SMART CITY: DESIGN AND IMPLEMENTATION OF AN IOT BASED 3.5 KVA INVERTER MONITORING

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Abstract

Offline inverters face the challenges of limited power monitoring and management in terms of load schedule. Hence, this research aims to design and construct an Internet of Things (IoT) enabled Smart 3.5kVA, 240V, 50Hz Inverter with a low harmonic distortion, digital display, multistage charging and 4 individually controlled output of same voltage and power rating. We designed a smart 3.5kVA inverter that has four outputs with the same voltage rating that can be individually controlled via the internet. The control and monitoring are done on an interface that is accompanied by the IoT part of the inverter. The interface is a cross-platform web-page written in HTML, CSS and PHP, and hosted on a cloud server. This interface helps the users to communicate with the IoT circuit as the name (interface) implies.

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KEYWORDS:
Internet of things (IoT), Inverter, renewable energy, electricity, online control, smart city, smart devices

INTRODUCTION

According to Dameri (2013): "a smart city is a well defined geographical area, in which high technologies such as ICT, logistic, energy production, and soon, cooperate to create benefits for citizens in terms of well-being, inclusion and participation, environmental quality, intelligent development; it is governed by a well-defined pool of subjects, able to state the rules and policy for the city government and development". Characteristics and tools used in defining a smart city are shown in Figure 1.

With the depletion of fossil fuels along with its demerits and search for sustainable sources of energy, energy conservation is essential to the development of a smart city. Hence, this research explores the use of the Internet of Things (IoT) in the monitoring of inverters' power supply.

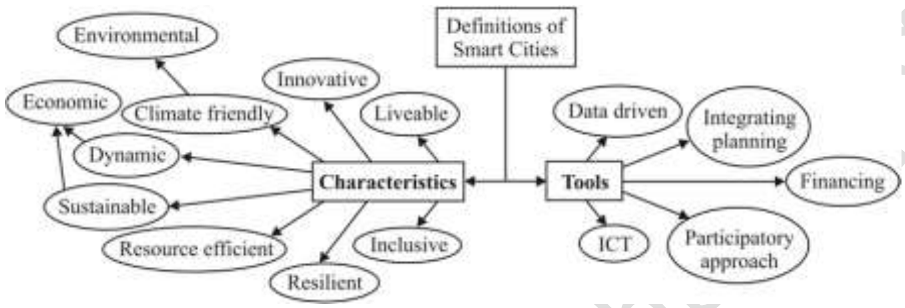

Figure 1: Characteristics and tools for defining a smart city. Sourced from Dameri (2013)

First, we describe IoT, its application and examines why we must apply IoT to inverter power utilisation. Then, we describe the use of IoT in the control and monitoring of the inverter power system.

Internet of things (IoT) is the inter-networking of physical devices (also referred to as "connected devices" and "smart devices"), buildings, and other items embedded with electronics, software, sensors, actuators, and network connectivity which enable these objects to collect and exchange data. Internet of Things (IoT) plays a vital role in connecting the surrounding environmental things to the network and makes it easy to access those things without internet from any remote location (Gubbi et al., 2013, Chen et al., 2014, Farooq et al., 2015).

And generally, people using the offline-type inverter (the inverters without IoT) are facing challenges of power monitoring and management; they do not have control on the loads that are on their inverting system when far away from the system's location. In this project, we designed a smart 3.5kVA inverter that has four outputs with the same voltage rating that can be individually controlled via the internet. The control and monitoring are done on an interface that is accompanied by the IoT part of the inverter. The interface is a cross-platform web-page written in Hypertext Markup Language (HTML), Cascading Style Sheets (CSS) and Hypertext Markup Language (PHP), and hosted on a cloud server. This interface helps the users to communicate with the IoT circuit as the name (interface) implies. Therefore, this research aims to design and construct an IoT enabled Smart 3.5kVA, 240V, 50Hz Inverter with a low harmonic distortion, digital display, multistage charging and 4 individually controlled output of same voltage and power rating.

The use of IoT approach makes the inverter controllable remotely. The status of the battery and operation can be viewed from anywhere in the world. More to it the four outputs can be switched ON or OFF over the internet, making the inverter perform better with ability to completely shut down the inverter or shut some part down, in other words, load schedule. Hence aids optimal utilization of the energy generated. It can be used as a control scheme for powering of electronics in the house, it can also help maximize the charge on the battery; switching OFF the output with the highest load capacity of gadgets not required to be in operation helps increase the duration of the operation.

