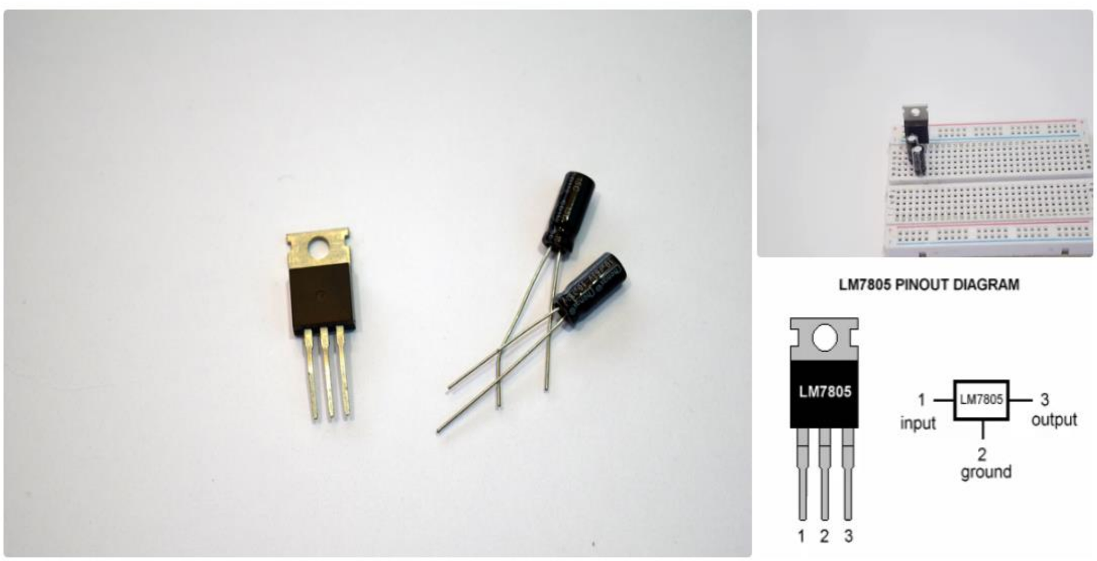

Plate I11: The voltage regulator on the Breadboard

The first step will involve connecting a voltage regulator, the atmega328 is a 5V microcontroller so is the Arduino Uno. So, we need a voltage regulator to supply steady voltage to atmega328IC. For this we will be using a L7805 voltage regulator. This chip is a popular voltage regulator and is cheap and serves the purpose of building an Arduino Uno. This voltage regulator gives a voltage of 5V and a maximum load of 1A.

(d.) The Circuit Configuration

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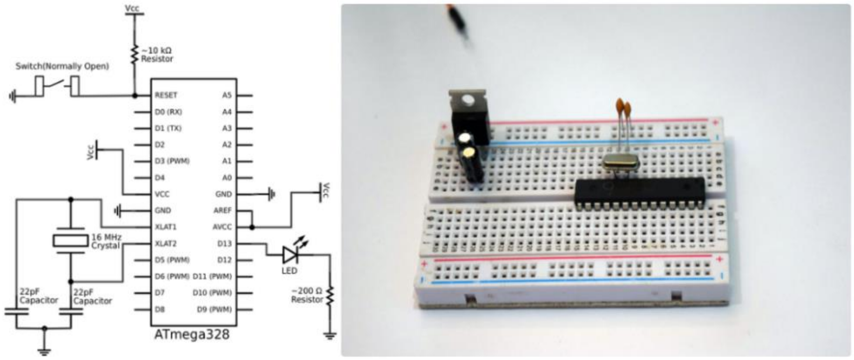

Plate IV: Connection from Arduino to an external circuit configuration.

The connection of Arduino to an external circuit may vary depending on the circuit.

(a.) Serial Connection

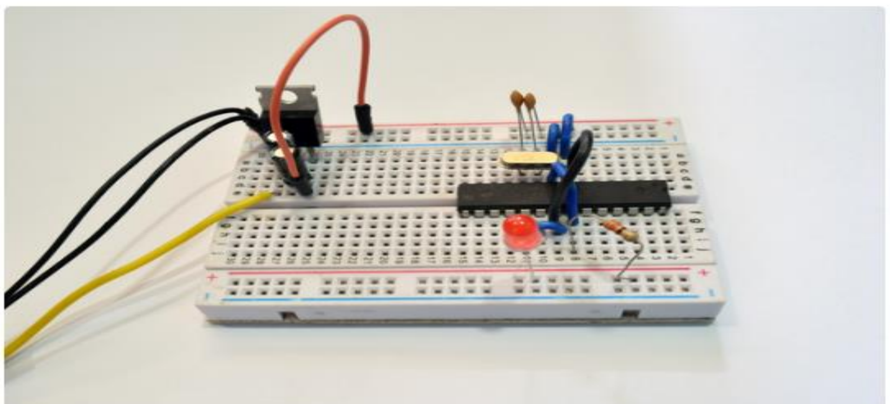

Plate V: Serial Connection

In the Atmega 328IC the pins 2 and 3 act as a serial port and the board is programmed by connecting pins to the USB to the serial converter. After the connections, the USB end of the converter is plugged to the computer and install the necessary drivers

