The Design and Development of a Computer Controlled Embedded Energy Management System

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Abstract— It is no longer new in and around Africa to witness cases of epileptic power supply, with some streets, towns, villages and even parts of cities attesting to having under par electrical power supply. This paper elucidates the complete operation of a novel embedded systems design, geared towards minimizing energy consumption by automatic regulation and dynamic load shedding among other methods of energy conservation. The Computer Controlled Embedded Energy Management System does the regulation by simply interfacing a Java developed desktop application through serial communication with a PIC microcontroller and other electrical and electronics components which make up the embedded system connected to the house's distribution board. The primary drive behind the development of this system is the statistical outlook which shows that Africa's electrical energy generation is well below demand while demand is on an exponential rise. The complete operation of the system is simulated on the ISIS Proteus simulation package and its methodology of operation is well explained in the content of this paper

IndexTerms—Energy, Java, Conservation, Embedded System, Microcontroller, Serial Communication

I. INTRODUCTION

Energy development and utilization in African nations varies widely, as only very few of these nations experience the reach of stable electrical power supply while others lack basic infrastructures and facilities to acquire this electrical energy. Knowing fully well that Africa as a continent is Power-deficient, it is therefore imperative to note that, as the electrical loading of the power network increases daily, there is a crucial need to establish a scheme that can adequately help in the effective management of the scarcely available electrical power in the home. It has been well explained that a larger proportion of energy is involuntarily and deliberately wasted by Africans in their homes, offices, market-place and industry, hence, the need to develop an innovative approach to equip house owners with a system to seamlessly manage the little electrical energy available to them.

The aim of this research work is to design and develop a novel computer controlled embedded energy management system which achieves energy conservation automatically by dynamically shedding consumer load while giving consideration to time, temperature, moisture, motion and other sensor devices connected to it. This energy saving technique inclined towards monitoring, controlling, recording and conserving electrical energy consumption is its key energy management functionality.

The project fully utilizes a Java based desktop application which is interfaced with a PIC Microcontroller (a small computer on a single IC [1]) and it's connected electronic accessories (electronic and electrical sensor devices) through serial communication. The combination of the PIC microcontroller, the serial connector and other sensor devices make up what is called Embedded System (a combination of software and hardware [2]).

The peculiarity of this research development is the automatic and dynamic load shedding technique, among several other load shedding techniques which provides better flexibility, real time monitoring and control, better energy-regulation practice and several other benefits which would be explained in the paper.

II. RELEVANCE

Statistics reveals that 29% of energy generated in most African nations is wasted due to the lack of energy management. However, this project fully utilizes the advancement in computer programming language and electronic systems to achieve automated energy conservation and control of home appliances which is highly relevant to the society in the following ways:

i. Reduction in home-energy consumption and cost, consequently improving the amount of power generation in African countries
ii. Real time monitoring and control of appliances
iii. Effective monitoring and targeting of energy consumption
iv. Automated energy distribution system
v. Security and comfort
vi. Digital metering and recording of electrical energy usage.
vii. 29% reduction in the carbon emissions produced in Africa, thereby reducing global warming.

All these will consequently lead to a longer term impact on the technological and economic development of Africa at large.

III. METHODOLOGY

The development methodology was by modules, and thereafter integrating the modules into a single unit. Figure 1 below shows the block diagram of the completely integrated unit

