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Developing an Automated Inverter for Efficient Energy Usage Based on Internet of Things Technology

Olawale Olaniyi Emmanuel AJIBOLA[1], Mosopeoluwa OGUNDIPE[2], Kasiopo David KURE[3], Hope UWA[4], Sheriff SANNI[5], Opeyemi Oladayo AKINTELURE[6] and Peter ODINE[7]

[1,2,3,4,5,6,7] *Department of Systems Engineering, University of Lagos, Akoka, Yaba, Lagos, Nigeria*

[1]oajibola@unilag.edu.ng / [2]sopeogun@gmail.com / [3]krkasi@yahoo.com / [4]uwahope007@gmail.com / [5]s.sanni@ymail.com / [6]mrakintelureopeyemi@gmail.com / [7]odinepeter@yahoo.com

Corresponding Author: oajibola@unilag.edu.ng

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Abstract: *This paper presents a method of conserving energy as a precursor for efficient monitoring of usage of electricity based on the concept of the Internet of Things (IOT). The prototype was deployed on a 5kVA inverter that derived its energy from a solar power system. This was achieved through the use of an Arduino Uno microcontroller which served the dual purpose of monitoring and regulating supply of power from the solar energy system over a Wi-Fi network using an android application. The outcome of the work showed that the IOTs technology is an excellent tool for control and monitoring of energy consumption in any setting. The result showed that within four hours of unguarded usage of energy, the system exhausted the charge stored in the battery. The device will enable user put the reserved energy to efficient usage by measuring and controlling energy dissipation through the android application in real time.*

Keywords: Energy conservation, electricity usage monitoring, solar power system, internet of things, efficient usage.

1. INTRODUCTION

The quest for affordable and reliable energy is one which is crucial to global development and stability, with renewable energy at its fore. Renewable energy sources are gradually replacing the traditional means of energy generation [1, 2]. The importance of energy in today's world economies cannot be overemphasized, especially in emerging economies like that of Nigeria. It is a major driver of holistic development in any nation of the world. Adequate access to energy is crucial for the social wellbeing and economic transformation of any State [3]. Adequate supply of electricity, for instance, may translate to truncation of poverty, boosting productivity among women, and accelerating education and health outcomes [4]. In Nigeria, it is estimated that only about 50.6% of the population have access to electricity. This deficiency has over the years become a herculean task to surmount. The Federal Government's Vision 20:2020 which aimed at placing Nigeria among the 20 biggest economies of the world by the year 2020 was a huge failure due to inadequacy of power supply [1].

Most African countries have potentials to generate the energy requirements for their states by harnessing the potential in solar energy, and Nigeria is not left out in this quest. Energy abounds in Nigeria, since any substance that consumes energy must give out energy. For instance, [5] submitted that Nigeria's crude oil and natural gas reserves were estimated at 35 billion barrels and 185 trillion cubic feet, respectively. Estimated at 2.75 billion metric tons, coal reserves in Enugu, has the potential of reducing the energy problem substantially [6, 7]. However, a more viable alternative to power generation that exists within the natural realm in the country is the hydropower resources, namely the Kanji and Shiroro dams in Niger State to mention but few. The abundant sunshine, the enormous wind resources and the seemingly inexhaustible hills of biomass all contribute a huge energy base which could support Nigeria's economy for decades [5, 8]. However, it is not clear if the problem of inadequate supply of electricity in Nigeria is limited to those of generation and transmission of electricity. In this paper, we opted for solar energy as renewable energy source because it is cheaper to harness than other modes of energy, and this can be achieved by individuals for a relatively affordable one-time cost [5, 9, 10]. Figure 1 is an affirmation that Africa is a solar rich continent and it would be wise to harness the sun's surplus energy for the betterment of all and sundry.

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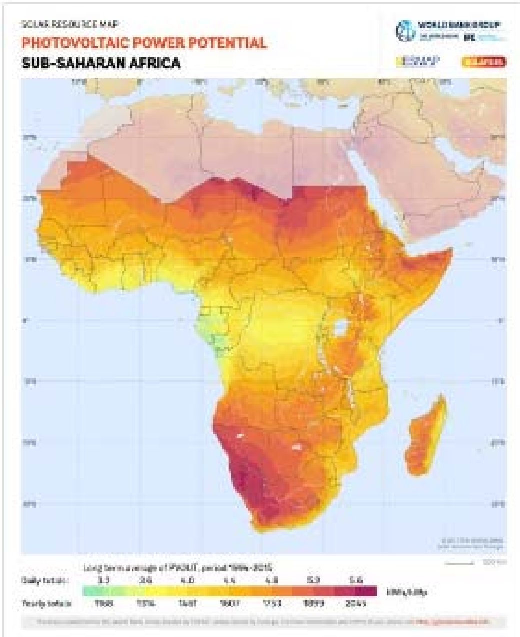