(f**.) Uploading the code**

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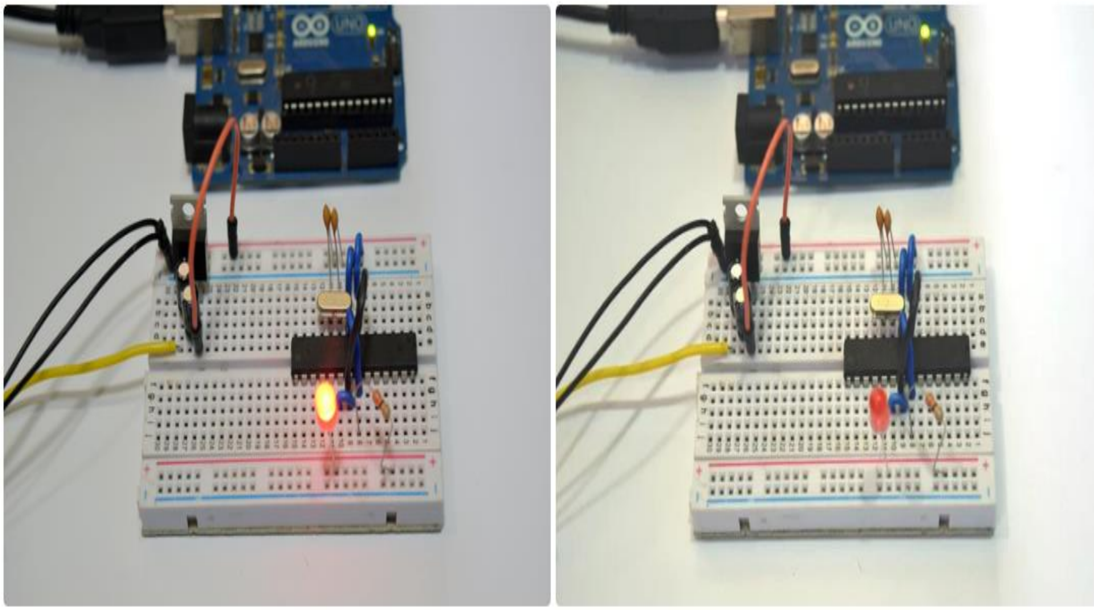

Plate VI: Uploading the code to the Arduino board.

The Arduino IDE is first downloaded and installed from the Arduino official website and thereafter the code is uploaded to the board. The suitable serial port, board are then selected. Hence the homemade Arduino is programmed, and the board is then tested as shown in plate viii

3.3.3 Analog to Digital Conversion on Arduino Microcontroller

Arduino Microcontroller has analog to digital conversions features on the analog pins. There are 6 pins designated for "Analog to digital" conversion labelled (A0 through A5). ADCs can vary greatly between Microcontrollers. The ADC on the Arduino is a 10-bit ADC meaning it could detect 1,024 (2^10) discrete analog levels. Some microcontrollers have 8-bit ADCs (2^8 = 256 discrete levels) and some have 16-bit ADCs (2^16 = 65,536 discrete levels).

The way an ADC works is complex. There are a few different ways to achieve this, but one of the most common techniques uses the analog voltage to charge up an internal capacitor and then measure the time it takes to discharge across an internal resistor. The microcontroller monitors the number of clock cycles that pass before the capacitor is discharged. This number of cycles is the number that is returned once the ADC is complete.

3.3.4. Relating ADC Calculation to a Smart Prepaid meter monitoring system.

This was used to calculate the incoming voltage to the prepaid meter monitoring system via an ADC terminal of the Arduino. The controller was connected to a voltage divider made of a Light Dependent Resistor (LDR) and a fixed resistor which calculates the amount of voltage to the ADC pin A0 in proportion to the light intensity. Whenever there is a difference in the expected ADC value and the threshold voltage, the system triggers the internet protocol (IP) Camera to capture the Power theft intruder and sends notification to the concerned authority against the suspected Power theft. The ADC reports a radiometric value. This means that the ADC assumes 5V is 1023 and anything less than 5V will be a ratio between 5V and 1023.

$$\frac{\text{Resolution of the ADC}}{\text{System Voltage}} = \frac{\text{ADC Reading}}{\text{Analog Voltage Measured}} \qquad (4)$$

Analog to digital conversion is dependent on the system voltage. It predominantly uses the 10-bit ADC of the Arduino on a 5V system, the relation can be further simplified thus:

$$\frac{1023}{5} = \frac{\text{ADC Reading}}{\text{Analog Voltage Measured}}$$

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3.3.5. Load Power Consumption and Analysis

For energy saving LED bulb power consumption:

Taking 10W LED bulb for example, consumes 10 Watts per hour. When the 10W LED bulb runs for 24 hours the total power consumption obtained from the energy meter was about 24 × 10 = 240Watts. This simply means that, in a year the total power consumption of the 10 Watt LED will be 10 × 24 × 365 = 86700 watts hour. This will act as a guide to generating values for Power consumption when the system is not controlled via Sensors as shown in the second column of Table 3.1. The third column was gotten by practically taking readings from the energy meter.

Table 3.1: Practical Comparison of Energy Consumption between Energy Saving Bulbs (without LDR & PIR sensors) and Energy Saving Bulbs (with LDR & PIR sensors)

Power ratings of the LED Bulbs	LED BULBS (Without PIR & LDR Sensors) kWh	LED BULBS (With PIR & LDR Sensors) kWh
Power consumed by 5W LED Bulb per day	120	14.2
Power consumed by 10W LED Bulb per day	240	28.4
Power consumed by 15W LED Bulb per day	360	42.6
Power consumed by 18W LED Bulb per day	240	51.12
Power consumed by 20W LED Bulb per day	240	56.8
Power consumed by 24W LED Bulb per day	576	68.16

System Implementation

Plate VIII shows the state of the input voltage when it is too high. At this level, the system does not allow any of the devices connected to it to switch. The input voltage here is 502V and practically, this is not ideal for any electronic gadgets. The incorporation of this voltage monitors and controller becomes necessary to protect the electrical appliances under control.

