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REVIEW ON MODERN TRENDS ON SMART REMOTE MODELS FOR MONITORING PV SYSTEM

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ABSTRACT

Monitoring systems is one of the key issues in solving solar energy challenges as a large percent of its energy tracked for utilization is lost. Such systems will ensure that quality and certainty in terms of available power from this clean and almost zero maintenance free source of renewable energy is guaranteed to a large extent. This paper thus reviewed published articles on smart monitoring systems for photovoltaic (PV) cells. Part of what is monitored using Electronic Control Unit (ECU) include PV panel voltage and current, voltage levels of each batteries, cumulative electricity generated by the PV system, AC power of the system, DC power indicating load shedding either in the PV modules or within it. Previous monitoring schemes used for PV systems were also reviewed as well as the current remote monitoring system which focused majorly on Internet of Things (IoT). PV financing was also investigated as it will make it possible for the PV financiers to monitor their investment in real time and have records of PV systems operation on the web if need be. Areas of applications of monocrystalline and poly crystalline panels were also considered.

1.0 INTRODUCTION

PV systems involve utilizing solar energy for the sole aim of power generation. With records from Nigeria Meteorological Agency and Reviews of peered reviewed journal articles, it showed that the amount of solar energy in Nigeria has not been optimally utilized. Though some companies or private individuals still try to utilize this free source of energy minimally. Research has also shown that the average efficiency of solar panels is less than 30%, thus making producers/manufactures of these panels as well as researchers to find ways of improving its overall efficiency. If this is achieved to at least 60%, it will be a very successful breakthrough in solar energy technology. It should be pertinent to note that initial investment cost of setting up solar PV system is quite expensive but however the running cost which includes its maintenance is very minimal. Currently, various kinds of solar panels exist. These include monocrystalline and polycrystalline panels. Research has also shown that polycrystalline panels are more effective than monocrystalline panels in the northern part of Nigeria. This implies that monocrystalline panels find vast application in the southern part of Nigeria while the polycrystalline panels find vast applications in the north with better and improved efficiencies. Photovoltaic (PV) systems are becoming more popular and it is promoted as a solution to greenhouse gases and sustainable energy development globally. These have increased the dependence of population on alternative battery-driven sources of electrical energy such as dc-ac converters and PV systems. Hence, the Electrical/Electronic Engineering field has been inundated with studying PV system technology in order to design more efficient and insurance backed PV modules, inverters, and batteries deployment.

2.0 RELATED WORKS

Mafuta *et al* (2016) developed a system that remotely monitored the performance of small scale for roughly one year. The system was designed with the aim of increasing technical sustainability of solar projects in rural communities of Malawi. Wire Sensor Networks technology was employed in the monitoring. Wolfe (2009) proposed an open source monitoring for remote monitoring of solar power applications. The researcher utilized open source in order to reduce the cost of developing and deploying monitoring system which are usually complex and expensive. Beranek *et al* (2018) developed a system based on a special data logger known as BB box which he claims has been used to follow 65 solar plants in Czech Republic. The system aimed at measuring the main parameters and characteristics of solar plants; collecting, diagnosing and processing data. The system communicates with the inverters, electrometers, metrological equipment and additional components of photovoltaic arrays. Magzari in 2015 proposed the creation of PV monitoring systems by designing photovoltaic system, building the analog circuitry for proper voltage and current readings, and creating webserver in WAN (Wide Area Network) that can be accessed anywhere in the world through internet connectivity. Wessels (2017) cited non standardization of solar panel insurance products, prohibitively high premium, misunderstanding of PV technologies by underwriters, and lack of comprehensive data on the operation of solar panel projects are the challenges in getting affordable insurance cover. Al-Dahoud *et al* (2014) developed a remote monitoring system for a set of panels using wireless sensor network (WSN). A graphic user interface was designed and adapted to tele-monitoring panels using WSN nodes. Pandian *et al* in 2018 utilized Internet of Things (IOT) in remote monitoring and PV panels. Transmission among the photovoltaic panels and server is performed by IOT while the current and voltage were processed by microcontroller unit (MCU). The measured data were transferred to hosting server using wireless transmission. ICCI Lombard of India launched its solar panel warranty insurance that provides cover against performance degradation of solar modules that are under performance warranty (ICICI Lombard, 2017). Coverage term is for a minimum of 15 years. In Japan, HDI Global SE currently runs a solar revenue shortfall for owners and investors of PV solar project (HDI Japan, 2017). Lack of sunshine is one of the biggest risk for owners and investors of PV energy systems in Japan. In order to achieve a high-performance PV plant, the incorporation of automatic data acquisition and monitoring technology is essential (IFC, 2011). This allows the yield of the plant to be monitored and compared with calculations made from solar irradiation data to raise warnings on a daily basis if there is a shortfall. Faults can then be detected and rectified before they have an appreciable effect on production (IFC, 2011). Insurance is based on the law of large numbers which states that as the number of identically distributed, randomly generated variables increases, their sample mean (average) approaches their theoretical mean (Routledge, 2016).It can be inferred that as the number of exposure units (policyholders) increases, the probability that the actual loss per exposure unit will equal the expected loss per exposure unit is higher (Ross, 2019).

