ISSN No:-2456-2165

Smart Energy Management System for Microgrid Applications in Offices and Homes

Elukpo, Agnes Obila, Iloh, John Paul Izuchukwu
Dept. of Electrical/Electronic Engineering,
Chukwuemeka Odumegwu Ojukwu University,
Uli Campus, Anambra State, Nigeria

Abstract:- The essence of Energy Management (EM) is mainly to optimize the cost of providing energy to end users without compromising the quality of supply, safety of end users and overall system reliability. In most private and public establishments, a huge chunk of total operating cost is dependent on energy cost. There is need therefore, for an efficient energy management system to ensure that an organization's energy bill is maintained optimal level at all times. This paper presents a Smart Energy Management System for Microgrid Applications (SEMSMA) using three offices in the Department of Electrical/Electronic Engineering, Chukwuemeka Odumegwu Ojukwu University as a case study. The system is designed to distribute power from a 2000W inverter among the offices and also perform real-time simultaneous monitoring of the energy consumption in each of the offices. Each of the three channels/offices is equipped with power measurement function for monitoring the energy consumption for each office. The system is designed to restrict each channel/office to a predefined maximum power allocation (threshold) based on the end user's request. Loads in the offices are connected to the main power distribution box (DB) through the SEMSMA circuitry. A power calculation algorithm is designed to use the current and voltage samples for continuously determining the amount of power consumed by each office. The calculated power is continuously compared with the predefined threshold and once the threshold is exceeded, the system automatically switches off the affected load/office. A liquid crystal display (LCD) is provided for displaying the status (ON or OFF), instantaneous power in watts (W) and total energy consumption in kilowatt hour (kWh). A ZigBee transceiver module is used for bidirectional communication between the SEMSMA circuitry and a remote computer via a Graphical User Interface (GUI) which provides an ultra low power (ULP) solution for remote operation and monitoring of the system. The system embedded software was developed in Proteus 8.10 simulation environment and implemented with the associated hardware circuitry to produce the physical prototype. The load profiles for the three offices were used to conduct an experiment for evaluating the performance of the system. The results showed that the system functioned with accuracy level of approximately 99.96%. Thus, the system is proven to have the capability to monitor and capture accurate energy consumption data for the offices both numerically and graphically via the LCD and remote GUI respectively.

Keywords:- *Smart Energy Management, microgrids, Adiuno Uno, current sensor, NRF24L01 and ZigBee.*

I. INTRODUCTION

Adequate power generation is one the key factors driving economic development and stability in all countries of the world [1]. However, when the power generated is not well managed or distributed properly there will be losses both in energy and revenue accruable to utility companies. In Nigeria's context, there is increasing interest in installation of renewable energy systems [2] like wind farms as found in the northern part of Nigeria and photovoltaic (PV) solar panels as installed by individuals and governments as alternative sources of energy for commercial, office and domestic uses in order to increase supply. The management and sharing of this generated power among end users are faced with challenges in balancing the demand and supply of energy due to the intermittent nature of energy from renewable sources such as photovoltaic (PV) systems. With renewable energy sources, energy management becomes somewhat complex and very critical owing to the various sources and loads that are interconnected and operated as a microgrid system. For this reason, smart energy management systems are being developed for microgrids. Microgrids are usually small electrical distribution systems consisting of generation sources, energy storage solutions and loads (especially buildings) [3]. Energy management system in a microgrid can be used to monitor, control, and optimize power consumption in the microgrid. A smart energy management is supposed to make a better establishment of connections within the electrical grid by establishing multi-way data communications among components, hence, making system more interactive [4]. Typical benefits of smart energy management include: reduction in financial costs of energy bills, fewer environmental damages and possibly addressing the issues associated with excessive power consumptions. To achieve an efficient communication link for implementing the energy management system, it is necessary to find a suitable protocol.