Tsiropoulou et al. (2017) examined the problem of coalition formation among Machine-to-Machine (M2M) communication type devices and the resource management problem. Each M2M device is characterized by three factors: energy availability, interest and physical ties are considered the coalition formation process and the coalition-head selection. Each M2M device was associated with a holistic utility function, which represented its degree of satisfaction terms of Quality of Service (QoS) prerequisites fulfilment. Given the created coalitions among the M2M devices, a distributed power control framework was proposed towards determining each M2M device's optimal transmission power to fulfil its QoS demands. The performance of the proposed approach was evaluated through modelling and simulation and its superiority compared to other recent approaches.

Dalip and Yayilga (2016) acknowledged that the emergence and evolution of IoT offer great advantages to improve substantially the management of electricity consumption and distribution to the benefit of consumers, suppliers and grid operators. The authors, however, noted that the introduction of IoT related devices and technologies in smart grids might lead to new security and privacy challenges, which the authors reviewed while proffering solutions to the identified challenges. Though, also a review paper, the work of Liu et al. (2011) focussed on the requirement for IoT applications to the smart grid in China in terms of perception layer, network layer and application layer.

Jabbarpour et al. (2016) discussed vehicle traffic congestion management using IoT owing to the challenges associated with vehicle traffic congestion management in terms of its dynamic unpredictable nature of the vehicular environment and urban centres. The authors rightly observed that vehicle traffic congestion leads to air pollution, drivers, frustration, and increased cost. In related work, Tsaramirsis et al. (2016) presented an IoT based smart parking solution utilizing a min-max detection algorithm. Numerical results presented, verify 98% accuracy of the smart parking algorithm.

An essential aspect of the smart city is the smart home. Examples of smart home platforms are Google Home, Amazon Echo etc. Some of the applications of IoT include in transportation, with its integration, communications, control, and information processing across various transportation systems is possible and also vehicle-to-everything communication (V2X), which consists of three main components of the connected environment: vehicle to vehicle communication (V2V), vehicle to infrastructure communication (V2I) and vehicle to pedestrian communications (V2P). V2V empowers vehicles to exchange data, V2I allows them to network with the transport infrastructure (traffic signs and lights etc.) and V2P senses signals from the user's smartphones to prevent collisions, involving pedestrians (Santos et al., 2017, Tsiropoulou et al., 2017, Kim et al., 2017, Kepuska & Bohouta 2018).

In this work we focus on boosting the efficiency of the inverted power, managing the output power by separation and distribution of the output for

various kind of residential loads, which can be monitored and controlled over the internet from a remote location. This is achieved by the concept of IoT. This particular design is limited to four outputs (240V, 50Hz each), with a total power rating of 3.5 kVA. Non- Industrial Commercial (corporate) and domestic premises were also considered for practical application and implementation of the inverter. The device is designed to run efficiently on not more than 70% of the maximum power rating. It also includes an overload protection circuit. But why is an inverter an essential requirement in energy conservation of smart cities and especially in Nigeria?
The rapid increment in industrialization and urbanization has led to an increase in the demand for electricity. In Nigeria, the demand for electricity far outstrips the amount supplied, whilst the supply is epileptic in nature. There is a far difference between energy demanded and supplied. However, due to the state of power generation in Nigeria, other sources have been considered by individuals, such as; transforming kinetic energy into electrical energy (popularly known as Generator) and renewable energy sources like the solar energy, windmill etc. (Anwana & Akpan 2016, Olaniyan et al., 2018).
The energy extracted from renewable and sustainable sources are usually in direct current form and there is a need to convert such to alternating current form for use by households and offices.

METHODOLOGY

A description of inverter design and implementation are well described in the literature. Examples can be seen in Kjaer et al., 2002, Omitola et al., 2014, and Lawal & Michael 2015 for consultation by the interested reader.

IoT Inverter Design

The IoT inverter is made up of two parts, inverter and IoT Device. Figures 2 and 3 shows the block diagram of sine wave inverter and IoT inverter operation. The IoT device collects data from the inverter setup and uploads them on the webserver. The data collected includes Battery Voltage, Battery Current, Inverter status (On/Off, Charging, Idle). The power button of the inverter is also accessible to the IoT device to control the inverter's operation remotely.

