A Remote Monitoring Unit for Solar Home Systems

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Abstract—This paper introduces the design of a low-cost low-power data-logging device for remote monitoring of solar home systems. The logging unit monitors voltage, current, power and temperature sensors, stores this data locally and sends it to a cloud-based store, either using Wi-Fi or General Packet Radio Service (GPRS). The system can be installed in any area with GPRS reception or Wi-Fi and monitored from anywhere with an internet connection. The data is presented in interactive graphs and maps via an Internet of Things (IoT) web dashboard.

I. Introduction

Solar home systems (SHS) can be utilised for electrification of areas for the 770 million people worldwide which do not have connection to a national electricity grid. SHS, comprised of a solar photovoltaic panel, charge controller, battery, and appliances, provide small amounts of power for household items such as charging phones, LED lights, radios, and televisions.

The practical implementation of SHS in, typically, remote rural locations make asset monitoring, operation and maintenance of these systems difficult. For example, in one programme over 30 % of SHS implemented had some form of fault reported within the first 12 months of operation. This impacts the economics and reputation of the SHS supplier and is highly inconvenient to the user. However, the faults were difficult to analyse, as their symptoms were reported verbally in varying levels of detail.

The ability to remotely monitor these systems in real time could help to improve their long-term performance and allow pre-emptive maintenance to be performed. Knowledge of the actual solar power generation and load provision on these systems helps a SHS supplier manage their assets and could help with the future development of lower cost and more efficient SHS.

II. Related Work

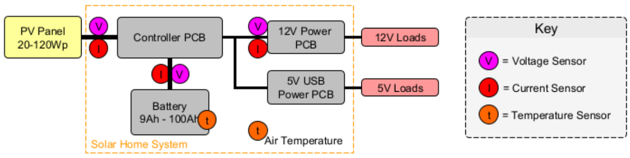
There are many stand-alone data loggers available, with a small sample given in Alphatemp Tech [1], Comark [2], DATAQ Instruments [3], & Measurement Computing [4]. These units are typically relatively high cost ($250 to $4,000) and would require additional sensors and are usually not open source.

Many solar home system providers are including remote monitoring systems within their products. This helps to them analyse use and hence payment for the system, and it also helps investigate faults and potentially highlight maintenance issues. Bboxx have the 'Pulse' remote monitoring system [5], Connected Energy provide 'last mile ICT', which includes a cloud-connected solar charge controller [6] .These systems are proprietary, they are usually built into specific products and the data obtained is commercially sensitive, so is not typically shared in detail.

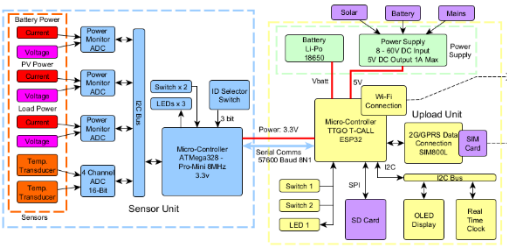
Many non-commercial monitoring units have been designed for use on off-grid solar power systems, with a review of some of these designs given in Kumar, Prajapati and Tiwari (2020). The majority of these units either require Wi-Fi connectivity or have a relatively high power consumption which makes then unsuitable for remote, low-power application.

A. Device overview

Here is an overview of the typical solar home systems to be monitored and the key sensors to include:



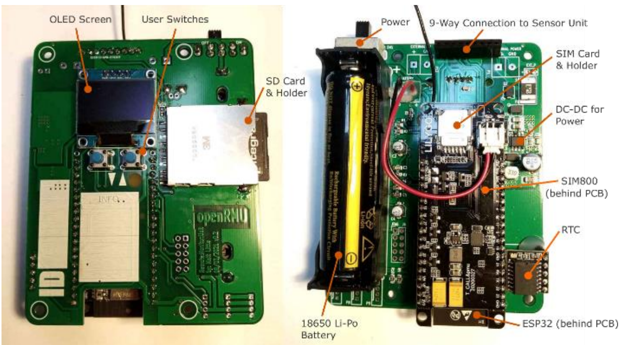
The main functions of the logging device are to read the various sensors, average and convert the sensor values, record the values to a removable memory device with a timestamp, and send the data to an online cloud data store at regular intervals. To complete these tasks and ensure low power operation, the design was broken into two sections: a "sensor unit", to handle regular reading and averaging of the sensor data, and an "upload unit" which 'wakes up' at regular intervals and records the data to an SD card and uploads the data to online cloud storage. These sections act independently but have a serial data communication connection. This means the data can still be monitored by the sensor unit while the upload unit sends data up to the cloud. The sensor unit can be swapped for different applications, without the additional expense of changing the upload unit. A block diagram overview of the monitoring unit design is given here:



The prototype consists of two circuit boards, the "upload unit" and the "sensor unit".