In this work, a Zigbee module is employed as the link for communication. The Zigbee module plays a key role in monitoring and directing load control for efficient power utilization. It provides the needed wireless communication platform running on a low data rate of $20Kbps$ to $250Kbps$ with minimum power consumption [5]. The communication module enables wireless transmission of measured data for current and voltage over the server module to and fro a remote computer or other digital display of storage device. In the case of overload or abnormality in power consumption, the server sends a control message to the microcontroller unit (MCU) through the zigbee module causing the microcontroller to cut off power to the particular load affected. The system is designed to support real-time

ISSN No:-2456-2165

monitoring and control functions from a central station via a graphic user interface (GUI) installed on a remote computer. The proposed system is suitable for implementation in small electrical distributions systems such as those of residential buildings and big offices. It is expected that widespread deployment of the system in buildings and offices will greatly impact the energy sector as reported in [6]. Some of the concepts presented in [7] were adopted in developing the proposed system presented in the paper.

The aim of this work is to develop a Smart Energy Management System for micro-grid applications, using a section of Department of Electrical/Electronic Engineering (EEE) building at Uli campus of Chukwuemeka Odumegwu Ojukwu University (COOU) as a case study. The specific objectives are; to carry out a load study for the three offices being considered; to develop models and relevant equations for characterising the system; to develop a smart control circuitry using ZigBee communication protocol, Arduino Uno microcontroller and a remote Graphic User Interface (GUI); to design and build the physical prototype of the system; to evaluate the performance of the system in order to determine its viability.

II. RELATED WORKS

In [3], the authors examined the role that buildings play in energy management within a smart microgrid. The relationship between Information Technology (IT) equipment and buildings on energy usage was discussed. It was reported that control of loads in various building subsystems such as IT and high voltage alternating current (HVAC) can lead to significant energy savings. Using the University of California San Diego (UCSD) as a prototypical smart microgrid, the authors demonstrated how buildings can be enhanced and interfaced with the smart microgrid, showing the benefits such relationship can bring as well as the possible challenges with the system implementation.

In [4] the authors presented the design, implementation and testing of an embedded system that integrates solar and storage energy resources to a smart home. The proposed system provides and manages a smart home energy requirement, by installing renewable energy, while scheduling and arranging the power flow during peak and off-peak periods. A two-ways communication protocol was developed to enable the consumer and the utility provider to better optimize the energy flow and the consumption efficiency. A prototype for the proposed system was designed, implemented and tested using a controlled load bank, to simulate a scaled random real house consumption behavior.

In [7], Smart Energy Management System (SEMS) proposed for effective electrical load management. It has two parts namely the energy management center (EMC) and the load scheduling. The EMC contains graphical user interface (GUI) which shows the runtime information and also carries out the data logging function. The load scheduling part was illustrated using MATLAB simulations. The hardware model was implemented using human machine interface (HMI), PIC18F4520 microcontroller and ZigBee communication module.

In other related works, the authors in [8] developed the energy scheduling strategy and domestic energy management for a residential building, taking technical and operational issues into account. In [9], an innovative single-objective energy management algorithm for domestic load scheduling was proposed, with the similar goal to minimize energy consumption cost. In [10], an investigation of similar residential energy management problem in multiple ways, was carried out, taking into account a time-domain simulation, incentive-based demand response (DR) actions and price-elastic load shifting.

III. METHODOLOGY

A. Materials

The materials used in this work consist of the following software and hardware components.

a) Software Materials: Three key software applications were used in the study.
   - Proteus Simulator 8.10: This was used for the modelling and simulation of the SEMSMA embedded system before the actual prototyping.
   - Visual Studio (VS) 2012: This was used for the design and implementation of GUI for remote control and monitoring of all the system operations.
   - Arduino SDK: This was used for programming the SEMSMA and its functionality.

b) Hardware Materials: The following key hardware materials were used.
   - Personal computer (PC): This houses the GUI designed for the SEMSMA.
   - Arduino Uno development board: This was used in the design and construction of the SEMSMA control circuitry and interface to the PC.
   - Relays: These are the electromagnetic switches for controlling (switching ON/OFF) each load under consideration.
   - Current sensors: These were used to detect the load current on each section of building.
   - NRF24L01 Radio transceiver module: This was used for sending and receiving control and measurement data to and fro the GUI.
   - Zigbee communication module: This was used to provide low cost, low power machine to machine (M2M) solution for remotely controlling and monitoring the smart devices in the SEMSMA.

