Cost-effective remote energy monitoring using the ESP8266 NodeMCU

Arthur James Swart

Abstract— ***Energy monitoring is critical to ensure the sustainability of a renewable energy system. It further makes possible the introduction of energy conservation, reduction and optimization. To achieve this for an off-grid system, or for numerous research sites, requires the use of remote energy monitoring where various parameters may be visually reviewed from anywhere and anytime using an operational internet connection. Various commercial products exist to fulfil this need that may prove expensive and cumbersome to use. The purpose of this paper is to present a cost-effective remote energy monitoring system using the ESP8266 NodeMCU. The research site was the city of Cape Town that is known for its Mediterranean climate. Results indicate that a simple data logging interface circuit, a ESP8266 NodeMCU, an ADC, a 3.3 V regulator, a LED lamp and a reliable WiFi network is all that is required to monitor the energy yield of a pico-solar system along with the ambient temperature. Watt Hours per day produced over a 6-month period by a 10 W PV module is shown along with the cloud cover percentage. Average Watt hours per day for July and August was 39,3 Wh/day and for October and November it was 51,8 Wh/day. It is recommended that more of these cost-effective remote energy monitoring systems be deployed across a number of research sites to enable the collection of reliable empirical data that can be used to optimize the design of off-grid solar energy systems.***

Keywords: cloud storage; data logging; PV; renewable;

1. INTRODUCTION

"The future is green energy, sustainability, renewable energy. [1]" Arnold Schwarzenegger, an Austrian actor, reportedly uttered these words that indicate that more of humanity is focusing on sustainable renewable energy systems for the future. This is not surprising given the global concerns over carbon emissions and climate change. The scientific consensus about climate change is largely in agreement that manmade carbon emissions have contributed to an increase in the average temperature of the globe [2], that can eventually lead to serious threats to public health [3]. It is critical that more sustainable renewable energy systems be deployed around the globe in an effort to try and mitigate climate change. One aspect of such a system includes energy monitoring.

Energy monitoring may be defined as a management technique that uses information as feedback to reduce or eliminate energy wastage and / or to control the current energy consumption while optimizing the operating procedure [4]. Another definition states that energy monitoring is a technical and management function which provides the capability to monitor, record, analyze, examine, and control energy flow through systems [5]. Reasons for energy monitoring include verification of energy consumption, identifying energy wastage, avoiding maximum demand loads, increasing reliability of energy supply, verifying mathematical calculations of power generation, detecting faults, enabling effective intervention to minimize possible energy losses, for quality assurance purposes and confirming the proposed design of a sustainable PV system [6-11].

A sustainable PV system must be able to operate continuously over a specified period of time within a given environment despite changing environmental conditions. Simulation software packages are often designed to account for unknown losses and environmental changes, that includes irregular shading. However, climate change is dynamic thereby requiring more empirical data to verify current simulation results and to update the factors for unknown losses in simulation software. This requires more practical installations of renewable energy systems with energy monitoring capabilities to provide this empirical data. However, this energy monitoring can be expensive due to hardware requirements [12].

The purpose of this paper is to present a cost-effective remote energy monitoring system using the ESP8266 NodeMCU that was deployed in Cape Town, South Africa, to determine the energy output of a pico-solar system and measure the ambient temperature. One of the research objectives was to make available real-time empirical and historical data that can be accessed from anywhere and at any time using internet connectivity. The paper firstly covers some typical cost-effective systems that are currently available for remote energy monitoring, after which the practical setup and research site will be explained. Quantitative data are presented in a number of graphs followed by the conclusions.

2. REMOTE ENERGY MONITORING

Three possible solutions exist that can enable remote energy monitoring, namely:

- Digital radio;
- WiFi; and
- LTE.