2.1 Monitoring System

Monitoring system is a key issue in deployment of engineering solutions. Monitoring system ensures that quality assurance is guaranteed.

2.2 PV panel voltage

PV panel voltage is a measure of electromotive force between the two terminals of panel as light is incident on its surface. The panels are made up of PV cells which produce open circuit voltage (OCV) of 0.5 – 0.6V at standard test condition. Voltage level produced is not constant; it depends on the temperature, intensity and frequency of light incident on the PV panels' face. A graph of power against voltage of the PV cell is shown in figure 2.1.

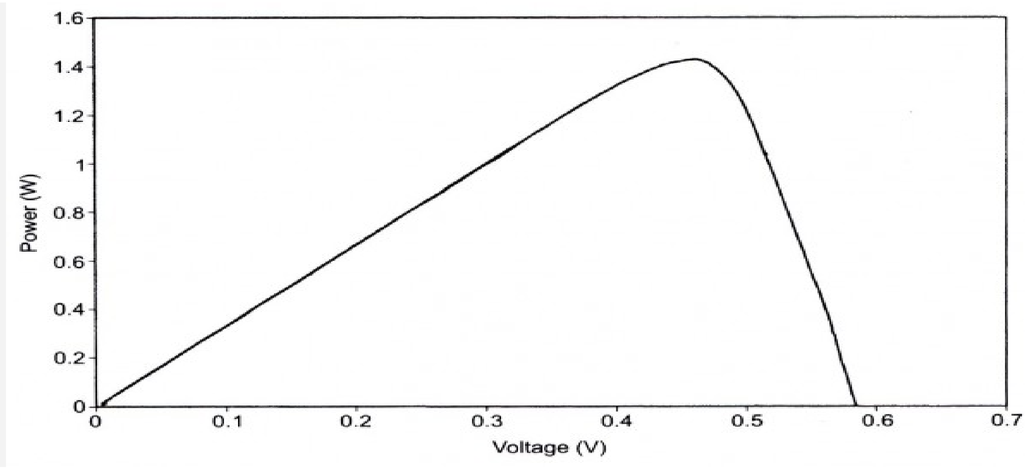

Figure 2.1: Typical power output Vs voltage of silicon PV cell (ITACA, nd).

2.3 PV Panel Current

PV panel current is the flow rate of electric charge through the panels' terminal. The current measured in amperes (A) is largely dependent on the temperature of the panel and solar irradiance. As current increases, power output increases thus charging the battery faster. A graph of current against voltage of the PV cell is shown in figure 2.2.