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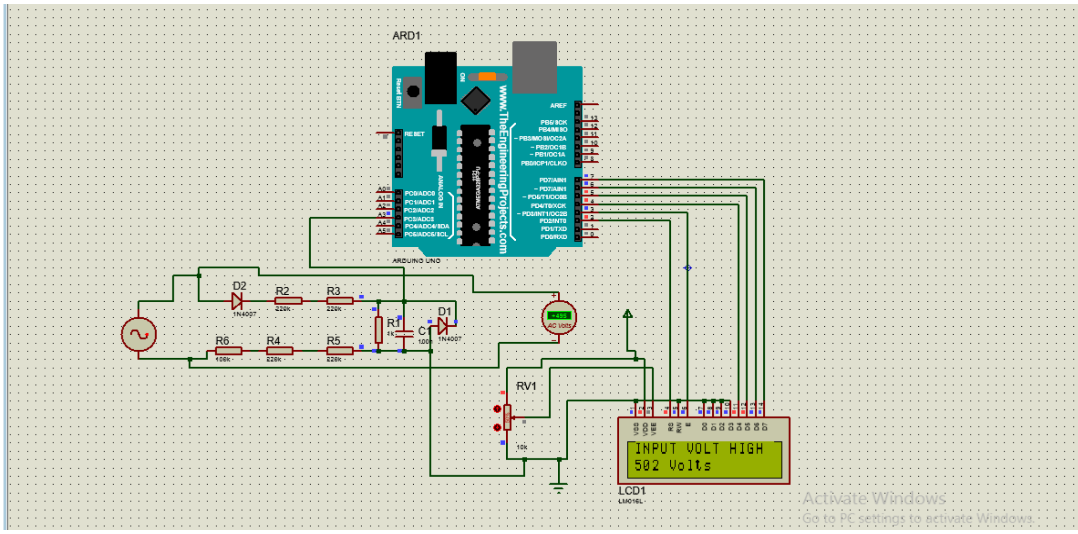

Plate VIII: Input voltage is too high (over voltage)

Plate IX depicts the state of the input voltage when it is too low. At this level, the system does not allow any of the devices connected to it to be controlled remotely. The input voltage here is 127V and practically, this is not ideal for any electronic gadgets. This causes some devices to draw more power than they should under normal circumstances. The incorporation of this voltage monitors and controller becomes necessary to protect the electrical appliances under control.

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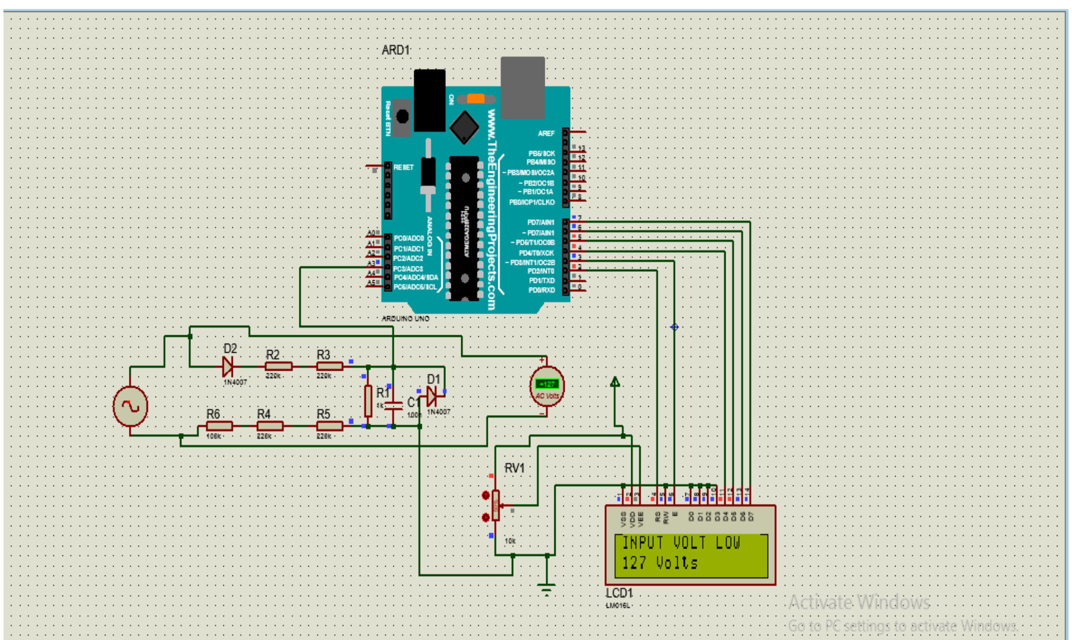

Plate VIII: Input voltage is too low (under voltage)

3.3.6 Validation of Developed System

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When a microcontroller-based energy management system is being validated at a medical facility, its performance, functionality, and dependability are evaluated to make sure it performs as planned and works well under real-world conditions.

Before the system, comes the unit test of each subunit to confirm the correct functionality of the system. Different materials selected were assembled in Proteus software to form the schematic setup for the design. All the components were tested one after the other and individually the subunit was built on the board and checked before it was finally transferred to main construction board. This was done to authenticate its functionalities. The entire circuit was arranged rationally according to design description. The project was executed using suitable component obtained from the design. The complete circuit diagram of the automatic load sharing and control system is shown in Figure 3.4. The written program was burned into the Arduino. Also, current transformer was wound of the required number of turns to suit the design. Power supply of 5V was also design for driving the circuit. The module was first tested on the breadboard before moving them to the Vero board for the soldering.