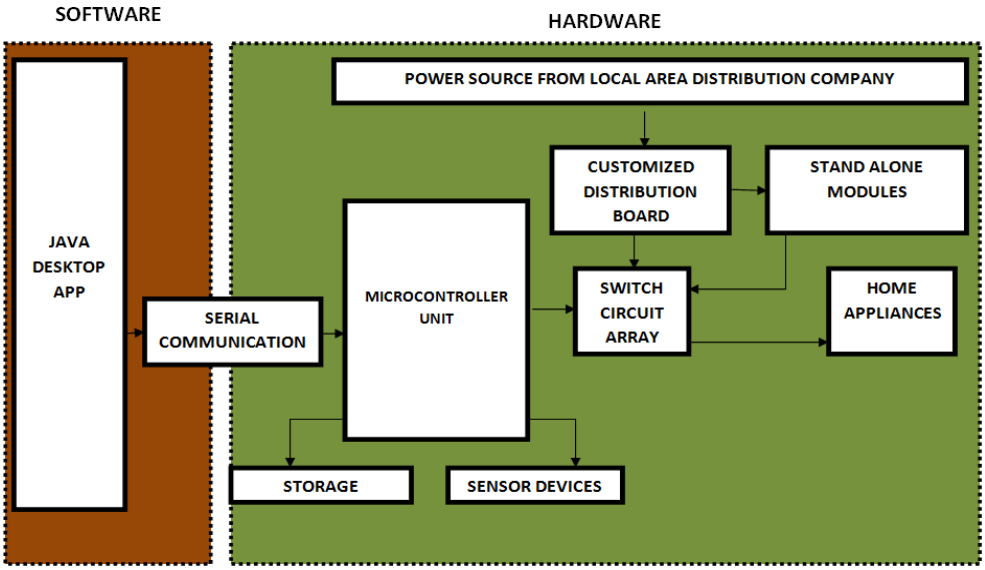

Fig 1: Block Diagram of the CCEEMS

The major components that make up the final integrated system will be explained in the sections below

A. Java Desktop Application Module

A comprehensive graphical user interface or GUI, pronounced /ˈguːi/ [3] is built to interface with the system as it is important to note that the user interface of any software is responsible for all interactions of the software/electronics device with the user [4], and in this case, our software in the primary point of interaction with the embedded system.

The Java Simple Serial Connector (JSSC) library is used to make such communicate with the serial port possible. The JSSC is designed to operate 24/7 multi-threaded systems and is currently successfully used in automation, data collection and recording. To make simulation possible, the Verilog Serial Port Emulator is used to create a virtual serial platform whereby the Proteus simulation serial connector connects with the java application's serial port.

For adequate data and usage tracking, the desktop application was developed with an SQlite database attached to it. SQLite is an in-process library that implements a self-contained, serverless, zero-configuration, transactional SQL database engine [5]. This will ultimately store user's session and usage records over time.

1. GUI Design Considerations

The following design considerations were taken into consideration.

i. Efficient feedback system
ii. Ability to provide adequate guidance to user
iii. Good Enough Aesthetics
iv. Ease of learning

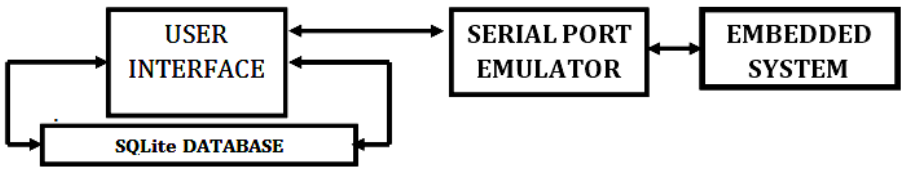

Fig 3: Clock Diagram of the Software Component Interaction

Code 1: Code Excerpt of the Serial Port Write Method Used by the Interfacing Java Application

```
void WriteToPort(String data, String Address){
   SerialCommunication.ClearToSend="0";
   int datalength;
   data = Address+""+data+".";  //Concatenate start and stop character to the data to be sent out
   datalength = data.length();
   String IndividualData[] = new String[datalength];
   try {
```

```
        for(int i=0; i<datalength; i++){
           IndividualData[i] = data.substring(i, i+1);
           try {
              Thread.sleep(500);
           } catch (InterruptedException ex) {
Logger.getLogger(SerialCommunication.class.getName()).log(Level.SEVERE, null, ex);
           }
          HomeEnergyManagementSystem. serialPort.writeBytes(IndividualData[i].getBytes());//Write data to port
        }
      }
      catch (SerialPortException ex) {
         msg.ErrorMessages(""+ex);
      }
   }
```

