SM^2 : SOLAR MONITORING SYSTEM IN MALAWI

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ABSTRACT

This paper describes recent work on the development of a wireless based remote monitoring system for renewable energy plants in Malawi. The main goal was to develop a cost effective data acquisition system that continuously presents remote energy yields and performance measures. A test bed comprising of a solar photovoltaic (PV) power plant has been set up at Malavi Primary School and a central management system at Malawi Polytechnic. The project output gives direct access to generated electric power at the rural site through the use of wireless sensor boards and text message (SMS) transmission over cellular network. The SMS recipient at the central site houses an intelligent management system based on FrontlineSMS for hosting SMSs and publishing remote measurement trends over the Internet. Preliminary experimental results reveal that the performance of renewable energy systems in remote rural sites can be evaluated efficiently at low cost.

Keywords – SMS, Wireless Sensors, Solar Power, Remote Monitoring

1. INTRODUCTION

The potential provided by solar power combined with the dangers raised by greenhouse gas emissions leading to climate change have paved the way for the adoption of the solar technology and subsequent investments in solar installations as a less polluting power source alternative. It has been recently reported [1] that if humanity could capture one tenth of one percent of the solar energy striking the earth, the World would have access to six times as much energy as we consume in all forms today. The African continent receives an average of 6kWh of solar energy per square meter every day [2]. Yet, as currently exploited, solar power is still an untapped resource representing only a minuscule fraction of the planets power generation capacity.

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Solar technology infrastructures provide the potential for social and economic advances in the rural areas of the developing world which generally suffer from a lack of appropriate and reliable electrical grids. However, the monitoring of their installation is an important parameter upon which wide deployment of such infrastructures depend. Some of the advantages of solar installation monitoring include (1) letting businesses and home owners to get a real-time readout of their solar panels with the associated economic benefit of making the best trade-off between switching between electrical and solar supply (2) rapid problem identification and preemptive resilience to failure allowing qualified service technicians to quickly fix the problem (3) self-repairing of the solar system through automated software when possible.

1.1. Related work

A variety of commercial monitoring systems are available for plants ranging from small-scale residential rooftop to large commercial renewable energy system (RES). These plants typically consist of a local electronic device (data logger) that connects to the energy system and records data over time and thereafter relays it on to the monitoring service provider's central data centre. These commercial tools comprehensively display transient real-time and historical graphical trends of RES plants, usually in Web based format over the Internet. In addition, some advanced applications offer system alarms and notifications via email or SMS during operation failure or when specific conditions are met. Companies offering remote monitoring products and services include SMA Solar Technologies [3], inAccess Networks [4], Fat Spaniel Technologies [5], Morningstar Corporation [6], SolarMax [7] and others.

Developed by the New York University, the SIMbalink project aim is to provide sustainable electrification solutions for rural areas. SIMbaLink is based on an extremely low cost real time solar monitoring system that reduces the

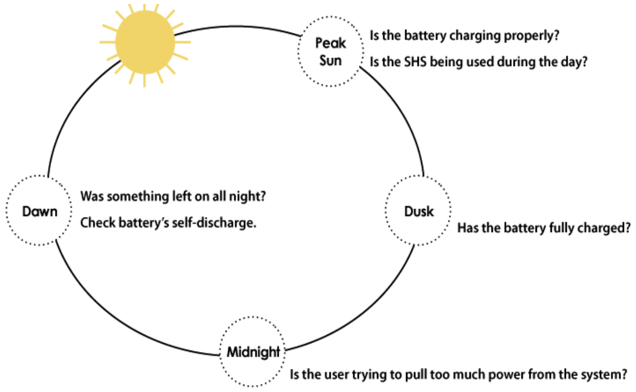

Figure 1. The SimbaLink System

maintenance costs and the time to repair. The system reveals important information about battery's state of charge and daily energy use. The data is transmitted over GSM cellular network to a regional technician to allow remote system diagnostics. However in their innovative solution, readings are only taken four times per day, as displayed in Figure 1. Consequently, this does not presents real time trends to enable critical performance analysis and timely detection of solar plant problem.