3.3.7. Simulate developed model.

The system was simulated using proteus simulation software as shown in Plate IX

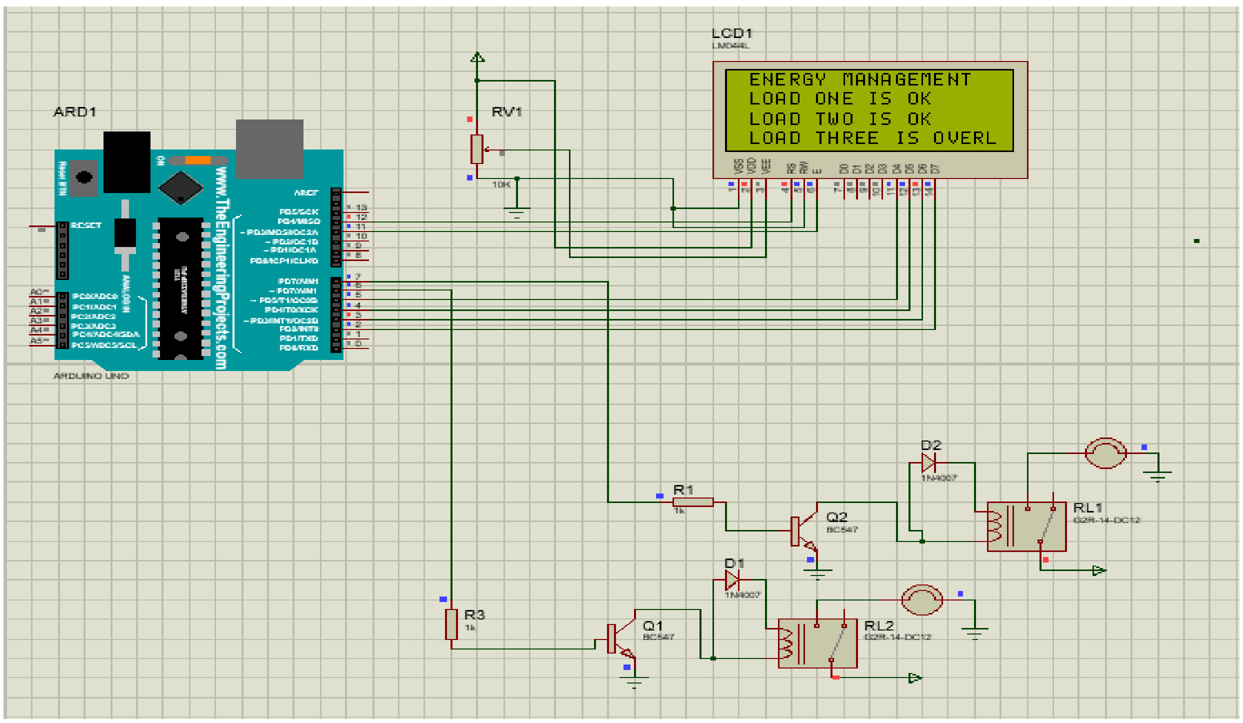

Plate IX: Circuit diagram of proteus simulation

An Arduino Switched Mode Powered Supply provides electricity to the system (SMPS). The loads attached to the Controller terminals are now ready for operation after the Arduino input or output pins have been setup. A current sensor is installed on each load, which calculates the amount of current drawn by each load and compares it to the threshold value. The controller automatically disengages the relay delivering power to that load if the current drawn by the load exceeds the threshold value. The UPS cuts down on downtime by holding the current for a few seconds before switching. It checks the current of the load again after 10 seconds, and if another load with a lower current capacity is attached, it activates the relay, connecting the load to the mains. On the plate IX above, you can see the final outcomes of the entire process.

3.3.8. Performance of Cost Benefit Analysis

Table 3.3.8 shows cost-benefit evaluation of installing an energy management system based on microcontrollers in medical institutions. It entails assessing the prospective costs and advantages of doing so. Hence, it is vital to keep in mind that the precise costs and advantages may change based on the medical facility's size, energy consumption habits, and extent of the energy

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management system. A microcontroller-based energy management system can provide medical institutions with several advantages. Here are some of the advantages:

Table 3.3.8: Bill of Engineering Measurements and materials evaluation

S/N	**Component**	**Quantity**	**Unit price**	**Total (N)**
1	ATmega328p Controller (Arduino UNO chip)	**1**	**10,200**	**10,200**
2	Crystal oscillator (16MHz)	**2**	**200**	**400**
3	ULN2003 relay driver	**3**	**550**	**1650**
4	Fixed resistor(220Ω)	**10**	**5**	**50**
5	22pF non polarized capacitor (2 pcs)	**2**	**30**	**60**
6	Signal diode (4148)	**2**	**30**	**60**
7	Rectifier diode (1N4007)	**4**	**40**	**160**
8	5V DC Relay module	**1**	**1600**	**1600**
9	Voltage regulator	**2**	**150**	**300**
10	Micro USB cable	**1**	**600**	**600**
11	Liquid Crystal Display (LCD)	**1**	**1500**	**1500**
12	Jumper wires (yards)	**2**	**800**	**1600**
13	Soldering lead (yards)	**5**	**300**	**1500**
14	Vero board (dotted)	**1**	**300**	**300**
15	Electrolytic capacitor (1000µF)	**1**	**200**	**200**
16	IC Socket (28-pin)	**1**	**150**	**150**
18	6x9 adaptable box	**1**	**1300**	**1300**
19	A lamp-holder	**2**	**250**	**500**
20	Light Emitting Diode (LED)	**1**	**20**	**20**
21	Control switch (SPST)	**1**	**300**	**300**
22	Push to make button	**1**	**100**	**100**
23	Screws	**4**	**50**	**200**

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24	Flexible wire (yards)	**4**	**150**	**600**
25	Energy saving bulbs (12V DC)	**1**	**450**	**450**
TOTAL AMOUNT = N23,800.00 (Twenty-three thousand eight hundred naira only)				

Energy savings: An energy management system based on a microcontroller can help optimize energy use, track consumption trends, and spot potential improvement areas. Over time, this may lead to lower energy costs.

Cost reduction: By using energy more wisely, healthcare facilities can cut operational expenses and redirect funds to other crucial patient care areas.

Impact on the environment: Better energy management helps medical facilities adopt more sustainable practices and reduces their carbon footprint.

Increased Equipment Lifespan: Effective energy management can stop power surges and fluctuations, extending the life of medical equipment and lowering maintenance and replacement expenses.

4.0 RESULTS AND DISCUSSION

The first test carried out was the system power consumption test. The total power of the device is the product of the voltage and current. The minimum and maximum voltage and current were recorded, and the power consumption calculated as follows:

4.1.1 Survey of energy sources

The results were used to develop the load profile of the entire hospital and how they are shared. From the results, the entire UNTH is fed by 750mVA transformer (six 500kVA sublet) and 500kVA, 100kVA, 1000kVA and 700kVA generators. Out of which 500kVA is feeding the Cardio Thoracic Centre (CTU & ICU) Units, Theatre, X-Ray/Radiology Units, Cardiac Catheterization Lab, and Main Laboratory

4.1.2: Load Enumeration Using End-User Analysis Method

From table 4.1 X-Ray Film Processor Tabletop, X-Ray Film Viewer and X-Ray Unit Universal consumed the highest amount of energy while the Lighting bulb (Energy saving) has the highest number of units.