Source: Global Solar Atlas

Figure 1: Photovoltaic power potential for Sub-Saharan Africa

In this work, the issues of energy conservation and efficient deployment of energy were considered. And the focus of the study is to construct a user friendly 5 kVA inverter with IOTs facilities embedded into it to facilitate the monitoring of usage and control of its switching subsystem as a conservative measure to ensure conservation and efficiency in usage of electricity in a household. According to literature, the most viable method to achieve such functionalities in a hardware system is the application of the IOTs. Most research efforts in this area have been focused on the applications of IOTs in the area of smart grid, which is essentially a mode of electricity usage control and monitoring for power distribution centres [11]. Smart grid generally refers to highly integrated power based grid having the capability to distinguish between different types of sources of energy such as wind energy, solar energy, hydropower etc. In the popular method for smart grid application, a microcontroller sends wireless data between the user and power utility through wireless modules for proper monitoring of electricity usage [9, 12]. We have studied the concept and tailored it to suit the needs of everyday electricity users by creating a system for individuals to monitor electricity consumption in real time, over the internet.

2. MATERIALS AND METHODS

The materials used in the study include: 6 Nos. 130W photovoltaic modules, a charge controller, 4 Nos. 12V, 100Ah deep cycle batteries, an analog to digital converter, a relay module, a Raspberry pi, a wired Ethernet connection, 20k resistor, 100k resistor, ACS 712 current sensor, Arduino uno, Arduino Ethernet Shield, Wireless router, Wires, an android mobile phone, 5kVA pure sine wave inverter: primary windings-gauge 16, secondary winding-gauge8, laminating sheet, sleverings (copper host), battery terminals, switches, sockets, pliers, resistors, capacitors, diodes, transistors, MOSFET, relays, IC (SG5324), connecting cables, heat sinks, fibre plates, and tapes.

The fabrication was executed in two phases: the construction of a 5kVA power inverter and the implementation of the internet of things system. Both systems were integrated to work seamlessly with the solar energy system which consists of six 130 Watts solar panels, a 24V charge controller, four 12V 100Ah batteries and 5kVA inverter that supplies an estimated 4450Wh of electricity to power a modest 3 bedroom apartment in Lagos, Nigeria, in accordance with [5]. All the components were connected as indicated in Figure 2.

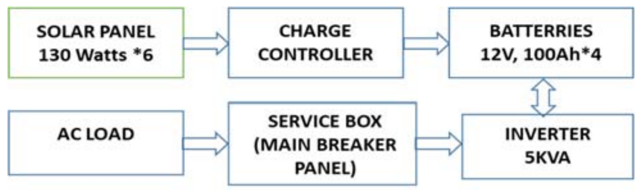

Figure 2: Block diagram for solar energy system

The internet of things system uses an Arduino Uno as a microcontroller for switching the solar energy system on/off over a Wi-Fi network and for measuring the battery percentage among other variables, in real time. The interface log-in webpage is www.thingspeak.com. This website is accessible to all stakeholders irrespective of their location globally. Our internet of things system therefore serves both as the control and monitoring system for our 5kVA solar energy system. Figure 3 is the block diagram for the connection of all the components of the internet of things module.

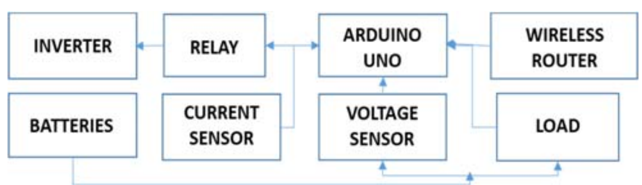

Figure 3: Block diagram for control and monitoring subsystem

The IOTs control and monitoring system employed in this work comprised of two major modules: an android application which enabled an android phone to switch the inverter on/off via a WiFi network and a webpage via which the battery's voltage, current and power status in percentage were accessed in real time

2.1 The Control Subsystem

This is the system that controls the switching of the inverter via a mobile phone application. The Arduino Uno microcontroller is the component that ultimately facilitates this function by sending messages to 6V DC relay which does the switching on/off of our 5kVA inverter. The relay was connected to the inverter switch and also to the digital pin 5 on the Arduino to enable it receive input messages from the Arduino to either switch the inverter on or off. The

Arduino sends these messages to the relay once it receives input user datagram protocol (UDP) packets from the mobile phone to which it is connected via a WiFi network. If the “inverter on” button is clicked on the mobile android app, the Arduino receives an ON packet and therefore drives the relay to switch the inverter on. The reverse occurs when the “inverter off” button is clicked. As an added safety precaution, this automatic switching system overrides the manual inverter switch.