B. Methods

A top-down development process was used. First, the load specifications for the offices under consideration were determined. This was followed by the design of the overall architecture of the SEMSMA. The system's software program was developed using a modified waterfall model with a feedback loop at each design stage. The SEMSMA was subdivided into various subsystems which were designed separately. The architecture, requirements, and algorithm for each subsystem were independently developed, and at the end of the designs, the subsystems were integrated to realize the SEMSMA.

a) System specifications:

Table 1 shows the summary of the specifications required for the system.

Source	AC
Supply Voltage	220 – 240 V
Frequency of supply	50 Hz
No. of Phases	Single
No. of offices (loads)	3
Total Load Capacity	2000 W
Wireless communication Protocol	Zigbee
Implementation procedure	Both simulation and prototyping

Table 1: System specification

b) Block diagram overview of the SEMSMA system:

The block diagram of the proposed SEMSMA showing the stages / subsystems involved in the work is shown in figure 1. The system is designed to monitor power consumption in each of the three offices namely the HOD's office, the Secretary's (general) office and the conference room. Each office is equipped with a load/power outlet (socket) and a ZigBee hub. The power outlet includes a power measurement function (power limiter) to measure the power consumption and then send the information to the ZigBee hub through ZigBee communication.

Each of the power outlets is restricted to a preset wattage (threshold) which will not be exceeded based on the end user's request. Loads in the offices are connected to the main power distribution box (DB) through the SEMSMA circuitry. Power consumption for each load (office) is acquired by measuring the current with the aid of a current sensor while the voltage is kept constant at 230 V. The power for each load is calculated using the measured voltage and current and the result is transmitted remotely to a control centre through ZigBee wireless communication where all the relevant power consumption data are displayed in real-time via the GUI.

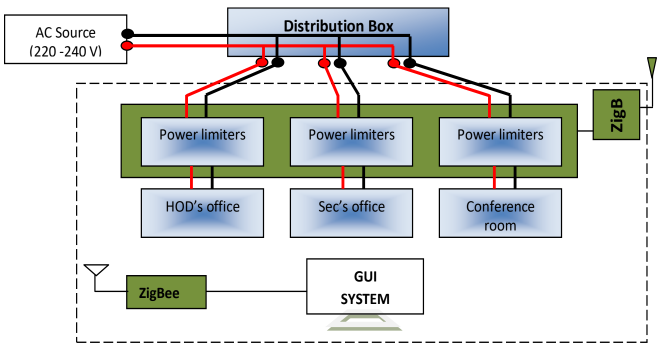

Fig. 1: Block diagram of the SEMSMA model for the case study

The ZigBee hub in each room (office) gathers the power consumption data and load status of the office and transfers the information to the monitoring system. The system displays the power information for the three offices in real time. The end-user can figure out what each office is consuming either via digital display on the power outlet or via the GUI at the control centre. The system is also equipped with data logging feature such that previously acquired power data can be accessed via the GUI in addition to the accumulated power (energy consumption) over a period of time.

The user can also access the power usage records for each office through the ZigBee hub database and can access the server to increase or reduce the power limit (threshold) requested for each office and also turn ON/OFF the loads in the offices whenever desired. The system stores the power limit assigned to the connected offices on the system's database and activates a load turn off operation whenever the set value is exceeded. The flowchart for SEMSMA design is shown in figure 2.