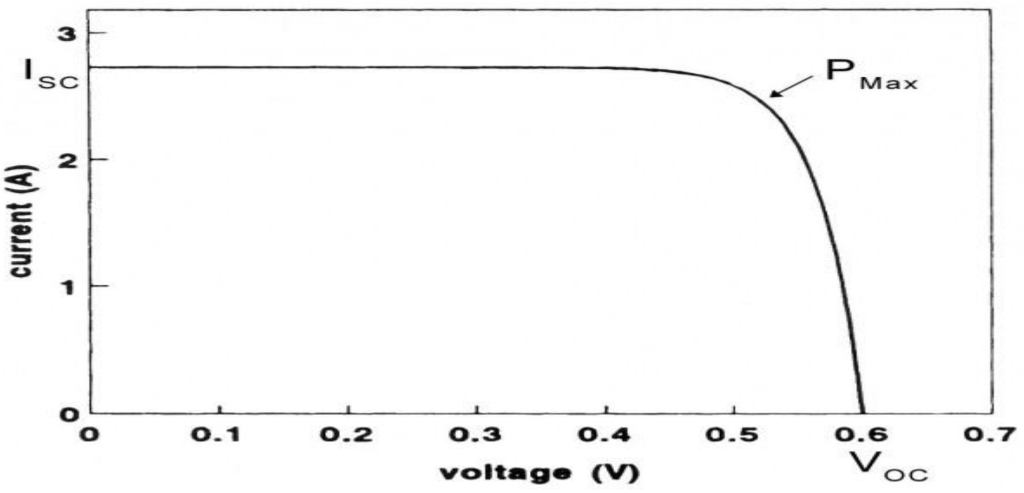

Figure 2.2: Typical I-V graph of silicon PV cell (ITACA, nd).

2.4 Inverter Load

Inverter load is part/portion/component of the electric circuit that consumes electric power. Load could be LED, TV, blender etc. In technical terms, electrical load is synonymous with current (Sharma, 2018). That is loading an inverter means drawing current from it.

Overloading an inverter for continuous and over 45 seconds can lead to ionization and burning out of the MOSFETs. The load could be resistive, inductive or capacitive.

2.5 Voltage Level of Each Battery

Voltage in a battery refers to the difference in electric potential between the positive and negative terminals of battery (Donat, 2017). Battery University (2017) defined battery as an electrochemical device that produces a voltage potential when placing metals of different affinities into an acid solution (electrolyte). The battery under consideration is rechargeable; it implies that energy in the battery drawn out during discharging can be returned by charge process. Rechargeable batteries normally have thicker electrode plate than the non-rechargeable types. Charge-discharge profile of a rechargeable is shown in Figure 2.3

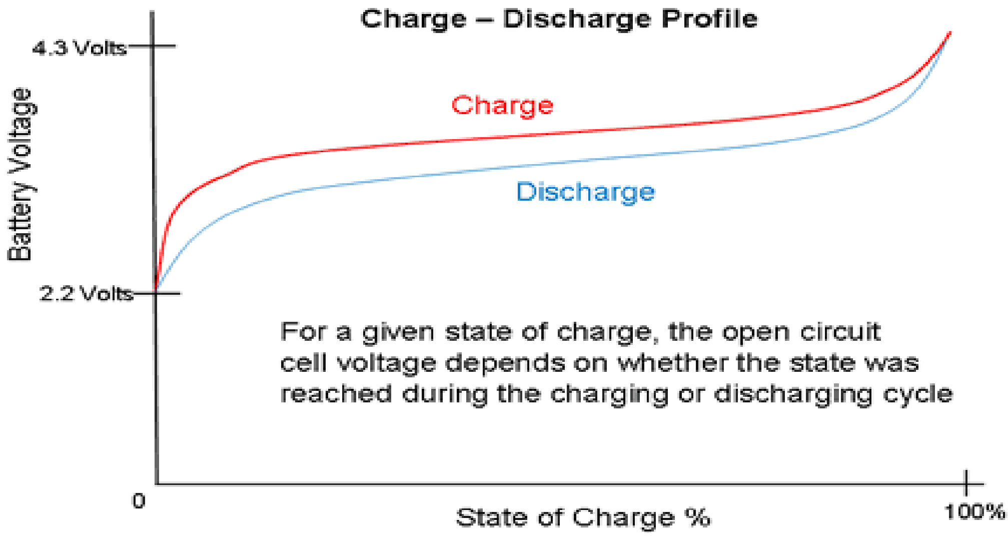

Figure 2.3: Charge-discharge profile of a rechargeable battery (2005).

2.6 PV System Financing

Cheap finance is a serious limitation to rolling out PV systems in developing countries. Interest rate is usually high and is more of short-term loan. The normally available option is outright purchase of PV system components which makes it unaffordable for low income earners and lower middle class. A promising approach to solve this challenge is the emergence of energy service companies (ESCO). These companies develop, finance, own, run and ensure the long-term viability of a deployed energy system. The end user only pays for the power consumed. ESCO firms are gradually making inroad into the Nigeria’s telecommunication industry. A typical example is the $20 million agreement signed by Pan African Towers (PAT) and Watt Renewable to deploy solar power in PAT managed/owned

BTS sites (Adams, 2019). Early results from the sites deployed are showing strong viability. With this ESCO model, there is need for comprehensive insurance that will cover the investment in case of any eventuality.