Table 4.1 Power consumption of various equipment in Radiology (X-RAY) unit

Medical Equipment	Wattage(W)	Units	Total Wattage(W)
X-Ray Film Processor Tabletop	60000	2	120,000
X-Ray Film Viewer	60000	2	120,000
X-Ray Unit Universal	60000	2	120,000
X-Ray Mobile	2500	2	5,000

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Ultrasound Scan (3 Probes)	2500	3	7,500
MRI Machine	3000	1	3000
Electrocardiograph 3 Channels	150	1	150
Hot Air Sterilizer	600	1	600
CT-Scanner	379	3	1137
Portable ultrasound Scanner	25	5	125
Mammography	750	1	750
Fan: Standing Ceiling	70 85	2 2	140 170
Television	50	2	100
Air Condition	746	2	1492
Lighting bulb (Energy saving)	15	6	90
Computer	60	4	240
			TOTAL=380494W =380.494KW

In addition, out of 20 lightening bulbs, 12 were selected for the outside light which can only be turned on automatically at night with the help of LDR and PIR. Hence the calculated saving is 1800watts per day. This amount of energy is being saved every day in addition to other medical equipment that are not being used unless a patient is admitted.

4.1.3 Load Prioritization Through Interview

Table 4.2 shows the outcomes of the interview. According to the findings, equipment in level 1 has the maximum rated capacity and, as a result, should be scheduled to run continuously throughout the cycle.

Table 4.2: Key for Load Add Levels

Level	Facilities
1	Cardiac Monitor, Oxygen Condenser, Apnea monitor for infants, Kidney Dialysis, Respirator, Ventilator, Pressure Breathing Therapy, Infusion Pump, Defibrillators, Incubators (Infant)
2	Suction Pump, Peritoneal Dialysis Machine, Kidney Dialysis Machine, X-Ray Machines, Ultrasound Scan, MRI Machine, C-T Scanner, Electrocardiography, Mammography, Fatal Monitor, Pulsimeter, Gastroscope, Colonoscope, Patient Monitor anaesthesia

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3	Centrifuge, Hot Air Sterilizer, Bacteriological Light, Nebulizer, Colonography Angiography, Fibre Bronchoscope, Laparoscopy System, Cardiotocography, Analyzer Haemoglobin, Oxygen Condenser, Trolly Instruments
4	Air Condition, Washing Machine, Refrigerators, Water Still, Water Bath
5	Lightening Bulb, Computer, Television, Fan, Photocopy Machines, Pumping Machines (SUMO)

The light dependent resistor (LDR) with passive infrared control Load level 5 which is designed to optimize energy usage and functionality based on detected motion during nighttime hours. Ten of the total lighting units are set to work at night and can only be activated when motion is detected in the area.

4.1.4 Sequential Method

The result of the algorithm for the implementation of the system developed is shown in Figure 3.3 and Figure 3.4. According to the algorithm, Power from the public utility is taken preference to generator and inverter.

4.1.5 Proteus Simulation of the Developed Model

The results of the simulation are as shown below in the following plates below:

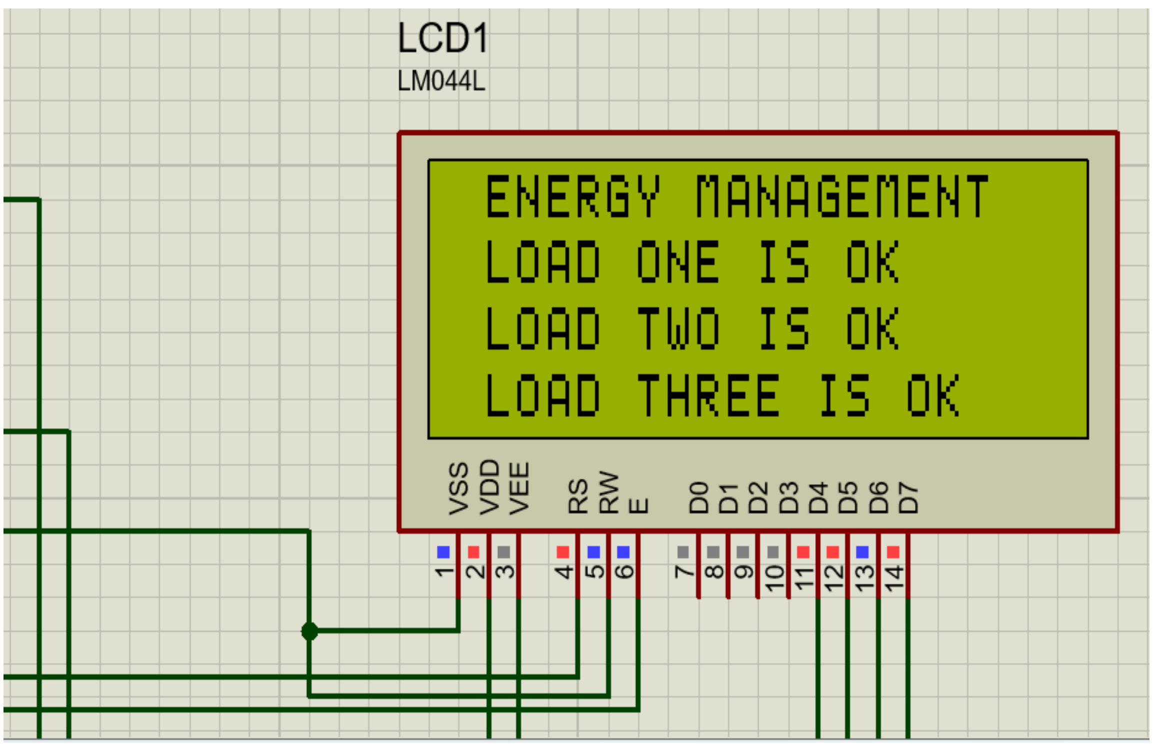

Plate X: Load in three OK

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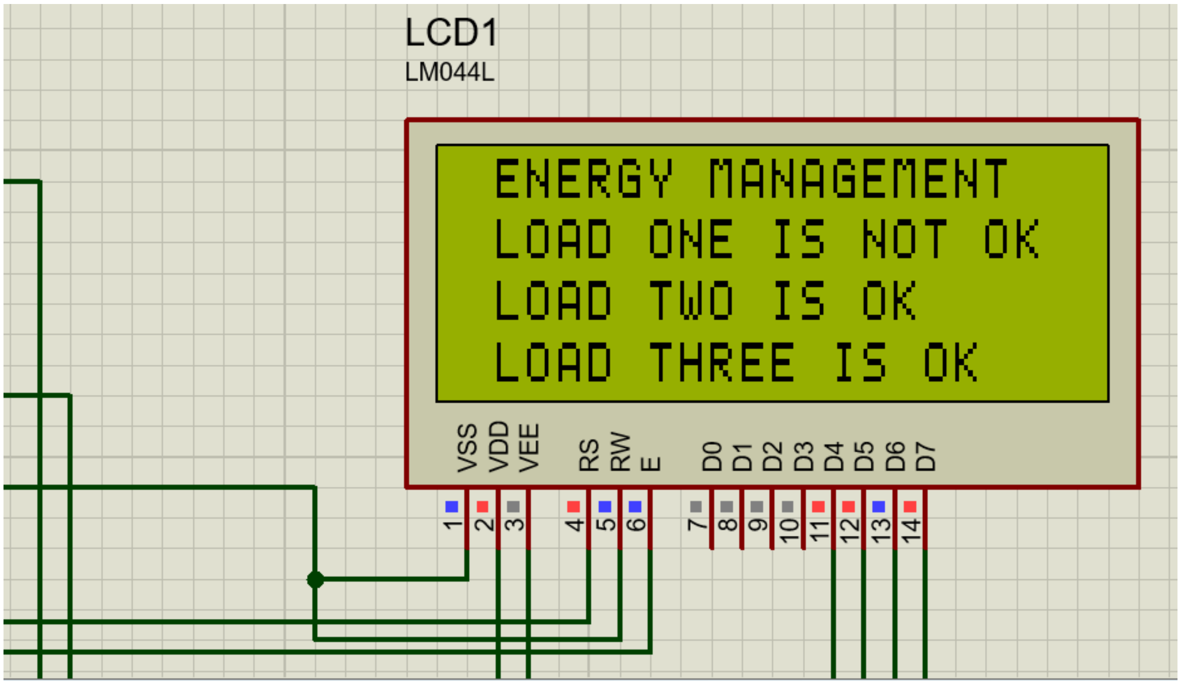

Plate XI: Load in one not OK

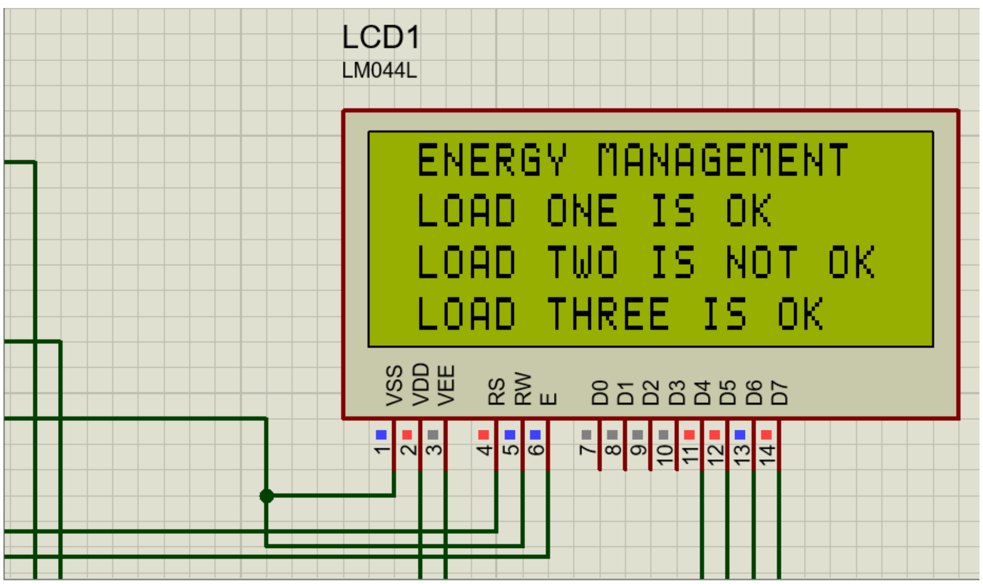

***Plate XII*: Load in two not OK**

The state of the load in each line is depicted in Plates X, XI, and XII respectively. According to the program commands in the microcontroller, the system toggles the status of the load to verify if loads in each of the lines are ok or not, and it reacts to the recommended algorithm of the user's source of priority.

4.2.1 System Power consumption test

The voltage and current values from the digital multimeter are multiplied to get the device's total power consumption. Throughout the measurements, the lowest and highest values for voltage and current were noted. These measured data were then used to calculate the

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device's overall power usage.

Table 4.3: Measured values from the research conducted.

S/N	Voltage (V)	Current (mA)	Power (mW)
1	7	87	609
2	9	100	900
3	12	120	1440

The device was quite unstable and caused the microcontroller to restart when it was powered with the 7V power supply. The 9V power supply ran the device smoothly without any glitches. And the current at which the device operated was efficient. The 12V caused the arduino micro-controller to heat up. This was because the arduino has on it a 5V voltage regulator that operates at an optimum voltage of 7V. Although the technical specifications indicated that it could handle up to a maximum of 18V, heating will cause inefficient use of power. Therefore, after considering the voltage range, the 9V power supply was selected for its availability and less heating.