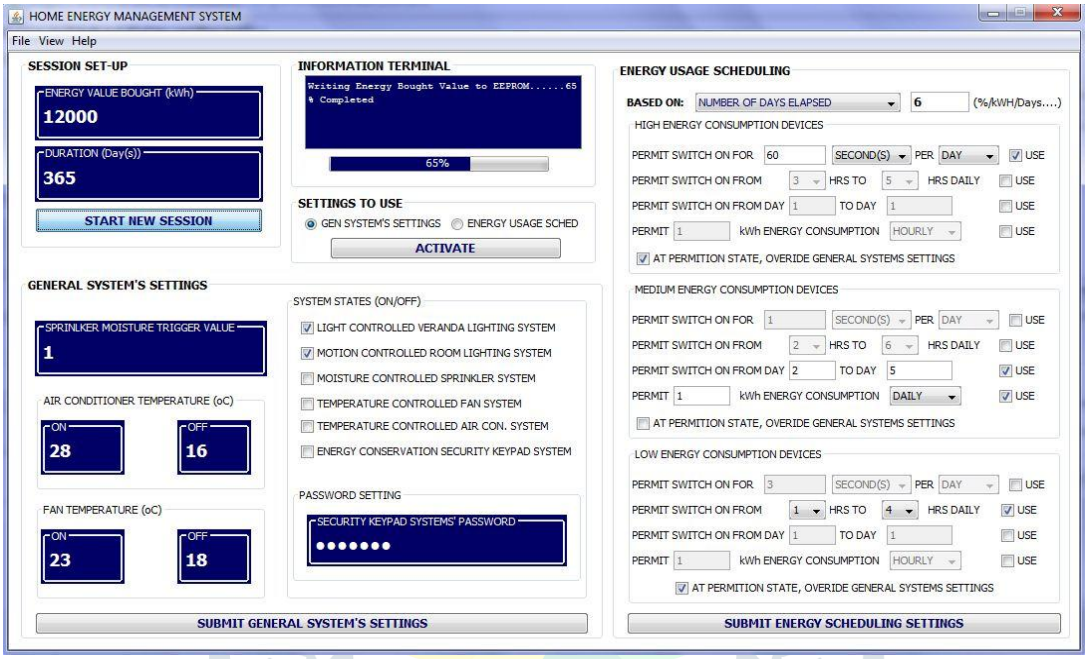

Fig. 2: Snapshot of the Interfacing Java Application

B. Serial Communication Module

The Java desktop application and hardware system are designed to communicate with each other via a 9 pin serial connector over a standard serial port interface used for serial communication of data. In this case, the data is sent and received one bit at a time between the computer and the PIC microcontroller.

The Universal Asynchronous Receiver/Transmitter (UART) controller is the key component of the serial communications between a device and a computer or between devices in general. It changes incoming parallel information from within the microcontroller or computer to serial data which can be sent on a communication line. At the destination, a second UART re-assembles the bits into complete bytes. It is therefore important that the sender and receiver both agree on timing parameters since there is no clocking signal in use. This explains why the baud which represents the state changes of the line per second must be the same. It is imperative to note that the higher the baud rate, the more bits per second that are transferred. Note that Baud rate refers to the number of signal or symbol changes that occur per second [6]

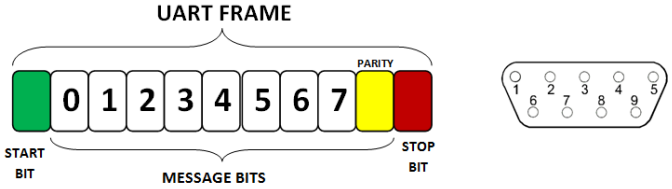

Fig 4**:** The UART Frame and Serial Port Connector

Table 1: Serial Port Connector Operating Principles

PIN No.	PIN NAME	DESCRIPTION
1	DCD	The dataset uses the Data Carrier Detect line to indicate that it has detected its carrier on the other side of the line.
2	RXD	This line receives the data
3	TXD	This line Transmits Data
4	DTR	The *data terminal ready* pin helps computer indicate that it is ready to send and receive data. DTR and DSR are mostly used to establish a connection. Its name expresses what it does, which is to signal its readiness to send and receive data
5	GND	The signal ground, i.e., the reference level for all signals.
6	DSR	The data set ready pin as mentioned above is used in conjunction with the DTR to establish a connection at the very beginning, i.e. the PC and the data set "shake hands" first to ensure they are both present and active. The PC sets DTR to HIGH, and the data set answers with DSR HIGH whenever transmission is to take place.
7	RTS	The request to send pin helps indicate the 'request to send' signal, as it is specially designed for data flow control. The computer signals with RTS that it wishes to send data to the data set.
8	CTS	The clear to send pin helps indicate the 'clear to send' signal. The receiving terminal sets the Clear To Send when it's ready to receive data through the line
9	RI	Ring Indicator

The most important lines are RxD, TxD, and GND. Others are used to indicate internal states.