2.7 Electronic Control Unit (ECU)

An electronic control unit is an electronic device/component/chip that does the job of coordinating other devices in an electrical/mechanical/electronic system. Cars, airplane, submarines usually have an ECU. ECU of cars in Nigeria is popularly known as brain box. If an ECU is removed, the whole system will seize to work. 44 pins PIC microcontroller; PIC18 (L) F4XK22 will be the ECU for this work.

2.7.1 Features of the ECU (Microchip, 2016)

Analog Features:

- Analog-to-Digital Converter (ADC) module: - 10-bit resolution, up to 30 external channels - Auto-acquisition capability - Conversion available during Sleep - Fixed Voltage Reference (FVR) channel - Independent input multiplexing.
- Analog Comparator module: - Two rail-to-rail analog comparator, Independent input multiplexing.
- Digital-to-Analog Converter (DAC) module: - Fixed Voltage Reference (FVR) with 1.024V, 2.048V and 4.096V output levels - 5-bit rail-to-rail resistive DAC with positive and negative reference selection.
- Charge Time Measurement Unit (CTMU) module: - Supports capacitive touch sensing for touch screens and capacitive switches.

2.7.2 Special Microcontroller Features:

A. 2.3V to 5.5V Operation – PIC18FXXK22 devices • 1.8V to 3.6V Operation – PIC18LFXXK22 devices • Self-Programmable under Software Control.

B. High/Low-Voltage Detection (HLVD) module: - Programmable 16-Level - Interrupt on High/Low-Voltage Detection • Programmable Brown-out Reset (BOR): - With software enable option - Configurable shutdown in Sleep • Extended Watchdog Timer (WDT): - Programmable period from 4ms to 131s • In-Circuit Serial Programming™ (ICSP™): - Single-Supply 3V • In-Circuit Debug (ICD).

2.7.3 Peripheral Highlights: Up to 35 I/O Pins plus 1 Input-Only Pin, High-Current Sink/Source 25 mA/25 mA, Three programmable external interrupts, Four programmable interrupt-on-change, Nine programmable weak pull-ups, Programmable slew rate.

2.8 Important Parameters Measure in a PV System

Monitoring often involves data or sensor cables which are separated from the power cables, along with that of recording or transmitting devices. Monitoring equipment can be referred to as monitoring subsystem in a PV system when monitoring the performance. Measurements to collect include cumulative electricity, AC and DC power consumption.

2.8.1 Cumulative Electricity (kWh)

Cumulative electricity generated by the system can be compared to the modules that tell how much energy the system can produce during some period of time to determine whether the system is operating properly. Such measurements are useful even if they are made weekly, monthly or less frequently.

2.8.2 AC Power (kW)

Another useful parameter is the power of the system at any given time. This information can be evaluated in combination with weather measurement, to decide whether the system output is what it should be.

2.8.3 DC Power

This comprises of the DC voltage and DC current which are important characteristics. They can indicate shedding in modules or within modules in the array. The DC power coming in from the array which is the product of the DC voltage and DC current can be compared to the AC output power to give the efficiency of the inverter.

$$P = V \times I \tag{2.1}$$

$$P(W) = V(V) \times I(A) \tag{2.2}$$

DC power is rated in Watt

$$Efficiency = \frac{\text{Useful output power}}{\text{Total Power Input}} = \frac{\text{Power output}}{\text{Power Input}} \tag{2.3}$$

$$\frac{W_{out}}{W_{in}} \times 100\%$$

Efficiency is rated in Joules while AC voltage is the output utilized from the inverter that powers our devices. AC frequency is the number of cycles per seconds in an AC sine wave and rated in Hertz. In the course of this work the standard for Nigeria is 50 Hertz. Weather measurement are often recorded with PV systems data with these measurements, comparison of the PV systems voltage and current as to what it could be under the existing weather conditions.

3.0. METHODOLOGY

This section analyzed various approaches used in monitoring pv systems.