Figure 4: The solar panel as installed

Figure 5: The control and monitoring system

Some of the mathematical equations and governing principles deployed at various stages in the study are as follows:

According to [13], the general equation for voltage divider is given by:

$$V_i = \frac{R_1}{R_1+R_2} \times V \quad (1)$$

where $V_i, i = 1,2,\cdots,6$ are the serial values of voltage, and the resistors R_1 and R_2 are two electrical impedances.

The conversion equation for Arduino voltage is defined as:

$$V_A = \left(\frac{5V_i}{1023}\right) * 6 \quad (2)$$

where 6 is the scaling factor. Suppose the battery charging rate is given by T, then:

$$T = \frac{V \times Ah}{W} \quad (3)$$

Figures 4 and 5 showed self-explanatory physical setup of the experiment with Figure 4 containing six solar panels connected in series, Figure 5 consists of the batteries (A), the solar charger (B) and the inverter (C) while Table 1 is a collation of the statistics of energy consumption for the pilot household, and Table 2 is the cost of installing a unit of the electric power supply system.

Table 1: Energy consumption for the pilot household

Load	Nos	Power (W)	Work hour per day(W)	Consumption (Wh)
Refrigerator	1	140	24	3360
Television	2	240	8	1920
Computer	1	200	10	2000
Light bulb	20	400	10	4000
Microwave	1	1000	0.5	500
Fan	5	250	10	2500
TV decoder	1	30	18	480
stereo	3	90	3	270
Total				15030

Table 2: Cost of installation of a unit of the device

Component	Rating	Quantity	Cost (Naira)
Photovoltaic cell	130W	6	120,000
Charge controller	48V	1	30,000
Battery	12V, 100Ah	4	125,000
Inverter (materials)	5KVA	Bulk	25,000
Raspberry Pi		1	10,000
Total			310,000

The essence was to ascertain the quantity of electricity required by a modest household to function optimally and to be able to make categorical statement about the energy economy of the same facility in real time. Since renewable and sustainable energy is the direction of research to ensure energy self-sufficiency globally [2], it is only imperative to experiment with a reliable source of energy preparatory to full blown green energy era.

3. RESULTS

The results of the study showed that there were tremendous improvements recorded in the monitoring and control of energy usage since it was possible to access, assess and direct the control unit of inverter from any location around the globe. One major area of application of the device is in the control of possible fire disaster that might result from faulty electrical connection by cutting-off power supply into the facility. The voltage and current from the batteries are the required variables which the Arduino reads from the batteries in order to derive the parameters required for the monitoring system. To this end, voltage divider comprising of 20k and 100k resistors were integrated into the system to reduce the input voltage read by the Arduino from the batteries from 24 volts to 4 volts based on Equation 1. This is because the Arduino is rated 5 volts, and any greater input voltage would damage it. The voltage divider was connected to Arduino input pin A2. An ACS 712 current sensor was used to read the current value of the batteries and was connected to the analog input pin A3. Because the Arduino reads all its input values as serial values (values between 0 and 1023), we had to derive some form of equations to convert from serial value to actual voltage and current values by using equations 2 and 3. The Arduino, connected via an Ethernet shield to the internet, then continuously sent the battery's voltage, current and power status in percentage (i.e. % charging or usage) to www.thingspeak.com/channels/59500.

The summary of our results as interpreted in graphical form are as presented in Figures 6 to 8. To demonstrate the effectiveness of the system, the charging system is disabled and energy drain is measured is terms of voltage, current and expended energy.