1.2 Contributions and Outline

A research project aiming at developing advancement in manufacturing, installation and maintenance support of new small scale solar and hydro electrical energy generating equipment in Malawi is being conducted by the faculty of Engineering at the Malawi Polytechnic. The project includes the installation of solar plants in rural primary schools and health centres. However, long distance and a poor road network between sites make it more challenging for the team to perform tests and monitor the performance of the plants. As a first step towards efficient management of the energy generating equipment, this paper reports on a solar system monitoring application developed as part of the whole project. The main features of the application include (1) solar power consumption monitoring using sensors measuring panel voltage and current capture (2) information dissemination using FrontlineSMS [9] and (3) data publishing using Web services based on PHP and associated graphing tools. As a new innovative solution that demonstrates a low cost mechanism for RES using the existing mobile network infrastructure, the proposed application present the following key benefits:

- Access to PV system performance from anywhere through the use of Internet.
- Reports of power output and energy production trends.
- Verification of system operation.
- Collection of data for service and maintenance planning.
- Use of open devices which lower the cost and enable the replicability of the solution.

The choice of using the GSM network was dictated by the lack of other solutions in the Malavi area. From the power consumption point of view, using a

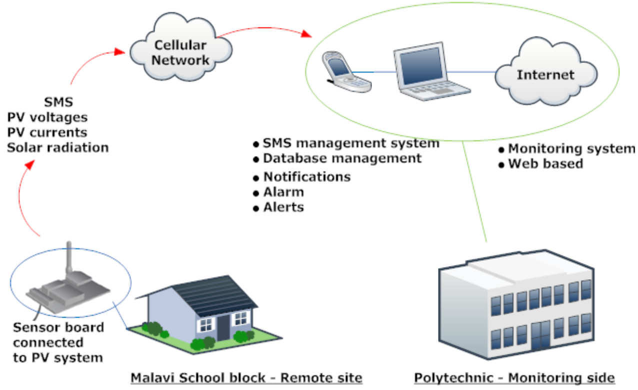

Figure 2. System Architecture: Solar PV withWireless Sensor and Central Management Servers

GSM module requires more energy than using low-power protocols such as Zigbee. From the connectivity point of view, GSM networks cover most of the country and connectivity costs are limited given the competition of two operators (AirTel Malawi Limited and Telekom Networks Malawi). The SIMbaLink project follows an approach which is similar to ours as it is based on Arduino devices and builds upon open source solutions. However, our solution makes use of FrontlineSMS to enable users to access the status of the system from remote.

The remainder of this paper is organized as follows. Section 2 describes the System Architecture while Section 3 presents some results from Malavi Primary school testbed. Section 4 contains our conclusions and examines the way forward.

2. SYSTEM ARCHITECTURE

A general view of the system is shown in Figure 2. It is composed of three elements: the remote site where the solar PV system is installed, the wireless sensor data capturing boards and the server side at the Malawi Polytechnic where system management is hosted.

2.1 Photovoltaic System

The solar system at the Malavi Primary school is made up of three key components; solar modules, charge controller and battery bank. The solar array is composed of two LORENTZ LA75-12S 75W PV modules [10] each module having 32 monocrystalline silicon cells. The manufacturer claims that the cells yield higher voltage making the module provide sufficient voltage as that realized with traditional 36 cell modules. In addition to that, each PV module is capable of yielding short circuit current (ISC) of 5.4A and open circuit voltage (VOC) of 21V. The StecaTarom 12A charge controller is the brain of the system which controls the amount of power going into and coming out of two 102Ah Deltec batteries. As such, it prevents the solar module from overcharging and the load from over discharging the batteries, thereby maximizing the battery life. Consequently, all components of the solar system are connected through the charge controller. A 600W TES inverter is installed to power a single AC socket and lastly the DC load consists of eighteen 11W bulbs.