3.1 Previous Monitoring Systems

Back in the years when PV industry was less developed towards the early part of 2000, PV monitoring system were made for specific PV systems, by combining off-the-shelf sensors and monitors that were mainly sought for other applications. Measurements were stored on the data logger at regular intervals. This data were later uploaded on the computer on weekly basis or monthly or even less frequently. The computer may remain connected to the data logger or might be carried to the PV site and to be connected to the data logger for each PV data upload. One disadvantage of this was the difficulty to measure safely the high DC load data coming from PV system. The current was also difficult to measure with the accuracy needed. A good measure is required by a good design by someone who understands the PV system. The measurements were often redundant as the important measurement are already been done in the inverter. These include the DC voltage and DC current which is needed by the optimum power tracker. The inverter also needs to monitor the AC voltage and frequency set by the grid in other to turn off if either one is too high or low to the set limit. As the PV system is developed, inverters became available with digital connections. When connected to a data streaming device, the measurement from these inverters includes values that the inverter needs to measure and digitize. Diagnostic information can be available from an inverter when it is not working and, in some systems control, information can be sent to the inverter with a digital connection. The inverters digital interface to the outside world maybe an extended part of the factory or in the field. Most inverters have an LCD display in the front which also shows the inverters performance data. The digital output includes the display data and perhaps other data as well. The digital output of some inverters can be read by computer with the standard connectors and software from the inverter manufacturer. It can typically read the output from several of the manufacturer inverters at once and data from a weather monitoring station if there is one. However, it cannot receive data from another manufacturer's inverters.

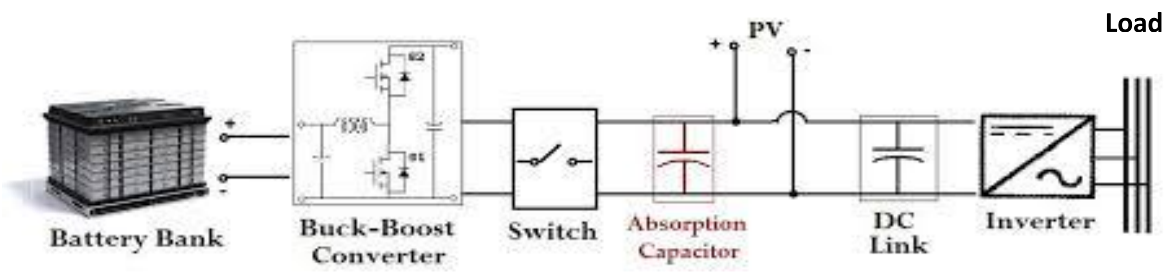

Fig. 3.1: Schematic of PV system.

3.2 Web Service

The most recent and popular type of monitoring is by web service. In this type of monitoring, data is sent from the inverter to the manufacturer's web site. The system owner can view and download data from the web site by using internet connection. The data may be password protected or may be available to the public. The web interface may be built in the inverter or a separate device. This type of monitoring requires internet access at the PV site, and at home over the home internet access using either a wired or wireless link to the home monitors router however, such access is not available in some places. Some monitoring systems can also send data over the cellphone or network using text messaging or GPRS connection. This data can be used by the manufacturer to upgrade or improve designs for promotional or business purposes. Figure 2.5 is a pictorial form of inverter independent system.