Digital radio is an opportunity to broadcast data and interactive services using radio frequencies (RF), and introduces an alternative for both the government and civil society to communicate over large territories [13]. Although it has been used extensively in audio broadcasts, it finds application in the transmission of telemetry. XBee modules may be used to build such a digital radio system providing wireless end-point connectivity to devices. These modules

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use the IEEE 802.15.4 standard networking protocol with both AT (transparent) and API (Application programming interface) serial interfaces [14]. They are designed for high-throughput applications requiring low latency and predictable communication timing. They can be used to create Personal Area Networks (PAN), as they can automatically 'sync' and pass serial data back and forth between identical modules without any additional work or configuration. They are relatively easy to set up with the added advantage of error correction. The main disadvantage is its limited range of communication (typically around 1 km) due to its on-board PCB antenna.

WiFi (Wireless Fidelity) is a technology that provides high speed wireless data over a short distance based on the IEEE 802.11 standard [15]. A WiFi connection can be established using a wireless router to create hotspots in the vicinity of a wireless adaptor, device or sensor to allow multiple end-users to gain access to the internet using the frequency range of between 2.4 and 5 GHz. One key advantage of having WiFi enabled devices is that it allows for the seamless connection to Local Area Networks (and thus to the internet). Disadvantages include low range and high-power consumption. Typical outdoor ranges are less than 150 m.

LTE (Long Term Evolution) is optimized for high-speed cellular networks up to 300 Mbps over 20 MHz bandwidth in a cell radius of over several hundreds of meters [16]. It is a standard for wireless communications with a number of advantages, that include high spectral efficiency, high peak data rates, as well as flexibility in frequency and bandwidth usage. It is a step up from 3G mobile networks offering the general public an improved mobile communication experience. The main disadvantages of LTE are the power consumption and the need for data packages to access the internet. Typical ranges are limited to the size of a radio cell around a few kilometres.

Each of the three technologies listed above have their own advantages and disadvantages, making them each suitable for specific applications. In this research, a free WiFi hotspot was available for most of the time, making the WiFi option for internet connectivity the most suitable choice. A number of technologies exist that may connect to a WiFi hotspot, including:

- Raspberry Pi;
- Arduino Uno; and
- ESP8266 NodeMCU

The Raspberry Pi is a small, powerful, cheap, hackable and education-oriented computer board introduced in 2012 [17]. It is a credit-card size computer developed by the University of Cambridge’s Computer Laboratory providing general purpose input and output (GPIO) connectors for sensors and electronic equipment. It usually runs Linux in a graphical environment and costs around $50 in South Africa (see Table 1 for a summary of the three technologies). It will require an extra ADC (such as the MCP3008) for analogue measurements.

The Arduino Uno is a microcontroller board based on the ATmega328. It is a compact open-source development board where the software/hardware is extremely accessible and very adaptable, offering a variety of digital and analogue inputs/outputs, a serial interface and PWM outputs [18]. It is easy to modify and update the software program as it connects to a PC via USB, communicating via the standard serial protocol. It is relatively inexpensive (about $8,75 in South Africa) with the required software freely available. It also has a large online community with a lot of references and examples. It will require an extra WiFi shield for RF communication.

The ESP8266 NodeMCU is a system on chip (SOC) and WiFi network that can carry software applications [19]. It is really a development board with a number of advantages. These include being a low-cost module based on the IEEE 802.11 b/g/n standards, reducing the hardware and space requirements of a system and having an integrated low power 32-bit microcontroller unit with an integrated 10-bit ADC and TCP/IP protocol stack. It can be purchased in South Africa for around $7,10. It will require an extra ADC to increase the number of analogue measurements (only one analogue input exists on this specific module).