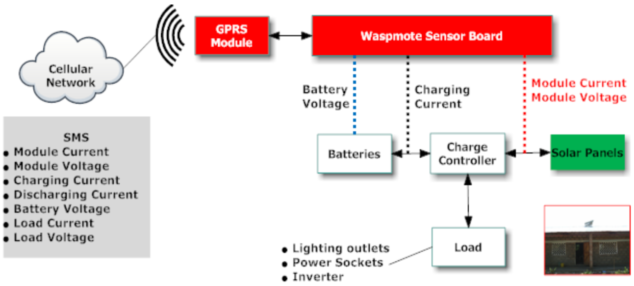

Figure 3. Detailed system architecture for remote data capturing and transmission

2.2 Wireless Sensor

Solar system monitoring is achieved through the use of the Waspmote mote by Libelium [11]. The main advantages of the Waspmote are 1) its modular architecture allows developers to choose a wide range of available modules depending on the application, 2) low-cost resulting from an open source software and hardware platform design, 3) an easy programming environment where the development phase and the adaptation to different needs takes little time and 4) the provision for a wide range of wireless applications. Using different modules, Waspmote can connect to low-power wireless networks based on 802.15.4 and Zigbee. In our case, we used the GSM module to send data to the Malawi Polytechnic. Equipped with a SIM card, this module allows to send and receive SMS and even to connect to the Internet via GPRS when available. The Waspmote has 7 accessible analog inputs, which can be utilized in capturing solar system performance parameters via analog sensors. Each input is directly connected to the microcontroller which uses a 10 bit successive approximation analog to digital converter (ADC). The reference voltage value for the inputs is 0V (GND) and the maximum value is 3.3V which corresponds to the microcontroller's general power voltage. Consequently, the board represents integer values ranging between 0 and 1023 which corresponds to actual input range of 0V and 3.3V. Figure 3 presents detailed system architecture for remote data capturing and transmission.

To accomplish voltage and current measurements, the Waspmote is equipped with two external circuits: Phidget 1117 voltage sensor [12] and Phidget i-snail-VC 100 current sensor [13]. The voltage sensor allows measurements up to 30 Volts, while readings of up to 100 Amperes can be achieved with the current sensor. Figure 4 shows the Waspmote with the GSM module during voltage sensor calibrations. Voltage reading is attained by tapping solar PV module voltage directly to a voltage sensor, which is connected in parallel with the charge controller, as depicted in Figure 5.

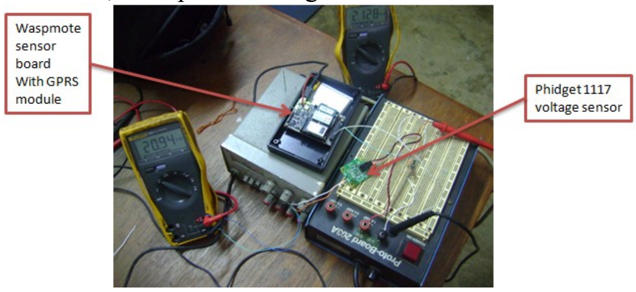

Figure 4. Sensor Calibration Setup

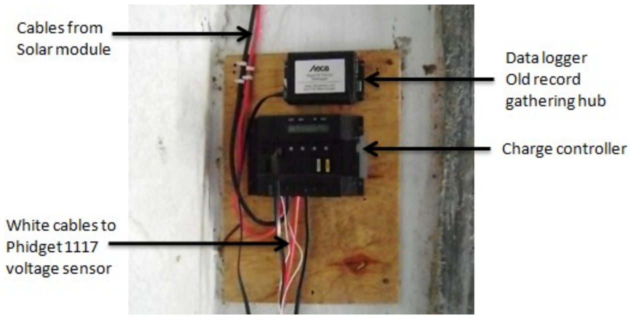

Figure 5. Wire connections to voltage sensor

The Waspmote board is programmed to calculate input voltage given a voltage reading at its analog input using the following method:
Solar system voltage (in volts) =
[(Read voltage * 200 * 0.06) - 30].

2.3 Central SMS Management System

Cost effectiveness of this project is entrusted on the rate at which the measurements are conducted, as this determines the total number of SMSs to be transmitted in a particular period of investigation. Experimentally, a 30 minute-measurement interval is being opted for and 8 readings are logged locally in Waspmote's SD card before transmitting. Ultimately, this results with a requirement of 6 SMS transmissions in a day. Currently, the cost to send an SMS within the same network is about 0.07USD (10 Malawi Kwacha), and a bulk sum of 180 SMSs can be sent for 12.60USD, which is the total running cost of monitoring the system in a month. In addition to comprehensively securing and transmitting solar system parameters over cellular network, from Malavi Primary School, the project mission attainment also depends on the central communication hub proficiency in data management, concise relying and presentation of performance trends on a Web portal. Consequently, it is essential to identify other system components that need to be integrated and propel towards actualization of the goals. Furthermore, due to limited project time frame, it was necessary to amalgamate with core tools that have been experimented and proved to be feasible for these kinds of projects and also that are highly adopted in robust Internet based infrastructure. Resultantly, en route to the ambition, diagrams comprising of main system building blocks are presented in Figures 6 and 7 that were opted as a blueprint in the designing of a central SMS management system at the Malawi Polytechnic.