C. Storage Module

The system makes use of the internal EEPROM of the PIC18F4585 Microcontroller Unit which serves as the storage media. EEPROM stands for Electrically Erasable and Programmable Read only Memory. Every data sent to the EEPROM is stored in a particular address location as directed during the write operation while he read operation also follows the same principle.

The PIC18F4585 MCU EEPROM has a memory space of up to 1MB which is more than sufficient to store all the required operational data. The EEPROM helps save every single input from the desktop application, thereby, giving the MCU an opportunity to retrieve such data when needed to perform cogent operations. Note that the EEPROM is kinds of novalatile memory [7].

Table 2: Table Showing PIC18F4585 EEPROM Memory Map

ADDRESS	00	01	02	03…….	0F
0000					
0010					
0020 . .					
03F0					

LEGEND

Storage Address

Address Specific Location

Data

D. Switching Module

The switching cycle is achieved by interactions between relays, pins of the ULN2003A chip and the MCU. The MCU pins required to trigger the switching action are connected to the input pins of the ULN2003A which is powered by a 12V input com port. The ULN2003A which is a high voltage high current darlington transistor array, grounds its corresponding output pin when there is sufficient input signals on its input pins. The relay on the other hand is an electromagnetic switch with an electromagnetic centre operated by a relatively small electric current. The coil of wire becomes a temporary magnet when electricity flows through it.

Fig 5: Switching Module Operation

When the MCU receives instructions to switch off a particular line of connection, its pin connected to that line is made high, passing signals into the ULN2003A pin directly connected to it. Considering the fact that the corresponding output pin of the ULN2003A in which the signal is received is grounded as soon as the required input signal is sensed, it therefore results in the grounding of the terminal of the relay connected to it, and then, the 12 volt relay triggers ON, thereby flicking the relay wiper towards the unconnected terminal.

1. *More Insight on ULN2003A*

ULN2003A is a High Voltage High Current Darlington Transistor Array, each consisting of seven NPN Darlington pairs. One of its important applications is in the driving of relays. The figures below provide a closer look into the schematic of the device.

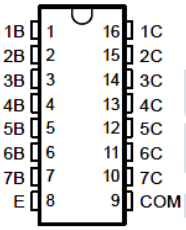

Fig 6: Packaged ULN2003A

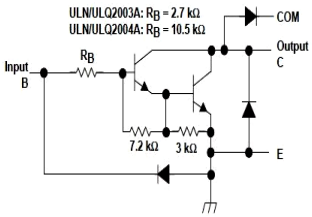

Fig 7: Schematic of Each Darlington Pair Inside the ULN2003A

E. Custom Built Distribution Board Module

The interface between the electricity supply mains (i.e. consumer power supply system) to a building and the consumer units or points is occupied by a device called Distribution Board. It encloses circuit breakers, fuses and earth leakage protection unit used to distribute electrical power to different consumer points or individual circuits. For this project, the board has a single-phase incoming power source connected to the circuit breaker of the board through a fuse. The HRCF (High Rupturing Capacity Fuse) which has a capacity of 100A, provides appropriate protection to the distribution while the circuit breaker performs both switching, protecting and safety functions in the distribution board.

The CCEEMS Distribution Board features a single incoming supply cable providing a single-phase power supply to the board. The supply is first connected through the 100A fuse to the main circuit breaker of 100A. The main circuit breaker allows the entire panel to be isolated for repair during fault and maintenance period. The output from the main Circuit Breaker (CB) is fed through a bus to series of individual fuse and MCBs (Miniature Circuit Breaker). The MCBs are classified into units as designed for the home energy management system. The main consideration for the classification is the energy consuming capability of individual unit. Figure 8 below shows the CCEEMS distribution board.