Table 4.4: Percentage gain in Energy Consumption between Energy Saving Bulbs with LDR & PIR Sensors

Power ratings of the LED Bulbs	LED BULBS (Without PIR & LDR Sensors) kWh	LED BULBS (With PIR & LDR Sensors) kWh	Percentage gain in power consumption with PIR and LDR
Power consumed by 5W LED Bulb per day	120	14.2	88.2%
Power consumed by 10W LED Bulb per day	240	28.4	88.2%
Power consumed by 15W LED Bulb per day	360	42.6	88.2%
Power consumed by 18W LED Bulb per day	240	51.12	78.9%
Power consumed by 20W LED Bulb per day	240	56.8	76.3%
Power consumed by 24W LED Bulb per day	576	68.16	88.2%

Percentage gain = $\frac{\text{Power without PIR \& LDR Sensors} - \text{Power With PIR \& LDR Sensors)}}{\text{Without PIR \& LDR Sensors}} \times 100\%$. On the average there is an 88.2% gain in power consumption when PIR and LDR are connected

4.2.2 Test Result for the Smart Street Light Control

Plate XIV shows the graphical representation of the analog and digital signal results obtained. When the light sensor was exposed to light, its output value changed from 100KΩ to about 3Ω on a digital ohmmeter. Analog to digital conversion technique was deployed to match the results based on a standard analog to digital metrics. Hence, 2.5 analog voltage is equivalent to 512 digital bits, 5 analog voltage is equivalent to 1024 digital bits in that order.

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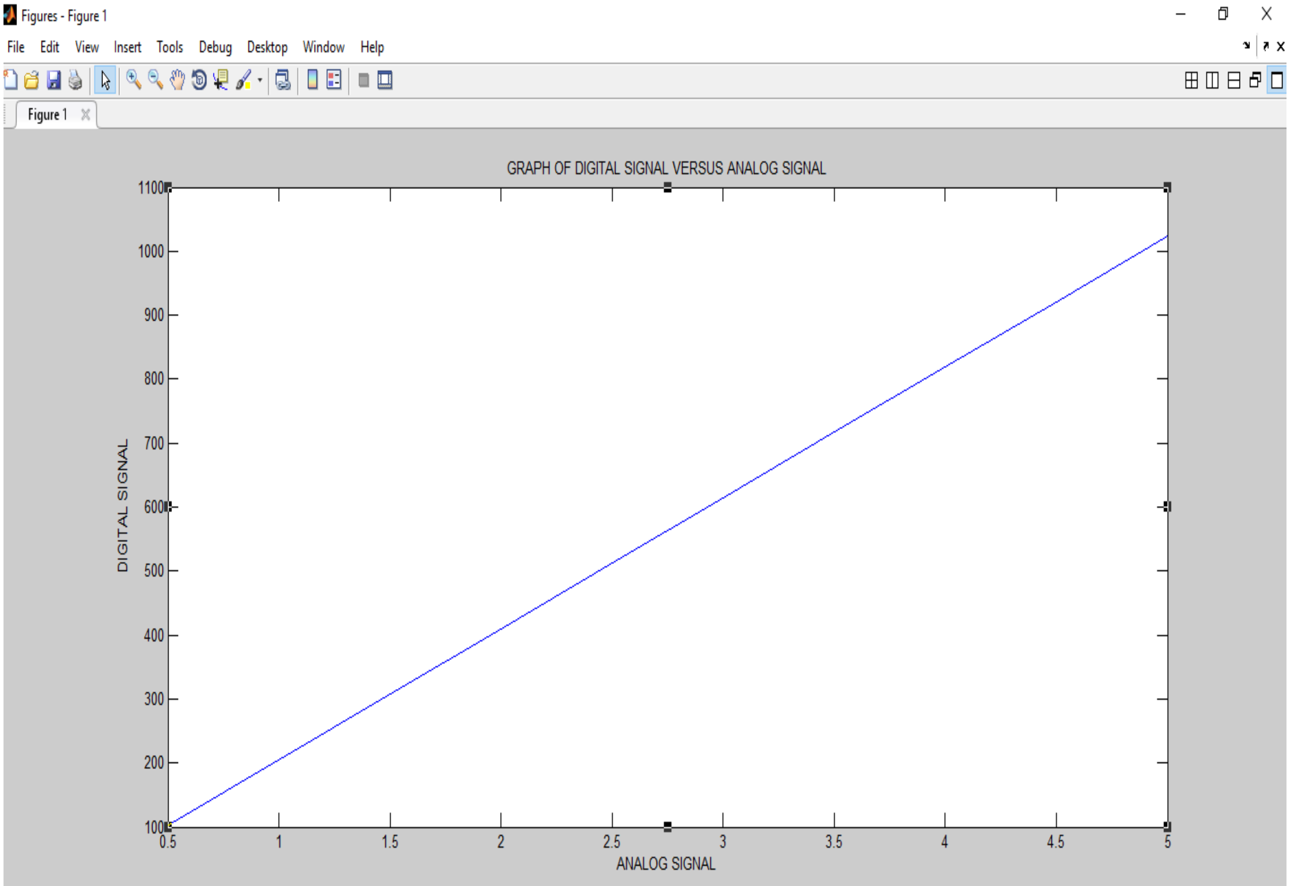

Plate XI11: Analog Signal versus Digital Signal

4.2.3The View Angle and Range Test

This test was to measure the view area of the device. The device was once again mounted on the ceiling of a room of dimensions $10\ m \times 5\ m \times 4.5\ m$. The device was able to detect the presence of a human being right at the entrance and at the end of the room. This made it possible for the device to keep the light on so far as the person was in the room and the fan was on.

4.2.4 Device Sensitivity Test

The sensitivity of the device is a measure of how fast it responds to a change in its state. The device was mounted in a room and three people engaged in an abstract activity in the room. The device maintained the on state of the lamp as far as the people were in the room. After exit of the three people, the device switched off the lamp.

Energy Saving and non-energy saving bulbs Power Consumption compared.