Table 1: Summary of technologies for WiFi usage

	Price in South Africa	Number of usable digital GPIO	Number of analog inputs	Extra requirements
Raspberry Pi Model 3	$50	28	None	ADC ($5,38) to enable analogue measurements
Arduino Uno R3	$8,75	14	6	WiFi shield ($7,24) to enable communications
ESP8266 NodeMCU	$7,10	11	1	ADC ($5,38) to increase analogue measurements

The ESP8266 NodeMCU was chosen for this research as it is the cheapest option ($7,10 + $5,38 = $12,48) with the lowest power consumption and space requirements. This is in line with the title of the paper that focuses on a cost-effective remote energy monitoring system. This system was deployed in South Africa to remotely determine the energy output of a pico-solar system and measure the ambient temperature.

3. PRACTICAL SETUP AND RESEARCH SITE

The research site was the city of Cape Town in South Africa. It is known for its Mediterranean climate, with warm summers (November through February) averaging a maximum temperature of 26 °C, and cool winters (May through August) with an average minimum temperature of 7 °C. Very little rain falls between late spring (September and October) and early autumn (March and April), while the majority of the annual rainfall occurs in the middle of winter (June) [20]. Figure 1 highlights the climate conditions of

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South Africa, where the Mediterranean climate is visible at the bottom left. The coordinates of the research site are also shown, as the latitude value was used for the tilt angle of a 10 W polycrystalline PV module. The orientation angle was set to 0° North, as the system is installed in the Southern Hemisphere.

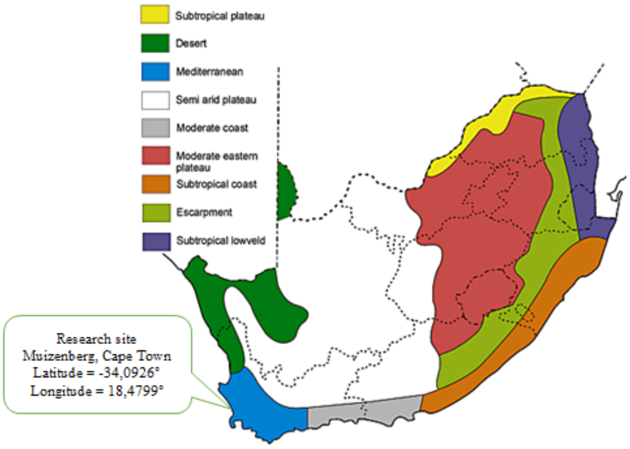

Figure 1: Climate features [21] of South Africa with the research site coordinates

Figure 2 shows the prototype of the energy monitoring system built on a breadboard. On the far bottom right is the ESP8266 NodeMCU that is connected to a MCP3008 ADC to increase the number of analogue measurements. Two analogue measurements are required, one being for the output voltage and one being for the output current of the PV module. Simply multiplying these two analogue measurements in the software program loaded onto the ESP8266 NodeMCU results in the energy yield, or output power, of the PV power. Calibration needs to be done as the voltage and current measurements are derived from a data logging interface circuit. This ensures that the input voltage to the ADC is always less than 3.3 V, being its operating voltage that is derived from a 3.3 V regulator.

Calibration is performed by measuring the various voltages and correlating it to the measurements shown on the cloud server. Calibration values are them amended in the software program and uploaded to the ESP8266 NodeMCU. A similar calibration process was described by Swart and Hertzog to ensure accuracy of subsequent results [22]. Current sensing is accomplished by measuring the voltage across a precision high power low value resistor (10 Ohm 10 Watt 1%) and dividing it then by the resistor's value. A similar process has been used in previous research on PV modules [23]. This process is included in the calibration factor. Voltage sensing is accomplished using a precision voltage divider network (100 k • and 10 k • each with a 1% tolerance). The load resistor is a 4 W LED lamp, that negates the need for a solar charger or battery. This type of load has been verified in previous research [24, 25]. The block diagram of the prototype system (which has a total cost of approximately $20) is presented in Figure 3.