B. Upload Unit

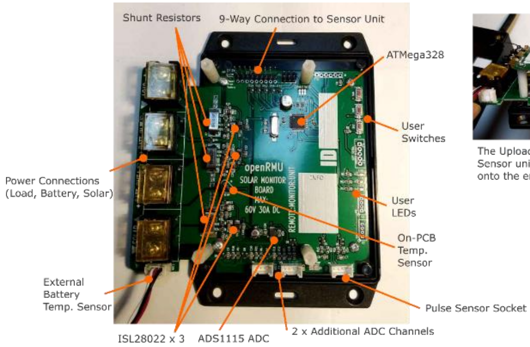
The upload unit is the main controller for the system. It is mainly in 'sleep' mode, which conserves energy, and will only 'wake up' to store data to a .csv file on the SD card, upload data via Wi-Fi or General Packet Radio Service (GPRS) or display data when a button is pressed. The data stored includes the average value, along with the maximum and minimum values within the time interval. This can help with fault finding, for example highlighting if there was an over-current condition, when the average value would not have shown this. The upload unit is based upon an ESP32 micro-controller and a SIM800L GPRS module. Time is regulated with a DS3231 real time clock which is maintained at Universal Coordinated Time (UTC) either through connection to a time server on Wi-Fi or through the GPRS connection. A small OLED display and two user interface buttons are available to show information. Here is the prototype upload unit circuit board:



The control and operation of the upload unit is determined by a settings text file stored on the root of the SD card. When the upload unit wakes up it reads this settings file and bases the unit's operation on those settings. The datalogger application logs data from several channels. For the upload unit firmware to convert raw data readings (e.g., analogue value or pulse counts) to physical values (e.g., voltage or temperature), each channel must be configured and converted. This configuration is done by writing a channels file, again a text file on the root of the SD card. The channels file allows the user to adjust the name of the channels and the order in which they are recorded. Each channel also has conversion factors that can be applied to calibrate the data. A full-size SD card is used to store the recorded data, along with the settings and channels information files.

C. Sensor Unit

The sensor unit is designed to be replaceable so different sensor units could be attached, but still communicate with the upload unit. The prototype sensor unit for use with solar home systems is shown here:



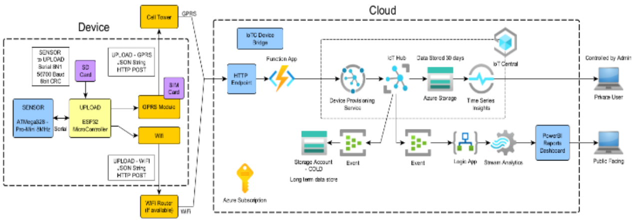
The Upload unit sits on top of the Sensor unit. The Sensor PCB fits onto the enclosure plastic base.

The sensor unit was designed for a field trial to monitor the SHS, which included the solar PV information, the battery information, and any load information, along with some temperatures. The sensor unit is based on an ATMega328 microcontroller. This unit runs at 3.3V and utilises a serial connection at 57600 baud between the sensor unit and the upload unit. Each sensor board has a microcontroller and additional firmware. The initial sensor unit design includes three ISL8022 power monitoring ICs with shunt resistors to monitor power, voltage and current for three channels. A 16-bit analogue to digital converter (ADC), the ADS1115, is used to measure two temperature sensors, with room for two more. The sensor unit firmware has been kept very simple, reading any attached sensors at regular intervals. It reports back the sensor values averaged over different time periods via the serial interface. The maximum and minimum values are also recorded. The max and min values are kept until they are read from the serial port, at which point they are reset. The sensor unit will sleep as much as it can between the tasks to conserve power but will wake up and respond to serial requests for the data as required.