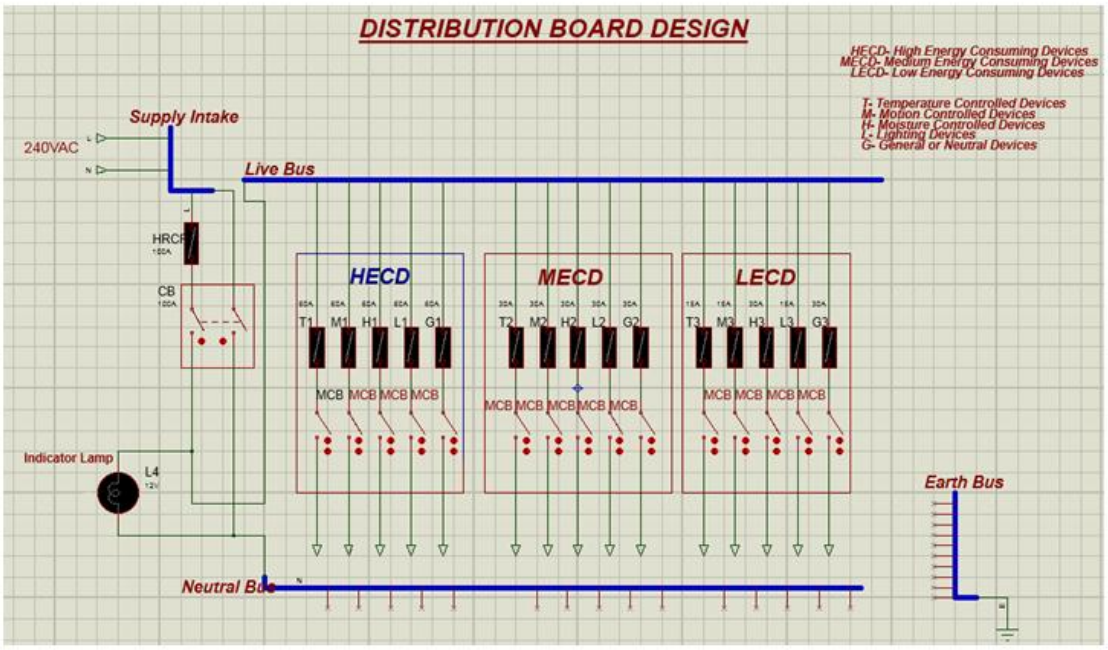

Fig 8: CCEEMS Distribution Board Design

1. *HECD - High Energy Consuming Devices*

These devices are high current-drawing devices, that is, they require a high current magnitude for their operations. The output from the distribution board supplies these high energy consuming devices when the breaker (s) closes. It is important to note that, for this class, the breakers (MCBs) and fuses have a rating of 60A. Examples of these devices, as peculiar to this project, are: air-conditioners, pressing iron, washing machine, heater, cooker etc.

2. *MECD - Medium Energy Consuming Devices*

This class of energy consuming devices is rated to operate at not more than 30A of the supply current. The sub-units individually have 30A fuse and MCB. Medium energy consumer devices for this project are; TV, sound systems, coffee brewer, dish washer etc.

3. *LECD - Low Energy Consuming Devices*

The low energy consuming devices are protected with a 15A fuse and circuit breaker. These devices are such whose maximum current drawn should not exceed 15A. Should there be, the fuse will blow and the MCB would trip off. Examples are: veranda light, room lights, electric clock, alarm system etc. It is important to note that each unit i.e., HECD, MECD or LECD have individual sub-units categorized as:

i. Temperature Controlled Devices (T)
ii. Motion Controlled Devices (M)
iii. Moisture Controlled Devices (H)
iv. Lighting Devices (L)
v. General or Neutral Devices (G)

4. *Installation*

The house is supplied from the distribution pole with a single (Live and Neutral) phase supply voltage of 220V. This supply intake is fed into subsidiary units in the house through the distribution board. Every section of the house is adequately supplied through the DB and any unit can be isolate by opening the MCB associated with it. The CCEEMS helps to achieve significant control and flexibility of the distributed power, as seen from the control block diagram below, the CCEMS is an optional system which can be isolated without affecting the input supply to the consumer units. The switching action of the control section is performed by a relay. Initially, the relay is closed at the normal operating supply terminal ensuring uninterrupted supply. As the relay closes when the CCEEMS output pin connected to the transistor goes HIGH, the control of the supply is given to the CCEEMS module.