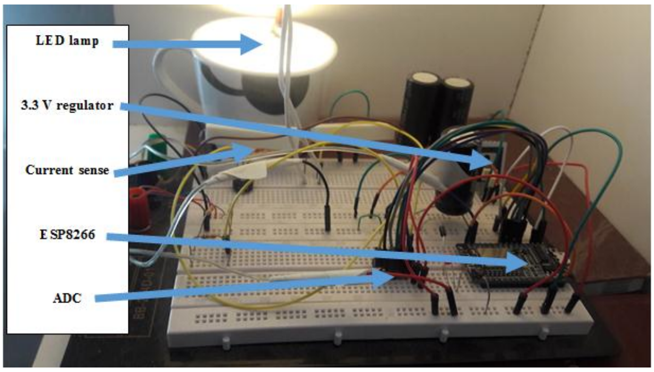

Figure 2: Image of the prototype circuit on breadboard showing the LED lamp that is placed in a cup

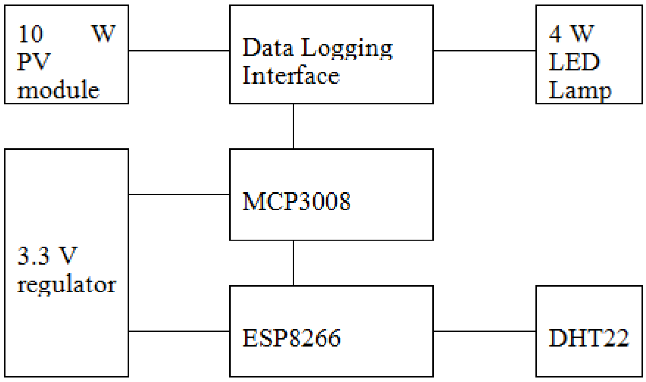

Figure 3: Block diagram of the practical setup

The block diagram constitutes four specific sections, namely the PV system section (PV module and LED lamp), the measurement and processing section (data logging interface, MCP3008 ADC and DHT22 temperature sensor), the communication section (the ESP8266 NodeMCU) and the power supply (3.3 V regulator). The ESP8266 NodeMCU has an onboard low-drop out (LDO) 3.3 V regulator that can comfortable provide 600 mA [26]. However, it was decided to use a dedicated external 3.3 V regulator to power additional ADC's (increasing the number of analogue measurements) and to reduce the power consumption and heating onboard the ESP8266 NodeMCU. The regulator is currently connected to a 5 V power supply unit which will eventually be replaced by a 12 V battery that is charged by the PV module to ensure sustainability.

The ambient temperature is measured using a DHT22 temperature and humidity sensor. This sensor operates off 3.3 V and provides a digital output with an accuracy of ±0.5 °C. It has a sampling rate of 0.5 Hz with a range of -40 to 80 °C. The DHT22 has been used with the ESP8266 for low-cost ambient monitoring [27].

The software program was written using the LUA programming language and compiled using the ARDUINO IDE environment. LUA is an interpreted language, were changes to the script are immediately active at the subsequent database operation, hence the development cycles are kept short and painless [28]. It is well-known as an embedded, lightweight, fast and powerful scripting language. LUA is especially suited to building prototypes, which was required for this research.

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The SSID of the WiFi network must be included in the program along with the network password and calibration factors. Data is uploaded to a cloud server (called Kineta) every 10 seconds, and can be accessed from anywhere or anytime using a working internet connection. The system can also be programmed to send scheduled reports or alarm notifications to an email address for a set of predefined criteria.

4. RESEARCH METHODOLOGY

An experimental research design is used where quantitative data is collected using a remote energy monitoring system built around the ESP8266 NodeMCU. The prototype system was installed in October 2017, after which faultfinding and calibration was completed. Severe load shedding in Cape Town resulted in a number of months being lost early in 2018, due to the downtime of the WiFi hotspot. Load shedding is seen as a sacrifice, where power from one area (or neighborhood) is turned-off (or sacrificed) to keep the power in another area on [29]. It usually follows a predefined schedule that is available on the internet, where up to two hours of load shedding per day per neighborhood can be realized.