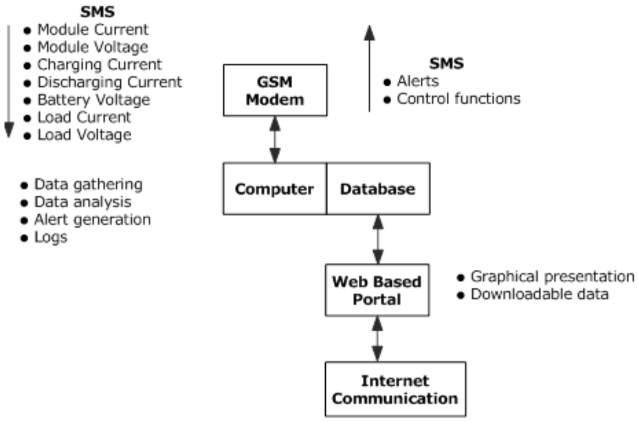

Figure 6. Remote site sensing mechanism

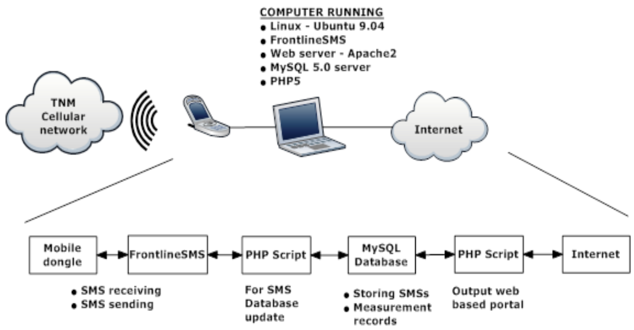

Figure 7. Remote site sensing mechanism

Through consecutive series of research studies, the following are typical elements used in constructing the Linux based central communication hub.

- Mobile phone in this case a Huawei mobile broadband dongle E160.
- Computer with the following packages:
    - LAMP bundle, which is a combination of Linux, Apache, MySQL and PHP
    - FrontlineSMS set up as an SMS gateway.

FrontlineSMS is an award winning open source software that turns a laptop and a mobile phone into a central communication hub. It is mainly used by the non-profit sector and non governmental organisations (NGOs) to reach specific groups of individuals within a target community. Its functionalities have found usage in sending information on health, security alerts, job information, and market prices from monitors, surveys and other data collection sources. Specifically in 2007, the software was internationally adopted to assist local NGO groups carry out citizen monitoring of the Nigerian Presidential elections. Furthermore in 2009, in conjunction with the Ushahidi mapping platform, the application was used to track essential medicine stock outs in several East African countries. On the other hand, in Kenya and Tanzania, FrontlineSMS is being implemented as part of social business to keep in-touch with farmers who have bought, or expressed interest in buying Kickstart pumps.

In this project, FrontlineSMS abilities are harnessed in obtaining a solution for capturing SMSs from wireless sensor motes that capture performance parameters of RES. Furthermore, in this scenario, FrontlineSMS works hand in hand with other scripts so as to house all received SMSs in a database for further analysis. A backend PHP script for populating a MySQL database is linked to the SMS gateway and once an SMS is received, the script gets triggered and acquires two strings which are ushered by FrontlineSMS's external command triggering functionality. In this case, the strings accommodate sender number and message content. However, apart from mere character passing to the database, the script also checks for particular keywords which signify a text message with solar readings from remote site. In addition, as the information encloses logged performance parameters that are different and also captured at different times, the script unscrambles the content and then updates MySQL table fields in a logical manner. On the other hand, the frontend PHP script connects to the database and retrieves parameter readings for web based presentation. Plotting is achieved with the use of JpGraph, an object-oriented graph creating library for PHP5. The library is completely written in PHP and can be incorporated in any PHP script. It supports several plot types; spider plots, pie charts (both 2D and 3D), scatter plots, line plots and bar plots just to mention a few.