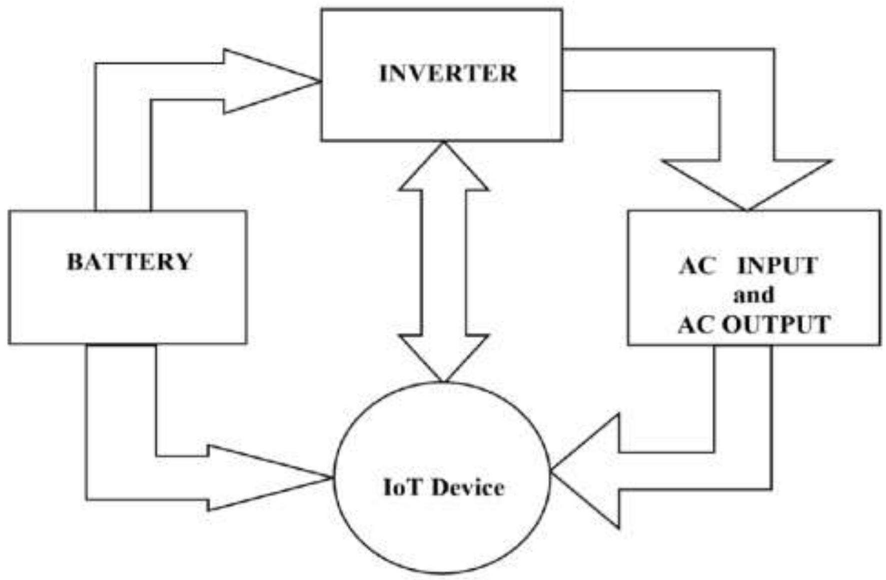

Figure 2: Block diagram

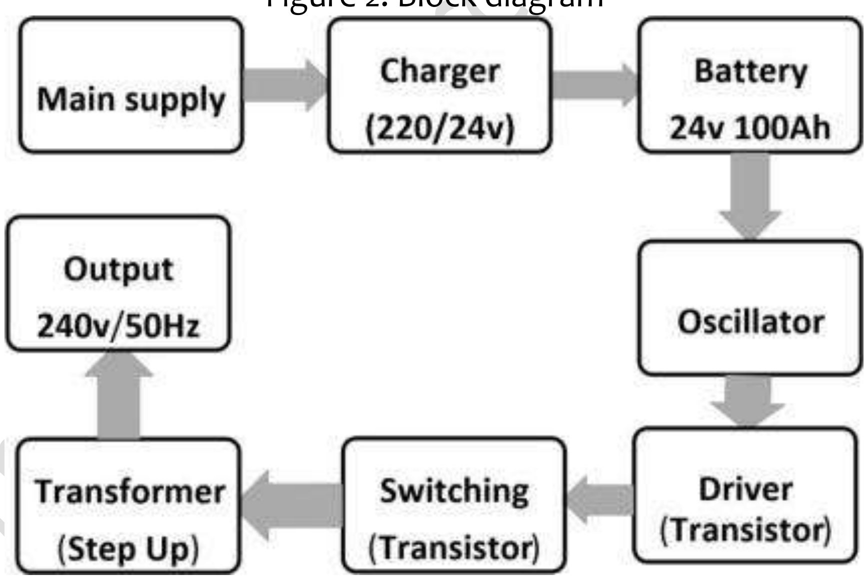

Figure 3: Schematics of a sine wave inverter

Inverter Data collection

The battery voltage, Current, Inverter Output voltage and Output voltage are the data collected by the IoT circuit. The battery voltage is measured at node 'battery sense'.