Reliable data was sourced between 25 June and 1 December 2018, representing a time period of 5 months. The reliability of the data was ascertained using data from two other websites, namely Accuweather (daily ambient temperatures) and World Weather Online (monthly cloud cover percentages). Accuweather can provide day to day historical weather data while World Weather Online can provides averaged monthly data. Voltage and current measurements were obtained every 10 seconds along with the ambient temperature. The data was downloaded from the Kineta website as a TEXT document and analyzed in MS EXCEL.

5. RESULTS AND DISCUSSIONS

Figure 4 represents the output power of the 10 W PV module measured over a period of 5 months. This data was downloaded from the Kineta website (cloud server) and analyzed in MS EXCEL. A data break occurred between 3 and 18 September 2018 which was influenced by load shedding schedules. The Watt hours per day is shown on the left hand primary x-axis and the Percentage Cloud Cover is shown on the right hand secondary y-axis. The rapid fluctuations in output power (for example, between 15 July and 29 August) is primarily due to cloud cover, which was between 34 and 42% (cloud cover percentages were downloaded from worldweatheronline.com [30]. A less rapid fluctuation is visible between 3 and 11 October and between 18 and 27 October 2018, which is primarily due to less cloud cover percentage (around 20% for the months of October and November). The dotted line (2nd order Polynomial) indicates that the output power increased between June and November, which suggests that the remote monitoring system is functioning correctly as the global solar irradiation curve dips in winter (June) and peaks in summer (December). This is further corroborated by the ambient temperature measurements shown in Figure 5.