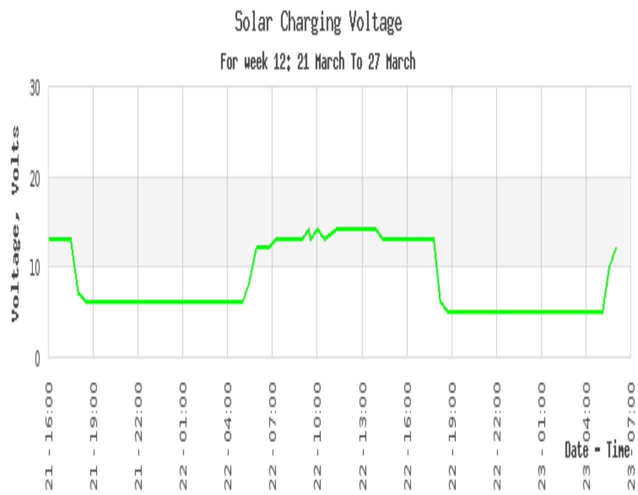

Figure 8. Solar Charging voltage

3. PRELIMINARY EXPERIMENTAL RESULTS

We conducted a number of experiments with the objective of monitoring the performance of the PV installation in terms of solar charging voltage, load voltage and Waspmote internal temperature. Figures 8, 9 and 10 show a graphical representation of these three parameters during a particular test period. Solar charging voltage had a constant trend as depicted in a snapshot of a two day period shown in Figure 8. Referring to the same result, it is clear that voltage follows a day/night pattern, as solar panels provide voltage during the day and provide little voltage during the night. In other words, during this season of the year voltage grows starting at 5 am and reaches its maximum at 7 am. In the evening, it starts to drop at 6 pm and by 7 pm the panels provide small voltages.

The Waspmote internal temperature is shown in Figure 9. This element has been monitored to check that the board is not exposed to excessive heat at the testbed site.

Apart from this, Figure 10 shows a trend analysis of the load voltage that is essential in supplying power to the eighteen 11W bulbs and a single AC socket of the school block.

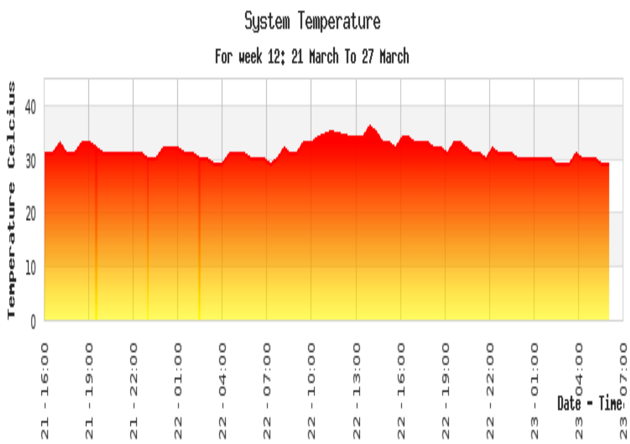

Figure 9. System Temperature

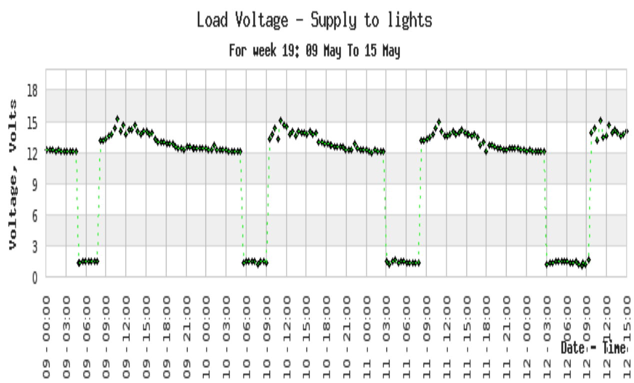

Figure 10. Load voltage (a)