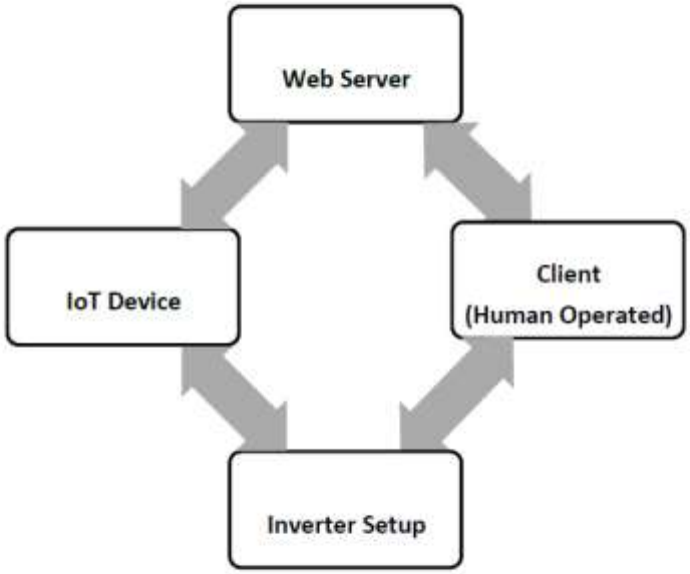

Figure 4: Block diagram of the IoT inverter operation

The circuit diagram of the smart inverter is shown in Figure 5. All battery readings are divided by 0.1304 (resistances ratio by voltage divider law) in the software to get the actual Battery voltage because of the voltage divider that is present in the circuit. The ACS758 current sensor supplies 40mV per Ampere of current flow through it to the inverter. When 40A is flowing through the current sensor, the current sensor will supply 1.6 volts to the ADC port of the microcontroller via the node 'current sense'.

The AC output and AC output sensor are designed with P621(U1 and U11) Optocoupler. The output AC power is rectified and the current is limited to feed the optocoupler's output LED. The output transistor in the optocoupler is configured as an inverting amplifier whose output is connected to the microcontroller for reading. Two Power Sensors are used in this design, one to sense Inverter output voltage and the other to sense the output voltage.

The 2.2mA output from the optocoupler is enough to operate the output transistor amplifiers circuit as a digital switch. When power is sensed, the output of the sensor circuit is digital zero (0v) and the output is digital one (5v). The output voltage of the inverter is read at node 'AC in sense', while the output voltage of the inverter is measured at node 'AC out sense'.

Data Upload to Internet Server

Data upload to the server is achieved through the use of sim900A GSM/GPRS module. The Data is converted to a string and uploaded to the server via HTTP. The data is saved on the server and displayed to the client (human user) upon request.

Command Download from Server

The server stores the user's commands (on command / off command). The IOT device polls the command page at intervals of 30 seconds to check if there is a pending command. When a command is found, it is executed and cleared to avoid repetitions of the same command.

Control of Inverter's Switch

The inverter switch is controlled by the IoT Device by sending a digital signal to node 'inverter button' that is connected to transistor Q1 via resistor R4. A digital high signal to Q1 closes the relay contact, thereby closing the inverter switch. In the other instance, a digital low signal causes the inverter switch to be opened. This operation enables the IoT device to control the inverter setup.

Display Unit

The display circuit is made up of microchip PIC16F876A and a 20 by 4 alphanumeric liquid crystal display (LCD). The PIC16F876A reads the battery voltage and current through the in-built analogue to digital converter (ADC). The signals from the control unit (mains signal, charge signal and backup signal pins) are connected to the output pins (a charge, mains and backup signals) of the display control unit. This enables the display unit to be able to display the status of the control unit, battery and load levels on the LCD.

Control Unit

The control unit is designed with microchip PIC16F876A. The PIC16F876A is selected because it has all the necessary peripherals that are needed to control and monitor the pure sine wave inverter. The In-built analogue to digital converter (ADC) of the PIC16F876A makes it possible to read the battery, feedback, and mains voltages. The In-built pulse width modulation hardware generates two complementary sinusoidal pulse width modulation (SPWM) signals that are needed to control the H-bridge. The control circuit indicates its operations and status through the pins that are labelled as mains signal, charging signal and backup signal. The pins labelled mains relay and charge relay controls the switch over relay and charging relay respectively.