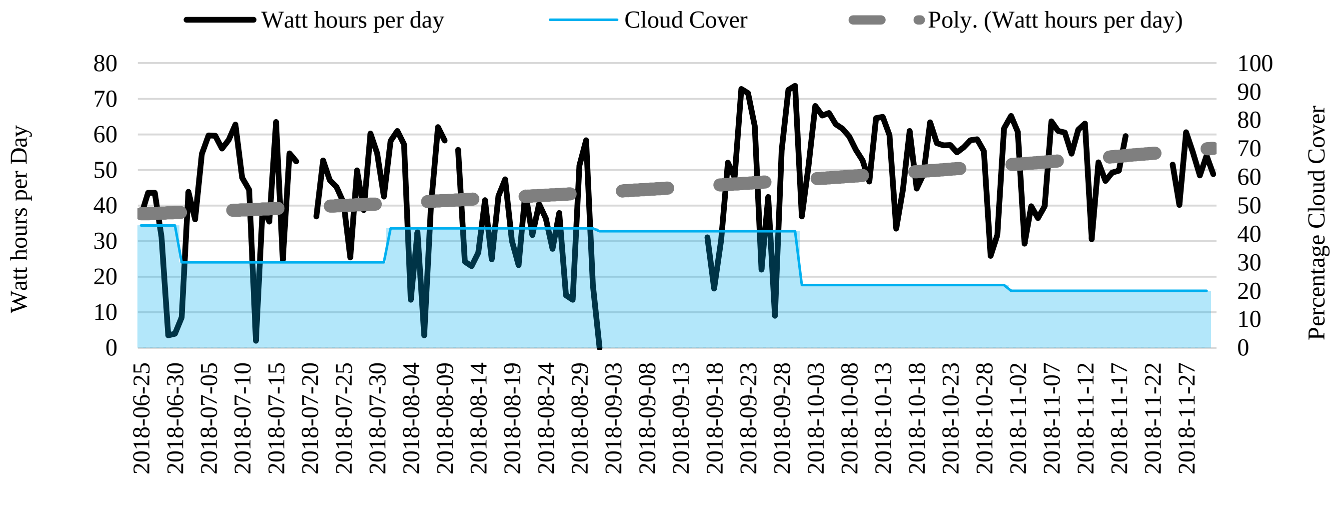

Figure 4: Watt hours per day along with the cloud cover for 6 months in 2018

The ambient temperature results of the DHT22 sensor connected to the ESP8266 NodeMCU is visible in dark grey while historical data from Accuweather is visible in light grey. A Pearson correlation between the two values reveals a statistically significant correlation of 0,862. It must be noted that the DHT22 sensor was mounted just outside a window under a zinc awning that would have influenced the temperature, resulting in its value being at times higher than the value from Accuweather. It is recommended to place the DHT22 sensor a few meters away from both windows and walls to obtain a more accurate result. Air temperature sensors should usually be installed in a properly ventilated solar radiation shield for accurate ambient measurements [31].

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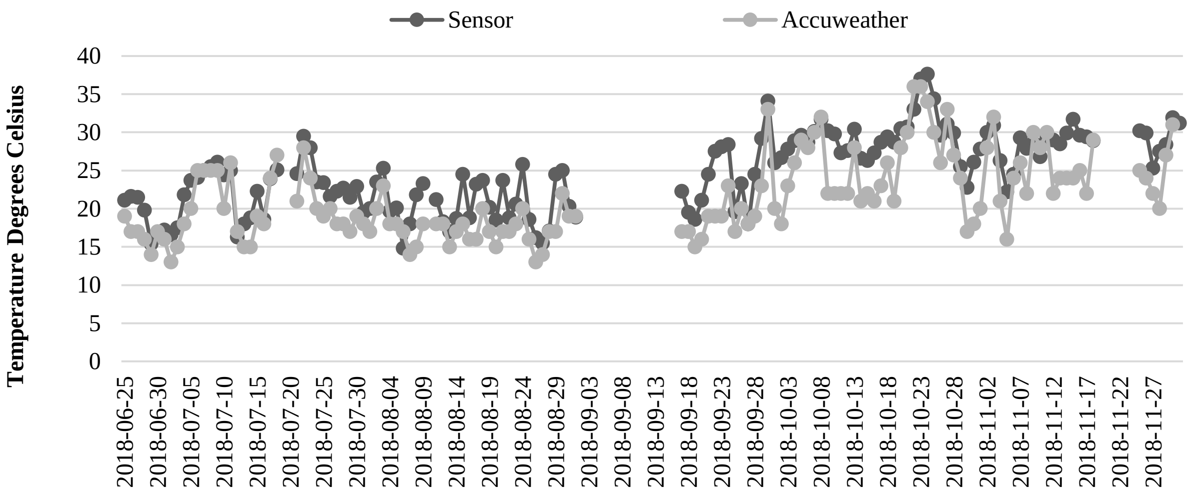

Figure 5: Temperature readings from the practical setup and from Accuweather [32]

6. CONCLUSIONS

The purpose of this paper was to present a cost-effective remote energy monitoring system using the ESP8266 NodeMCU that was deployed in Cape Town, South Africa, to determine the energy output of a pico-solar system and measure the ambient temperature. Results indicate that the amount of Watt hours per day vary between winter and summer in accordance with the the solar radiation curve. Rapid fluctuations in the Watt hours from day to day is also related to the percentage of clover cover. The average Watt hours per day for July and August was 39,3 Wh/day and for October and November it was 51,8 Wh/day. A statistically significant correlation of 0,862 was established between the DHT22 sensor connected to the ESP8266 NodeMCU and historical data downloaded from Accuweather. This helped establish the reliability of the remote-energy monitoring system. The cost of the prototype system is around $20, which is cost-effective when considering the Raspberry Pi and Arduino Uno. The following step is to produce a PCB of the prototype circuit to enable mass production. The 5 V power supply unit also has to be replaced with a 12 V battery that is charged by the PV module. It is recommended that more of these cost-effective remote energy monitoring systems be deployed across a number of research sites to enable the collection of reliable empirical data that can be used to optimize the design of off-grid solar energy systems.

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