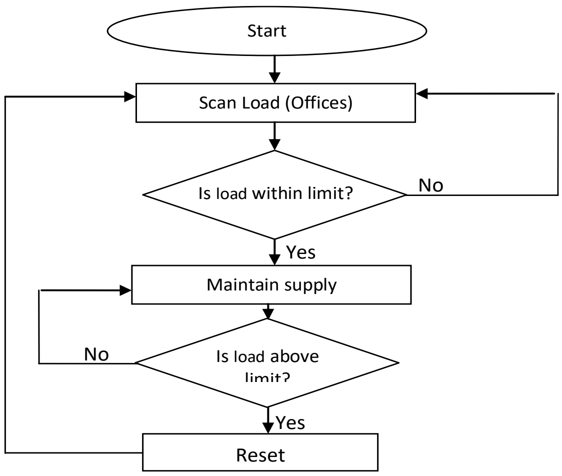

Fig. 2: Flowchart for the SEMSMA

c) SEMSMA operating principle

The SEMSMA operates by continuously sampling the current flow on each channel with the aid of current sensors into a dedicated channel buffer at a precise selected sampling rate of 500 Nanoseconds. Subsequently after the sampling, a square algorithm is run to take the squares of each samples and an average taken on each of the channels used to work out the root mean square (RMS) using square-root algorithm. While the current sensor samples the current, the output voltage is also sampled for use in implementing the power consumption algorithm. All of these take place in the ardiuno uno microcontroller (the main processing unit) which is responsible for the execution of the SEMSMA algorithms. At the end of all computations, the results representing the power consumption of each office are displayed on the LCD which is then compared against the maximum power (threshold) allocated to the office. If the power consumed exceeds the allocated value, the relay(s) dedicated to the affected channel(s) would be deactivated thereby cutting off power to the load(s) in the affected room(s) or office(s). The maximum power allocated to each office or channel is sent and received from the remote computer GUI software via the **NRF24L01** which is a ZigBee enabled module with a by-directional communication.

ISSN No:-2456-2165

d) Prototyping of the SEMSMA:

The designed system was built physically by integrating all the hardware and software components of the subsystems. The photos of the prototype are shown in figure 3.

Fig. 3: Photos of the SEMSMA prototype

IV. RESULTS AND DISCUSSION

A. Results

a) SEMSMA GUI Display:

The SEMSMA responses to power consumption in the offices were evaluated through experimentation with the system prototype built. Whenever any of the offices exceeds the preset threshold, the system trips or cuts off power supply to that office. Power is restored to the office only when the control unit is notified for reconnection. Figures 4, 5 and 6 show the GUI display on the remote computer when all the offices are switched OFF, when HOD's office is switched ON with the two other offices switched OFF and when all the offices are switched ON. Note that RED indicator represents OFF status while GREEN indicator represents ON status.

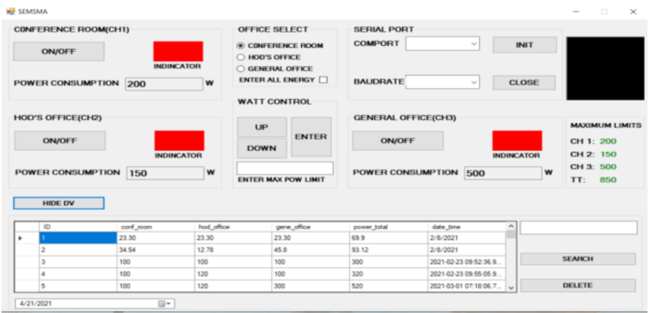

Fig. 4: GUI showing all offices switched off

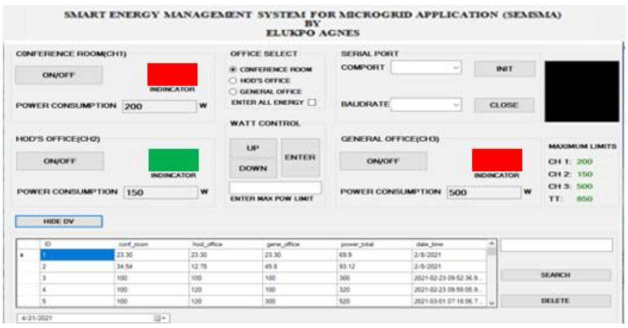

Fig. 5: HOD's office ON while Conference room and Secretary's (general office) OFF

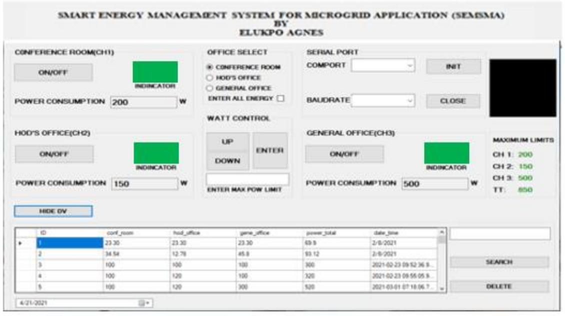

Fig. 6: Computer GUI when all offices are ON

b) Evaluation of Monitoring and Control Functions:

The proto typed system was subjected to test with the power threshold for each of the offices set as follows: HOD's office = 1000 W; Secretary's office (general office) = 600 W and Conference room = 400 W. Keeping the supply voltage constant at 230V, the loads for each of the offices were gradually increased and the current and power measurements were recorded accordingly. The results for each of the offices are shown in Tables 2, 3 and 4 while the corresponding graphs are shown in figures 7, 8 and 9.

P (W)	I x 10^{-2} (A)	P (W)	I x 10^{-2} (A)	P (W)	I x 10^{-2} (A)	P (W)	I x 10^{-2} (A)
50	21.74	480	208.70	530	230.43	800	347.83
100	43.48	300	130.43	560	243.48	820	356.52
10	4.35	320	139.13	580	252.17	840	365.22
180	78.26	340	147.83	600	260.87	860	373.91
100	43.48	360	156.52	620	269.57	880	382.61
120	52.17	380	165.21	640	278.26	900	391.30
140	60.87	400	173.91	660	286.96	90	39.13
160	69.57	420	182.61	680	295.65	540	234.78
180	78.26	440	191.30	700	304.35	960	417.39
150	65.22	460	200	720	313.04	980	426.09
220	95.65	480	208.70	740	321.74	1000	434.78
250	108.70	500	217.39	760	330.43	0	0
20	8.70	520	226.08	780	339.13		

Table 2: System results for load variation for HOD's office

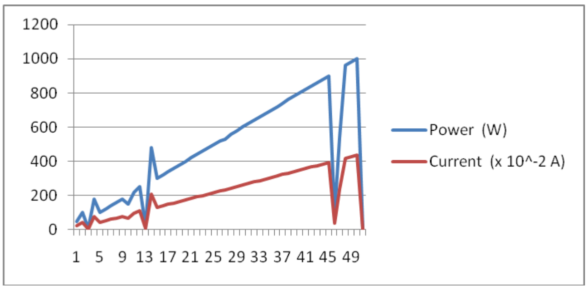

Fig. 7: Load variation and response for HOD's Office (P_{max} = 1000W)

P (W)	I x 10^{-2} (A)	P (W)	I x 10^{-2} (A)	P (W)	I x 10^{-2} (A)	P (W)	I x 10^{-2} (A)
50	21.74	220	95.65	420	182.61	460	200
100	43.48	250	108.70	440	191.30	480	208.70
10	4.35	20	8.70	460	200	500	217.39
180	78.26	480	208.70	480	208.70	520	226.09
100	43.48	300	130.43	500	217.39	530	230.43
120	52.17	320	139.13	520	226.09	560	243.48
140	60.867	340	147.82	380	165.22	580	252.17
160	69.57	360	156.52	400	173.91	600	260.87
180	78.26	380	165.22	420	182.61	0	0
150	65.22	400	173.91	440	191.30	0	0

Table 3: Load variation and response for General (Secretary's) Office

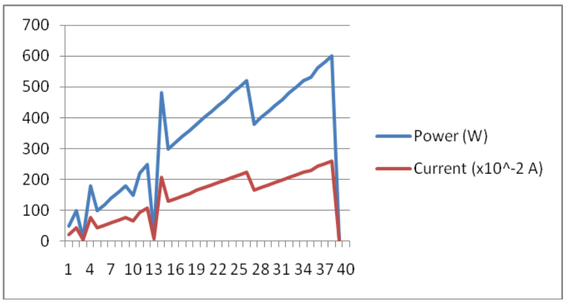

Fig. 8: Load variation and response for General (Secretary's) Office (P_{max} = 600W)