From the results obtained from the digital energy meter showed clearly that combining LDR and PIR sensors in designing an energy management system proved to be the most effective since the PIR sensor did not just come because motion disturbed rather it came on as result of sensing darkness in addition to the motion. This really made the choice of combining these two sensors an excellent combination. Plate XIV shows the graphical representation of the energy consumption of the LED Bulbs in two categories.

a. When LDR & PIR sensors were not incorporated into the Control system

b. When LDR & PIR sensors were incorporated into the Control system

From the table 4.4 and Plate XIV, it was clearly noted that if energy saving LED bulb rated 24W should be used for 24 hours without being controlled by sensors, then energy consumption per hour would be 576 KWh whereas if the bulbs are controlled by sensors,

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only 68.16 KWh of energy would be consumed. The difference in energy consumption becomes 507.84 KWh loss or gain of energy depending on either one uses sensor based or not

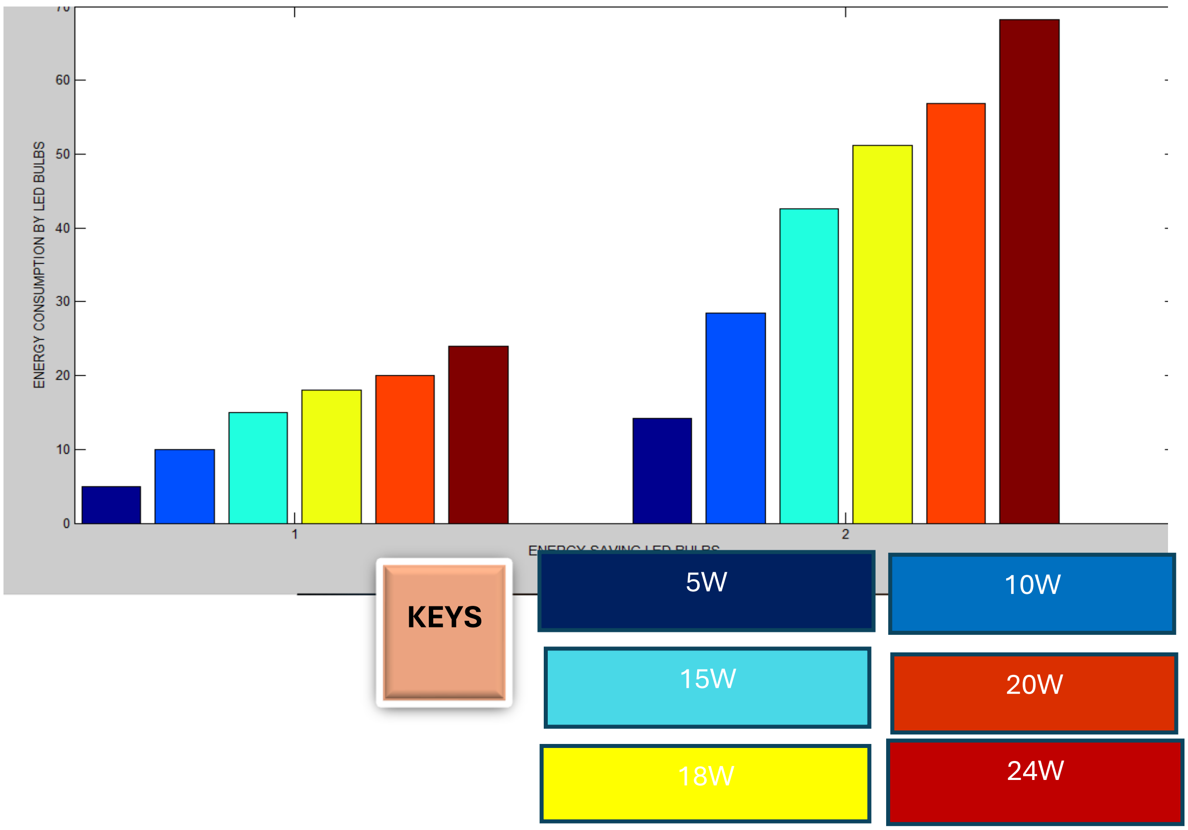

Plate XIV: Energy of Sensor based and non-sensor-based LED Bulb energy Consumption

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This work presents a microcontroller-based energy management system for preserving energy sustainability in medical institutions. To test the proposed idea, a public power utility, generators, and PV panels are created and used. Generators and photovoltaic systems were added into the system to ensure an uninterrupted power supply because power from utility sources is not reliable and consistent. To move the load to the available power source, the proposed method is employed.

The suggested approach provides a practical method for real-time load sharing and control. The Micro Controller-based Energy Management System is a system that is specifically intended to monitor generator overload. The Arduino is used in conjunction with a relay and a transistor to create an energy management system for healthcare facilities. The Arduino is essentially designed as a controller to communicate with the relay, which is connected to a lamp and fan via a PIR sensor, as well as a thermostat via a temperature sensor. The results demonstrate that using Arduino can reduce the amount of energy consumed by electrical appliances. Furthermore, the system can be used on both small and large scales, such as office buildings, hospitals, banks, stadiums, houses, and hotels.

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Nonetheless, this system was created for Energy Management, which takes light intensity into account and interfaces with Arduino Microcontrollers to manage the utilization of appliances such as light intensity rather than simply turning them on and off. In addition, the prototype system calculates the current drawn from each appliance depending on appliance usage and sends it to an Arduino Microcontroller, which calculates the total power spent by the appliances over time.

The appliances are turned on when there is a human in the proximity. The passive infrared, which serves as a motion sensor, accomplishes this. A greater quantity of energy can be saved by using appliances less frequently.

5.2 Recommendations

Following the importance of energy management in the power sector, I will make the following recommendations.

1. More enlightenments should be carried to improve the public especially those in rural areas and hospitals on the merits on energy management systems.

2. The proposed model should be adopted by hospital and by extension other public place to ensure that power wastage is minimised.

3. Future Studies: The sensor tends to turn on in the presence of both animate and inanimate items, which is one of the work's limitations.

More research can be done to ensure that a model is established that uses artificial intelligence (AI) to detect and classify items as they appear to the sensor, ensuring that only humans can activate the sensor.

5.3 Contribution to Knowledge

Medical facilities can create efficient energy management policies with the help of microcontroller-based energy management systems, which maximize energy efficiency through data analysis, control algorithms, and real-time monitoring. Demand response techniques and energy exchange programs are made possible by integration with smart grid technology, which improves overall energy management. Such systems facilitate the adoption of sustainable energy practices, supporting energy efficiency, smart grid technology, and regulatory compliance in healthcare facilities by giving facility managers the ability to make decisions.

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