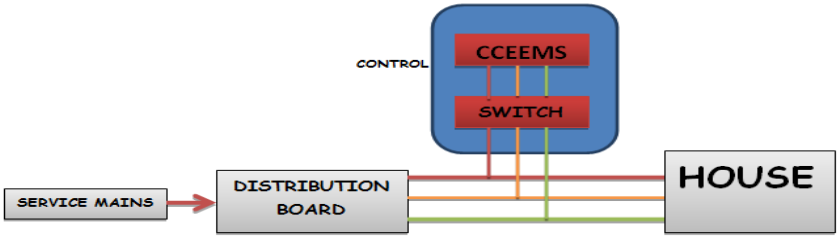

Fig. 9: CCEEMS Control In Relation to the Distribution Board

For installation, the following wiring consideration should be made.

1) From the supply main meter to the DB: 16mm2 Cu/PVC Cable
2) Output from the DB to different units: 2.5mm2 Cu/PVC Cable
3) Earth bus to the earth rod: 10mm2 Cu/PVC Cable
4) Earth Leakage Circuit Breaker (ELCB) should also be incorporated against earth fault.

F. Sensors and CCEEMS Stand alone modules

Sensors are analog devices or transducers which detect a particular event or changes in the environment and provide a corresponding measurable electrical or optical output. The inputs from the environment could be motion, light, temperature, moisture and other forms of physical phenomena. The outputs are mostly electrical or optical signals which are transformed to a form readable by humans for effective measurement and recording. The process of conversion of the input by the sensor to give the desired electrical output is called transduction. There are various types of sensor devices ranging from miniature thermometers to complex industrial proximity sensor.

The sensor devices play a very crucial role in the design and development of the computer controlled embedded energy management system as it provides the necessary interface (i.e. input) needed by the MCU to effect necessary control action. The analog output from the sensors are fed as input into the microcontroller where they are digitized by the ADC converter for necessary switching/control action as programmed into the microcontroller, since the microcontroller cannot directly interface with the environment to make any decision, the sensors would collaboratively work together with it to achieve various controls as required. For this project, the different sub-modules needed to be controlled and their respective transducers are:

1) **Temperature Controlled Fan and Air Conditioning System:** This uses a temperature sensor to detect the room temperature and its output is fed into the MCU for regulated switching of the fan and the air conditioning system. This typically helps to minimize wastage of energy by controlling the cooling system with respect to the atmospheric temperatures.
2) **Light Controlled Veranda Lighting:** This requires a light sensor (LDR) whose properties change with the intensity of light. During the day, the veranda light is OFF because of the reduction in resistance (of the LDR) and small voltage value across it. But at night, the resistance of the LDR becomes high due to the reduction in the photons of light energy it receives and the voltage across it becomes high enough to switch ON the veranda light.
3) **Motion Controlled Room Lighting System:** This enhances house owners with the ability to control the Switch on-and-off action of lights in the room or apartment when the movement of an occupant is electronically sensed. The detecting device (i.e. sensor) for this system is the PIR sensor.
4) **Moisture Controlled Water Sprinkler System:** This module involves the design of an automatic, user friendly water sprinkler system which detects the soil moisture level and performs the necessary switching actions. The system uses a humidity sensor to detect the soil moisture level and provides the required output into the microcontroller

The sensor devices make a crucial part of the design of the computer-controlled embedded energy management system because it facilitates direct interface and interaction between the system and the appliances or equipment available to be controlled.

IV. IMPLEMENTATION

Figure 10 below shows a schematic, representing the model of the actual circuitry of the CCEEMS. The model shows the interconnectedness of the embedded components which comprise of the storage, customized distribution board and the electronic components working in conjunction with the microcontroller unit.