The firmware for the upload and sensors units was written in C++, using the Arduino IDE to upload to the units. The PCB design has been produced using KiCAD, which is a fully open-source electronics design suite.

D. Data Collection

This unit connects via Wi-Fi or a GPRS connection to upload data for cloud storage. For the initial deployment of devices, Microsoft Azure was chosen as the IoT device data cloud storage platform, although other data storage platforms can be used by altering the firmware on the upload unit. Within Azure, the 'IoT Central' application is used to control and display the data. Graphs can be displayed, and data downloaded for all the parameters recorded. A bespoke Azure function has been written to take the data from the GPRS connection and move it into IoT Central. This can also include adding custom timestamps, so data can be monitored and then batch uploaded. Data is stored into a 'cold' long term data store at very low cost. When new data arrives at IoT Central it is also added to a data 'stream' within Microsoft Power BI. Power BI allows visual data reports to be created for different clients and applications. These reports can be public facing, viewable on any browser, and can easily be included onto a website. An overview of the flow of data is given here:



III. Responsible Innovation

The design proposed here was developed to help improve the performance of renewable energy systems in remote location. Small amounts of electrical power can be life changing for remote rural and poor communities, but these solar systems are relatively high cost and have payback periods of 12 to 24 months. Without knowledge of the assets then it is unknown how long these systems actually work. Adding monitoring can help highlight errors and maintenance required and so improve the lifetime of these systems.

At present the prototype design is too expensive and too complex. By simplifying the design it is hope that the environmental impact is reduce and the lower cost will make the unit more suitable for use in smaller systems.

The unit is designed to be re-usable for different applications with different sensor boards, to help increase the monitoring units lifetime.

IV. Author Bio(s) / Experiences

I am an electronic engineers who has been fascinated by solar power since seeing my first solar power system aged five.

My work has been influenced by time I spent working with remote communities in the Philippines with Engineers Without Borders UK. I was implementing wind, solar and hydro systems but noticed that there were many systems already installed that were not working. While funding had been available to pay for the systems, there was not money for long-term operation and maintenance and a lack of spare and replacement parts. I wanted to find a way to remotely monitor these systems and provide pre-emptive maintenance.

As a research associate at CREST, Loughborough University I worked on implementing SHS in Tanzania which had a similar issue, with a number of units failing within six months. This prototype was developed to monitor a sample of the SHS provided through this project.

Some papers that relate to this work include: [7][8][9].

V. Acknowledgements

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VI. References

[1] Alphatemp Tech (2021) Stand Alone Data Loggers. Available at: https://alphatemptech.co.uk/stand-alone-data-loggers/ (Accessed: 7 June 2021).

[2] Comark (2021) Standalone Data Loggers. Available at: https://www.comarkinstruments.net/product-category/products/data-loggers/standalone-data-loggers/ (Accessed: 7 June 2021).

[3] DATAQ Instruments (2021) Stand-alone Data Acquisition and Data Logger Systems. Available at: https://www.dataq.com/data-logger/stand-alone/ (Accessed: 7 June 2021).

[4] Measurement Computing (2021) *Data Loggers & Measurement Computing*. Available at: https://www.mccdaq.com/data-loggers (Accessed: 7 June 2021).

[5] Bboxx (2022) *Bboxx*. Available at: https://www.bboxx.com/technology/ (Accessed: 7 December 2022).

[6] Connected Energy (2023) *Connected Energy*. Available at: https://connectedenergy.net/home-1 (Accessed: 4 May 2023).

[7] Blanchard & Little, (2022) Pre-feasibility methodology to compare productive uses of energy supplied by stand-alone solar photovoltaic systems: A Tanzanian case study, Energy for Sustainable Development, Volume 70, , Pages 497-510, https://doi.org/10.1016/j.esd.2022.08.018.

[8] Barton et Al, (2021), A Portable Power Station for Humanitarian Contexts, IEEE International Humanitarian Technology Conference, DOI: 10.1109/IHTC53077.2021.9698942

[9] Blanchard & Little, (2016) Developing an Open Access Monitoring Device for Off-Grid Renewables, International Conference on Development in Renewable Energy Technology, DOI: 10.1109/ICDRET.2016.7421511