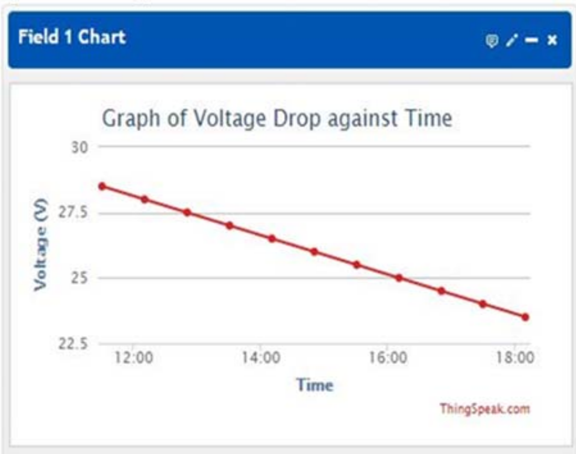

Figure 6: Rate at which voltage drops

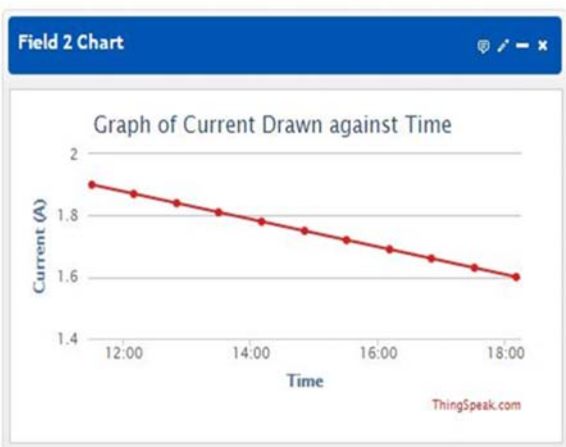

Figure 7: Rate at which current is drawn

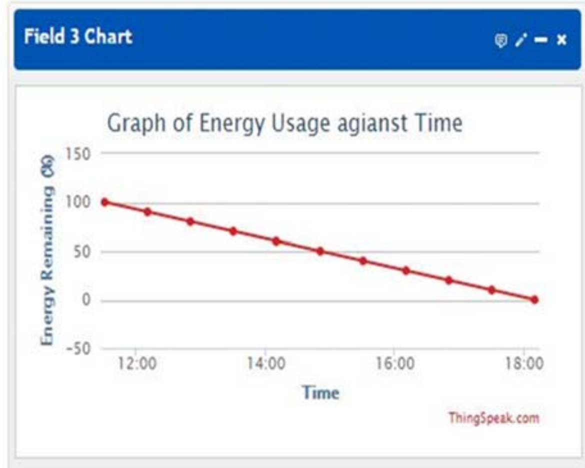

Figure 8: Graph of expended energy in percentage

Thus Figure 6 gives the graphical analysis of voltage drop with usage as monitored on the android smartphone. Figure 7 is a measure of corresponding drop in current for the same period while Figure 8 presents the graphical interpretation of the energy expended during the period under consideration.

4. DISCUSSION

This research presents a detailed method for control and monitoring a 5kVA solar power system using the Internet of Things. As verified both from experiment and the equation 3, the six 130watts solar panels takes approximately 10 hours to charge the batteries. Once the batteries were fully charged, they were placed on load till the batteries were drained to allow for proper testing. The duration given in Figures 6 to 8 was the duration it took to get complete results from the testing. In Figure 8, the rate at which potential difference of the batteries drops (in Voltage) has been exemplified. The four 12Volts, 100Ah batteries were pair-connected in series to obtain 24Volts, and both pairs were connected in parallel to give 200Ah. Readings of the potential difference were taken as the batteries voltage dropped steadily, thus giving the decreasing straight line of Figure 6.

In figure 7, the rate at which the current was drawn from batteries by the appliances has been graphed. The graph shows a steady decreasing current throughout the testing time. Figure 8 harmonizes the rate of consumption of energy in percentage. It relates with the user in a language that is easy to understand irrespective of the professional training of the user. The percentage scale is easier to interpret unlike the voltmeter reading which may not appeal to nonphysical scientists who understand safe interval within which to operate the solar system. The system was then monitored to estimate the likely time the stored energy will be exhausted given that 50% of it has been consumed. Thus enabling the user to efficiently manage the unexpended energy.

One major drawback of this technology is the fact that the control of the inverter can only be done via a Wi-Fi network, thus causing the user to incur additional expenditures on Wi-Fi connectivity. However, the internet of things technology is adaptable to other automated switching devices with control and monitoring functionalities. The overall goal of the study is to eliminate waste of energy resources by conserving available energy and ensuring that energy generated is efficiently put into use. And the outcome of this work is in agreement with the works of [14, 15]. This study is a contribution to the body of knowledge that will ultimately solve Nigeria's energy problem. If the results are adequately applied it is expected, with certitude, that within the next couple of years, solar and other forms of renewable energy will be more popular in the country and efficient energy conservation applications will be entrenched into our energy culture. And the results are in consonance with the works of [12, 16, 17].

5. CONCLUSIONS

In this work, we have developed a control and monitoring module for a 5kVA solar energy system for proper monitoring of energy usage in a three bedroom apartment located within the Genesis Estate at Aboru, Lagos, Nigeria. The system has been tested for three years since 2014 and it has been found to be reliable. The overall objective of the work is to stimulate the interest of the hoi polloi to conservation of energy for efficient deployment of available energy resources using internet of things prowess. 5KVA solar power system provides an alternative option for electricity generation and the control and monitoring system proposes a better approach to ensuring energy conservation for optimum use. If the outcome of the research effort is diligently applied, it would eliminate the predominant wasteful disposition of Nigerians with regard to electricity usage and engender a more responsible, energy conservation conscious Nigerian populace.

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