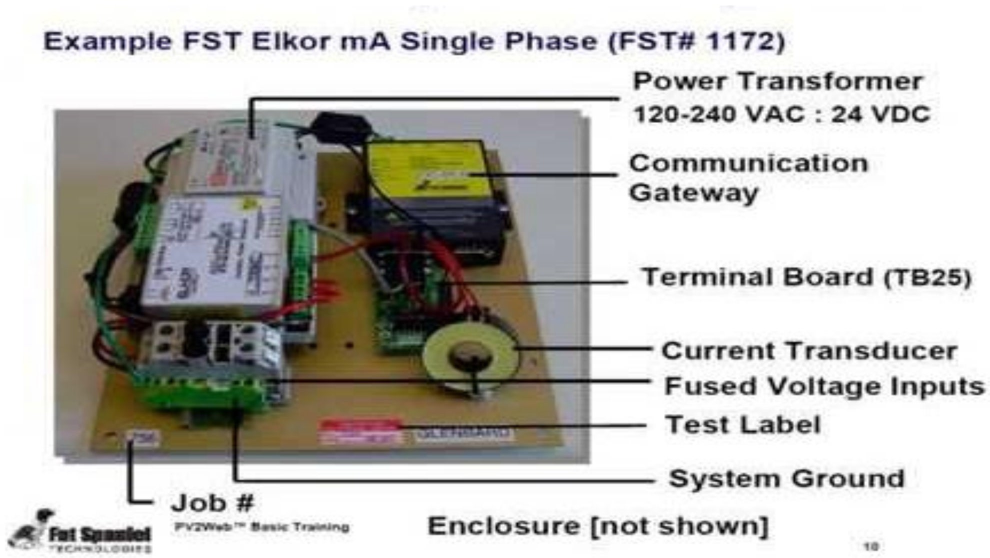

Fig. 3.2: Inverter Independent System.

3.3 Remote Monitoring Using IOT

The internet of things (IOT) method focused on inaccessible areas such as the deserts and roof tops. Complex systems were used that embedded wide area network. GPRS module and a cheap microcontroller was used to transmit processed data from the system to the internet which was easily accessed from any point. This method measured the voltage output, current output and ambient temperature. It also compared data with old databases and reference values and transmits an alarm captured either via test message or internet data. This information was in Real-time and helped in its maintenance, detection of faults, aided troubleshooting of faults and population of data and incidents.

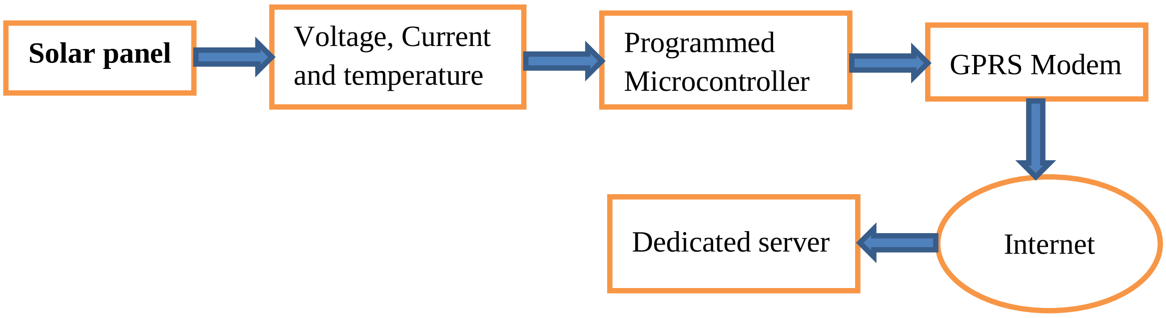

Fig 3.3: Block Diagram of Remote Monitoring using IOT method.

From the block diagram in figure 3.3, solar rays are converted to electrical energy, and this passes through the voltage and current sensors. The temperature sensor is also embedded to measure the ambient temperature of the environment. This data is further processed and transmitted with the aid of a programmed Arduino Uno, a microcontroller to the GPRS modem. Gathered information on the GPRS modem is further conveyed to a dedicated Server via the internet. IOT method can save energy and manpower and there is still need to upgrade to modern devices and sensors that are very compatible. As a way of illustration, sensors can measure AC voltages and current outputs, power consumed by load, solar irradiance and corresponding outputs on each solar panel.

4.0 CONCLUSION

Various schemes for monitoring PV systems are very important to solar energy development and advancement all over the world. This work considered various monitoring schemes and their behaviours were illustrated graphically. Plots of current and voltage for a silicon PV cell as well as charge discharge profile of a rechargeable battery PV panel voltage as investigated by other researchers were reviewed. Voltage battery levels in other to ascertain the State of Charge (SoC) as well as PV financing were investigated. Features of Electronic Control Unit

(ECU) that enables it carry out these various monitoring functions as well as the important parameters to be measured were also considered. Previous ways of monitoring PV systems were reviewed, to assist in getting an understanding on how best to improve on them and give an idea in areas that needs to be enhanced for optimum performance. The relevance of web service for remote monitoring of PV systems and internet of things (IOT) applications was considered. The components of IOT for monitoring PV systems include solar panel, measurement of voltage, current and temperature, programmable micro controller, GPRS modem, Internet and a dedicated server. Detailed workings of the functions of these various components were also stated in this work.

5.0 ACKNOWLEDGEMENT

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