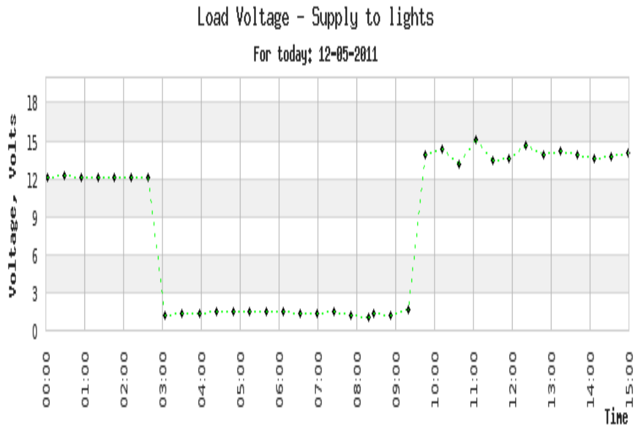

Figure 11. Load voltage (b)

For simplicity, referring to Figure 11, during the night the system obtains a constant voltage of about 12 V, which is supplied from the batteries. However due to activities that are running at the school during this period of investigation, the battery voltage is not sufficient enough to supply power throughout the period of little solar energy. Consequently, at around 3 am, the battery voltage drops and results in the switching off of the load power and commencement of battery charging. This effect is evidently observed as there is a complete power outage until around 10 am during which the school block obtains power directly from the solar panels after full charging of the batteries. This output indicates that the system was under designed and there is a need of adding one or more batteries to meet the required energy demands of the rural community school. On the project website it is possible to visualize these results on weekly, monthly and yearly graphs.

4. CONCLUSIONS AND FUTURE WORK

A sensor-based monitoring application built around a solar photovoltaic power plant at Malavi primary School has been presented in this paper as part of a bigger project led by Malawi Polytechnic. The application uses a Waspmote sensor board from Libelium where two phidget sensors have been grafted to allow voltage and current readings. The proposed application combines built-in Waspmote SMS capabilities and the widely known FrontlineSMS software to achieve information dissemination from the PV system site to the monitoring site and also from this site to the PV system's supervisors. This is augmented by web publishing using PHP and associated graphing tools. The proposed monitoring system is currently running and has proved to lower management cost as timely information reaches the group at the Polytechnic right in front of their work stations. This can assist in alerting technical team of remote circumstances and also ease system study time for the researchers. The designed system monitoring website enables users to select specific monitoring times to suit the analysis at hand. The preliminary results presented in this paper logically agree with what is expected as the trend for solar module voltage during the day and night.

There is room for future work to extend the capabilities of the proposed system in different directions. One way is to expand it to effectively measure more performance parameters such as current consumption of different users of the PV system. The proposed system could also be extended to allow a smooth switchover between electrical and solar power supply depending on time-of-the-day power needs. Using the attribute of the GSM communication channel to allow easy system replication to other remote rural RES plants is another avenue for future research work.

REFERENCES

[1] "Smaller, cheaper, faster: Does Moore's law apply to solar cells?": http://goo.gl/qcUcm

[2] "Africa: Time to go solar": http://goo.gl/w0QXt

[3] SMA Solar Technologies Monitoring Systems: http://goo.gl/Bc7bq

[4] inAccess Networks Site Controllers: http://goo.gl/kfwe3

[5] Fat Spaniel Solutions: http://goo.gl/mSfl8

[6] Morningstar Products: http://goo.gl/hCJ5Y

[7] SolarMax MaxVisio: http://goo.gl/OaZYg

[8] "SIMbaLink: Towards a Sustainable and Feasible Solar Rural Electrification System", Nahana Schelling, Meredith J. Hasson, Sara Leeun Huong, Ariel Nevarez, Wei-Chih Lu, Matt Tierney, Lakshminarayanan Subramanian, and Harald Schutzeichel, Proceedings of the International Conference on Communication Technologies and Development (ICTD), 2010

[9] FrontlineSMS: http://www.frontlinesms.com

[10] LORENTZ LA75-12S: http://goo.gl/bBImt

[11] Waspmote by Libelium: http://www.libelium.com/products/waspmote

[12] Phidget Voltage Sensor 1117: http://goo.gl/vLM1p

[13] Phidget i-snail-VC 100: http://goo.gl/qmGsn