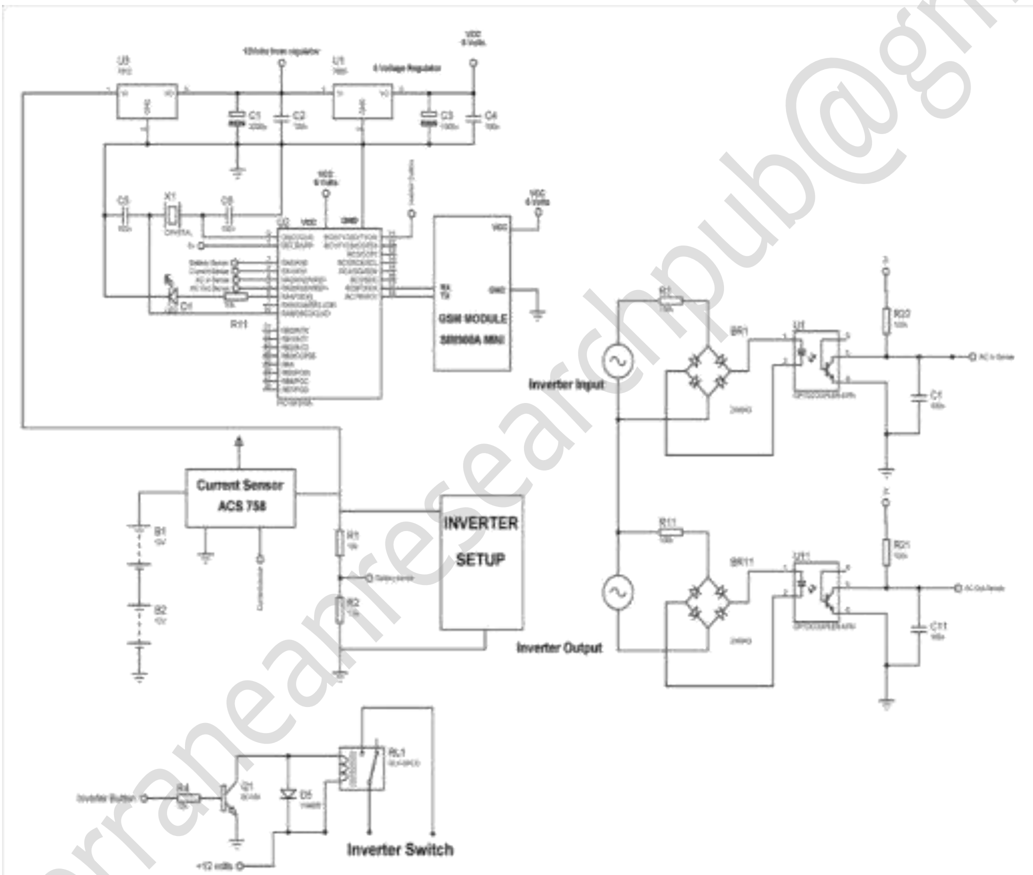

Figure 5: Circuit diagram of Smart Inverter

H-bridge Driver

The H-bridge driver circuit is a buffer circuit that transfers the signals (SPWM) that are generated by the micro-controller to the power MOSFETs. The buffer circuit is used to prevent the MOSFETs from damping or attenuating the signals that are being generated by the microcontroller.

Four MOSFETs are connected in parallel to make each switch in the h-bridge. This was done to increase the current handling capacity of the h-bridge and to prevent overheating of the power MOSFETs.

The charging voltage and current are controlled by the control unit by changing the duty cycle of the 10 kHz PWM signal that is sent to the H-bridge driver during charging. A multistage charging algorithm is implemented in the control software to ensure that the batteries are charged according to the manufacturer's specification.

Feedback

The feedback circuit is used to return a small proportion of the inverter's output voltage to the control unit. A step-down transformer is used to reduce the output voltage and to create isolation between the high voltage output of the inverter and the control circuits. The potentiometer is used to set the output voltage to 240V and the control unit ensures that the output voltage is kept at the pre-set voltage by adjusting the duty cycle of the switching SPWM signals. Figure 6 is a diagrammatic representation of a feedback circuit.