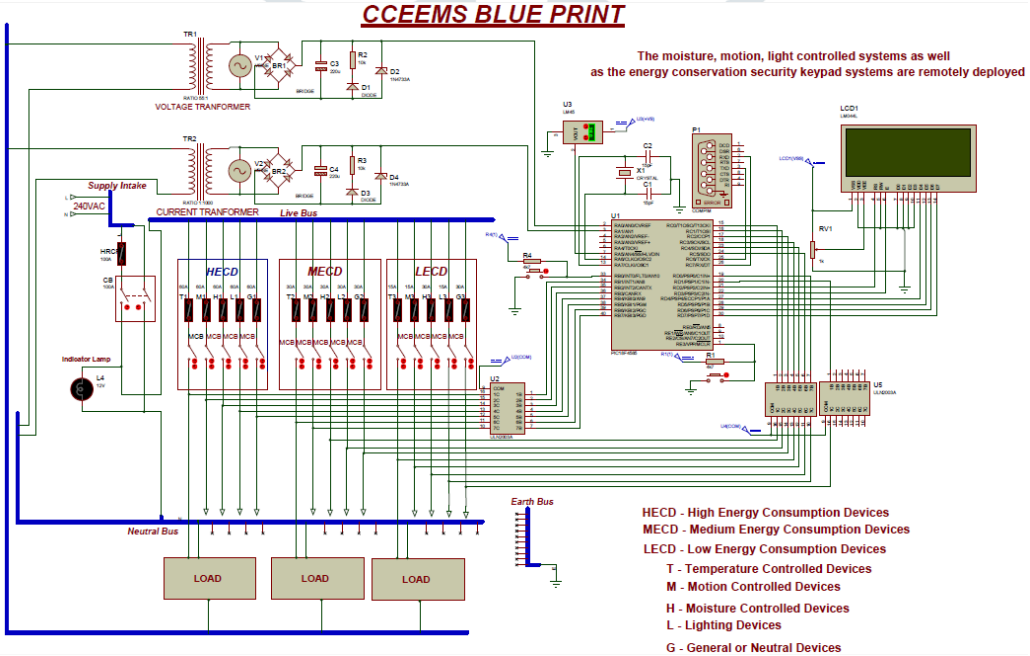

Fig 10: Blueprint of the CCEEMS System

V. Novelty and Peculiarity of the Device

The CCEEMS is uniquely designed to divide devices within the house into 3 major classes which are the:

i. High Energy Consuming devices (HECD)
ii. Medium Energy Consuming devices (MECD).
iii. Low Energy Consuming devices (LECD)

This is made possible via the HEMS custom built Distribution Board which also goes further to divide each of those classes of devices into temperature controlled, moisture controlled, light controlled and general devices. With this classification, a single MCU connected to a each of these buses via the switching circuit can make switching decisions for all devices in the house connected to that particular bus. The possible novel decisions which are not incorporated in any such similar device till date are listed below:

1) Permit HEDC, MEDS and LEDC class of devices to switch ON for a desired number of seconds, minutes or hours per day, week, month or year, as the case may require
2) Permit HEDC, MEDS and LEDC class of devices to switch on from a particular hour of the day to another hour of the day, on a daily basis
3) Permit HEDC, MEDS and LEDC class of devices to switch on from 'day x' to 'day y' of the total number of session days set.
4) Permit HEDC, MEDS and LEDC class of devices only a particular kWH of energy consumption, hourly, daily, weekly, monthly or yearly

One peculiarity of the CCEEMS is its ability to override individual module functionality during the active moments of any of the 4 above mentioned scheduling process. For clarity, find below a hypothetical question solved by the system

Hypothetical Question

'If the Air conditioner which is an High Energy Consuming Device is supplied power at the time of the day scheduled by the user, should the air conditioner also give reservations to the go ahead decision from the temperature controller module before switching on?'

Practical Solution

This scenario is well taken care of by the system, as the settings GUI asks the user if he or she would like to override individual module operation at energy scheduling permit state

The system also gives the user the flexibility of completely deactivating the energy scheduling settings, consequently allowing the individual modules to carry on their tasks or totally disengaged the embedded system, allowing power coming directly from the local distribution company go through to the house

VI. Impact Analysis in Africa

To realize the effect the adoption of this novel device on the African continent and also the current situation of the African power sector, a quick survey was designed, pointing towards understanding the culture of an average African home towards energy conservation. The information gotten from the survey will help paint a more graphical picture of the power usage patterns, availability and the current state of the African power sector. The survey was titled 'Understanding the Energy Conservation Culture of the African Man'

The survey questions were responded to by 100 persons, of which 94% of these respondents reside in Africa. A summary of the survey's results are shown below.