P (W)	I x 10^{-2} (A)	P (W)	I x 10^{-2} (A)	P (W)	I x 10^{-2} (A)
50	21.74	160	69.57	300	130.43
100	43.48	180	78.26	320	139.13
10	4.35	150	65.22	340	147.83
180	78.26	220	95.65	360	156.52
100	43.48	250	108.70	380	165.22
120	52.17	200	86.96	400	173.91
140	60.87	280	121.74	0	0

Table 4: Load variation and response for conference room

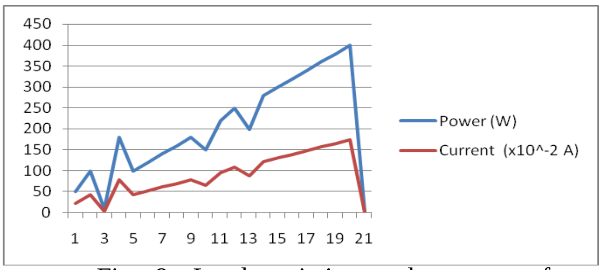

Fig. 9: Load variation and response for conference room (P_{max} = 400W)

B. *Discussion*

With the applied voltage kept constant at 230V while the loads in the offices were varied, it can be seen from figures 7, 8 and 9 that power supply to the offices were automatically switched off for each of the offices at the following current values: **4.348 A** for HOD's office, **2.609 A** for secretary's office, and **1.739 A** for conference room, as displayed on the system's LCD. Similar results were obtained on the remote computer as viewed from the GUI. These current values imply that power cut off from the three offices occurred at **999.6 W**, **599.76 W** and **399.84 W** respectively. These figures showed that the system performed very well with an accuracy level of **99.96%.**

V. CONCLUSION

A smart energy management system for microgrid applications (SEMSMA) was designed and implemented. The results showed that the system can be used to accurately monitor and control power consumption in a building or an office. The real-time data logging feature provided in the remote GUI of the system can provide adequate information for optimal control of the user's energy consumption/bills in both short and long term scenarios. This SEMSMA can find applications in homes, offices, hotels and various organisations where high energy bills contribute to huge operating costs.

REFERENCES

[1.] S.O. Oyedepo. Energy and sustainable development in Nigeria: the way forward, *Energy*, Vol. 2, Issue 15, 2012. http://www.energsustainsoc.com/content/2/1/15
[2.] https://www.ovoenergy.com/guides/energy-sources/renewable-energy-types
[3.] Y. Agarwal, T. Weng and R.K. Gupta. Understanding the Role of Buildings In a Smart Microgrid. *Design, Automation & Test in Europe Conference & Exhibition*, pp1- 6, 2011. https://www.researchgate.net/publication/224235947_Understanding_the_role_of_buildings_in_a_smart_microgrid.
[4.] A. A. Al-Ali. Smart Home Renewable Energy Management System. *Energy Procedia Elsevier,* , 12, 120-126. 2011.
[5.] M. Y. Mehrizi-Sani. Distributed control techniques in microgrids. *IEEE Transactions on Smart Grid* , 2901-2909. 2014.
[6.] S. Y. S Aman., & V. K. Prasanna.. *Energy Management System:" State of the art and emerging Trends"*. IEEE Publishers. 2013.
[7.] F. Baig, A. Mahmood, N. Javaid, S. Razzaq, N. Khan, & Z. Saleem. Smart Home Energy Management System for Monitoring and Scheduling of Home Appliances Using Zigbee. *Journal of Basic and Applied Scientific Research* , 880-891. 2013.
[8.] M. Tasdighi, H. Ghasemi, & A. Rahimi-Kian. Residential Microgrid Scheduling Based on Smart Meters Data and Temperature Dependent Thermal Load Modeling. *IEEE Transactions on Smart Grid* , *5*, 349–357, 2014.

[9.] A. Barbato, A. Capone, G. Carello, M. Delfanti, M. Merlo, & A. Zaminga. House energy demand optimization in single and multi-user scenarios. *IEEE International Conference on Smart Grid Communications (SmartGridComm)* , 345–350, 2011.
[10.] M. Parvizimosaed, F. Farmani, & A. Anvari-Moghaddam. Optimal energy management of a micro-grid with renewable energy resources and demand response. *Journal of Renewable and Sustainable Energy* , 5, 2013.