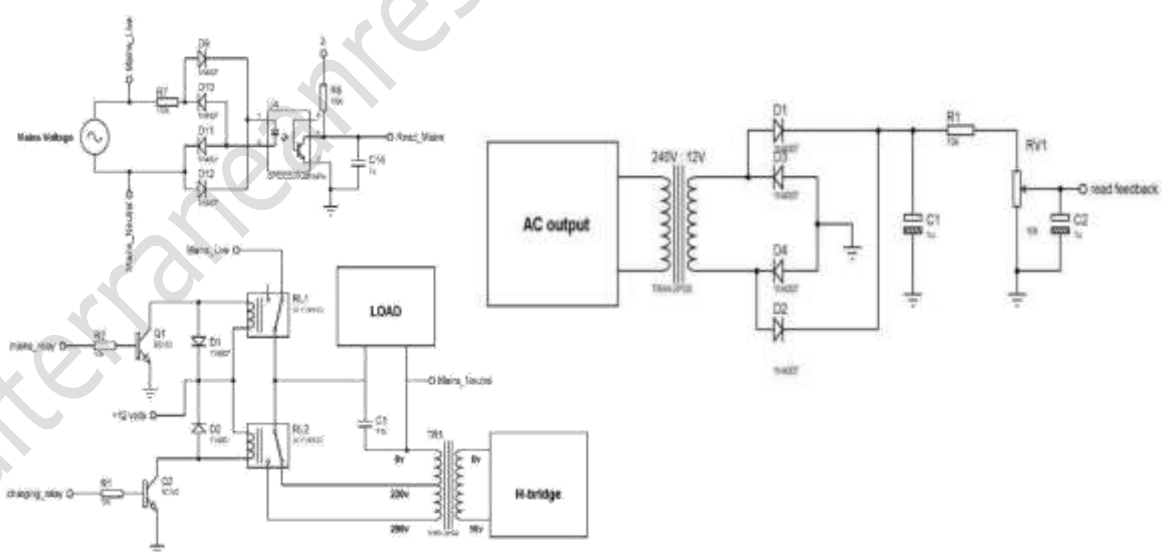

Figure 6: A feedback circuit

Switch Over

The switch over-circuit performs the function of sensing the mains voltage and switching the mains voltage over to the load. The optocoupler is used in the circuit to ensure isolation between the mains and the control unit. The optocoupler is configured as an inverter amplifier. Therefore, the presence of a low voltage at the read mains pin of the control unit indicates the presence of the mains voltage. When the mains voltage is detected by the control unit, the control unit activates the mains and charging relays by sending a digital high to the transistor switches that are connected to the relays after putting the inverter off. Activating the mains and charging relays connects the mains voltage to the load and the mains voltage is also connected to the 240V output of the transformer which is the charging input. The H-bridge rectifies the alternating current from the transformer and it supplies a direct current to the batteries that are connected to the inverter. A Switch Over Circuit is shown in Figure 7.

Control Software

The control software of the control and the display units were written and compiled with CCSC compiler program. CCSC compiler was used because it is common and has a lot of online support and sample codes. The generated firm wares were burnt into the microcontrollers with the open-source USB programmer hardware called USB PIC PROG

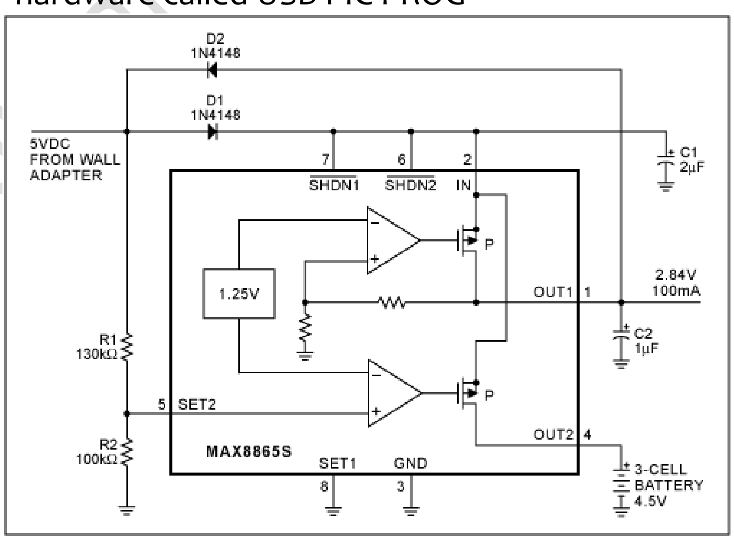

Figure 7: Switch over-circuit

Implementation and Result

Implementation

The IoT device circuit diagram was simulated on the Proteus before converted to a printed circuit board using express PCB. Figure 8 shows the IoT device circuit board. After construction, some tests were carried out on the project which includes the use of a digital multimeter to check the output characteristics of the inverter such as output voltage and current and the use of IoT device with the created server to check, monitor and control the output voltages and currents to the inverter. The data acquisition algorithm in the embedded system is implemented using CSS compiler that executes two main programs which are for battery monitoring and load monitoring systems. The CSS compiler executes the data acquisition program that retrieves inverter parameters from IED with JSON where all of the data is processed and converted according to the structured query language so that the data could be stored in a cloud database. The data acquisition that is written in C-programming is scheduled to execute in every 45 seconds.