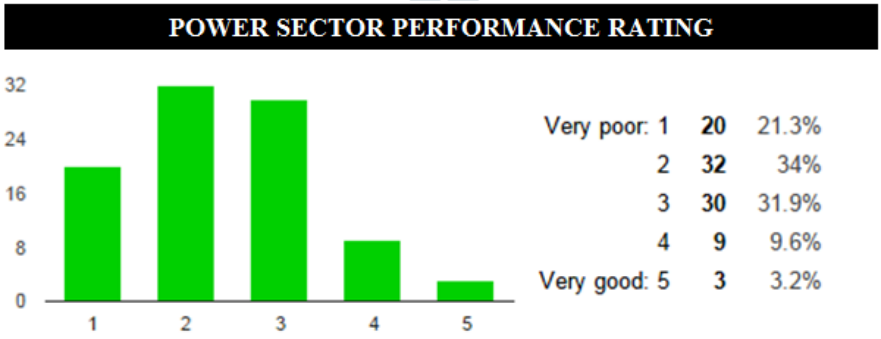

Fig 11: Power Sector Performance Rating

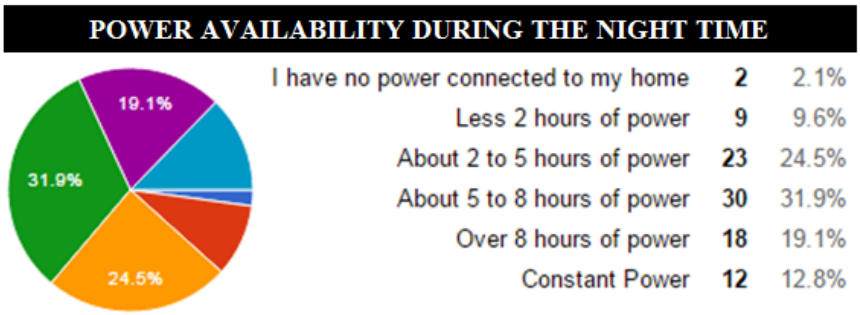

Fig 12: Power Availability (Day)

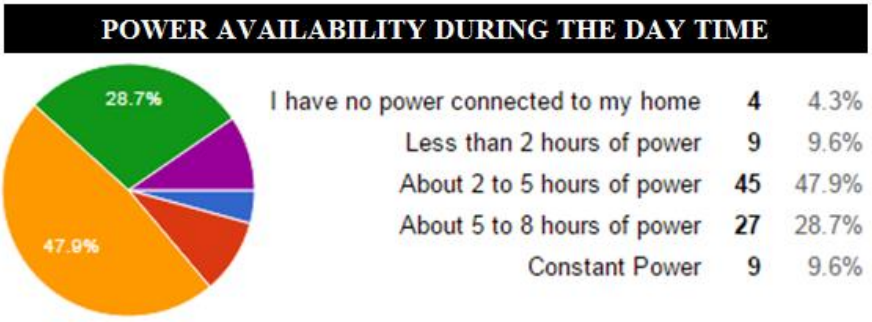

Fig 13: Power Availability (Night)

As can be seen from the Figures 11, 12 and 13 above, the result of the survey showed that, 58% and 34% of the respondents had less than 5 hours of steady power supply per day and night, respectively.

VII. Acknowledgement

We will like to recognize the contribution of all those who ensured maximum engagement in our survey. Also, Olumide Oyetoke, Echono Sunday, Ogundipe Eunice and Ireoluwa Obatoki for their professional advice during the course of this project.

VIII. Conclusion

The result of the quick survey reveals the degrading state of the African power sector. At 4.1% growth, Africa's per capita energy consumption is growing faster than any other region of the world. Annual availability is placed to be about 150 kWH per capita per year, an amount only sufficient enough to switch on a light bulb for about 1 hour 36 minutes a day per person. Nonetheless, improvements can be achieved if we embrace conservation, hence, the need to avail African homes with a solution such as the CCEEMS, to help conserve the currently scarce power supply.

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