IoT Testing

The following tests and assertions were carried out on IOT device to know its capabilities, functions and operations via the web platform. The operation of the system is such that when a command is initiated on the web platform, there is an execution period of fewer than 40 seconds within which the command is being sent to the server so that it is being obtained by the microcontroller for execution. The microcontroller with the help of the sim900 module allows for easy, remote and seamless collection of command from the webserver. Web server functions as a storage house that holds the command for execution. Upon obtaining the command in raw text format, the microcontroller's input unit process and convert it to a binary and hexadecimal file which is executable by the control unit which, sends a corresponding electrical signal for the command received. Figure 9 shows the execution period when the command has been picked up for processing and waiting for an update. After successful execution of the

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command, there is a response back to the server which indicates that the command has been successfully executed. However, after the execution period, the microcontroller at a period of 15 seconds queries the server for the outstanding command from the web platform which has been initiated by the user and the process starting again.

Figure 8: IoT device circuit Board 1 and 2

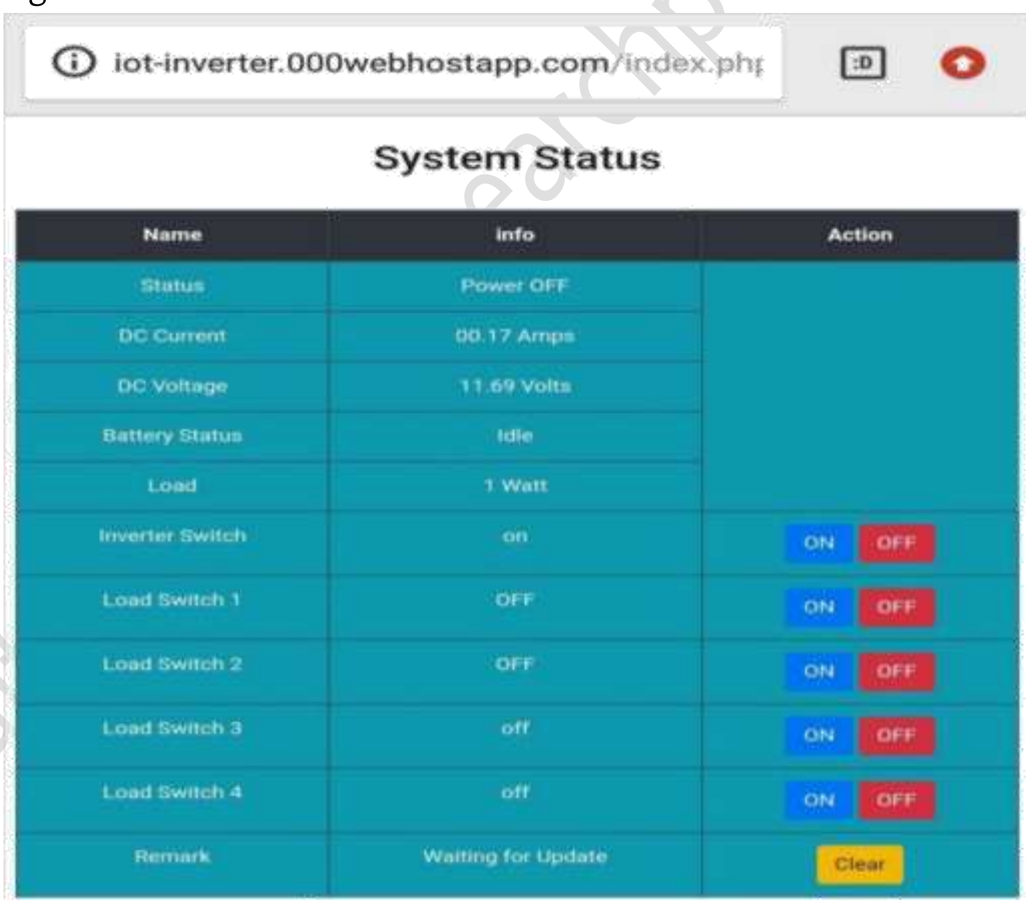

Figure 9: Waiting for update IoT web platform interface

Conclusion and Recommendation

In this research, a user-friendly web-based platform was developed and incorporated with an IoT device which allows for remote monitoring and controlling of a 3.5kVA inverter. The successful integration of IoT with an inverter suggests that it can also be deployed to homes and industries for remote monitoring and control of supply. Also, for the furtherance of this research, the security vulnerabilities can be blocked by building encryption-based system for safe transmission and reception of data.

REFERENCES

Anwana, E. O., & Akpan, B. (2016). Power sector reforms and electricity supply growth in Nigeria. *Asian Journal of Economics and Empirical Research*, *3*(1), 94-102.

Chen, S., Xu, H., Liu, D., Hu, B., & Wang, H. (2014). A vision of IoT: Applications, challenges, and opportunities with China perspective. *IEEE Internet of Things Journal*, *1*(4), 349-359.

Dalipi, F., & Yayilgan, S. Y. (2016). Security and privacy considerations for IoT application on Smart grids: Survey and research challenges. In *2016 IEEE 4th International Conference on Future Internet of Things and CloudWorkshops (FiCloudW)* (pp.63-68). EEE.

Dameri, R. P. (2013). Searching for Smart City definition: a comprehensive proposal. *International Journal of Computers & Technology*, *11*(5), 2544-2551.

Eremia, M., Toma, L., & Sanduleac, M. (2017).The smart city concept in the 21st century. *Procedia Engineering*, *181*, 12-19.

Farooq, M. U., Waseem, M., Mazhar, S., Khairi, A., & Kamal, T. (2015). A review on internet of things (IoT). *International Journal of Computer Applications*, *113*(1), 1-7.

Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future generation computer systems*, *29*(7), 1645-1660.

Jabbarpour, M. R., Nabaei, A., & Zarrabi, H. (2016). Intelligent guardrails: an IoT application for vehicle traffic congestion reduction in smart city. In *2016 IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GREENCOM) and IEEE cyberphysical And social computing (CPSCOM) and IEEE smart data (SMARTDATA)* (pp.7-13). IEEE.

Kjaer, S. B., Pedersen, J. K., & Blaabjerg, F. (2002). Power inverter topologies for photovoltaic modules-a review. In *Conference Record of the 2002 IEEE Industry Applications Conference. 37th IAS Annual Meeting* (Cat. No. 02CH37344) (Vol. 2, pp. 782-788). IEEE.

Kepuska, V., & Bohouta, G. (2018). Next-generation of virtual personal assistants (Microsoft Cortana, Apple Siri, Amazon Alexa and Google Home). In *2018 IEEE 8th Annual Computing and Communication Workshop and Conference (CCWC)* (pp. 99-103). IEEE.

Kim, C., Misra, A., Chin, K., Hughes, T., Narayanan, A., Sainath, T., & Bacchiani, M. (2017). Generation of large-scale simulated utterances in virtual rooms to train deep-neural networks for far-field speech recognition in Google Home.

Lawal, S. A., & Michael, A. O. (2015). Design, Construction and Performance Evaluation of 1KVA Pure Sine Wave Power Inverter. *International Journal of Scientific & Engineering Research*, 6(3), 1288-1303.

Liu, J., Li, X., Chen, X., Zhen, Y., & Zeng, L. (2011). Applications of Internet of Things on smart grid in China. In *13th International Conference on Advanced Communication Technology (ICACT2011)* (pp.13-17).IEEE.

Olaniyan, K., McLellan, B. C., Ogata, S., & Tezuka, T. (2018). Estimating residential electricity consumption in Nigeria to support energy transitions. *Sustainability*, *10*(5), 1440.

Omitola, O. O., Olatinwo, S. O., & Oyedare, T. R. (2014). Design and Construction of 1KW (1000VA) Power Inverter. 1-13.

Santos, J., Wauters, T., Volckaert, B., & De Turck, F. (2017, November). Resource provisioning for IoT application services in smart cities. In *2017 13th International Conference on Network and Service Management (CNSM)* (pp. 1-9). IEEE.

Tsaramirsis, G., Karamitsos, I., & Apostolopoulos, C. (2016).Smart parking: An IoT application for smart city. In 2016 3rd International

Conference on Computing for Sustainable Global Development (INDIACom) (pp.1412-1416). IEEE.

Tsiropoulou, E. E., Paruchuri, S. T., & Baras, J. S. (2017, March). Interest, energy and physical-aware coalition formation and resource allocation in smart IoT applications. In *2017 51st Annual Conference on Information Sciences and Systems (CISS)* (pp. 1-6). IEEE.