Embedded Trusted Monitoring and Management Modules for Smart Solar Panels

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Abstract— **This paper investigates developing a prototype of smart solar panels. This architecture consists of a panel monitoring module and the central management unit. The monitoring module is to be embedded inside each PV panel making it secure to transfer the trusted data via Wi-Fi to the central Management unit (which can accommodate an array of PV panels in an installation). This module is required for data storage and provides the ability to upload secure data to the cloud. This platform presents the ability to securely manage large numbers of rooftop solar panels in a distributed ledger by implementing block chain algorithm. For achieving this purpose, Module 400 is envisaged to be turned into a Blockchain node as it provides the infrastructure to implement this technology.**

Keywords- Panel Monitoring Smart solar panel, Embedded Solar Panel, Blockchains, IoT, Smart Energy

1. INTRODUCTION

In recent years, individuals have been closely involved in low carbon energy ecosystems. The focus for this paper is on renewable energy generated at the point of consumption as rooftop integrated photovoltaics. Increasing the usage of solar energy worldwide can lead to reduced cost of PV modules by 2020 [1] and price reductions of lithium-ion batteries and other storage features such as RedFlow's [2]. While solar energy consumption is free, there is still an operational cost which needs to be covered. On the other hand, only specific wavelength of the solar radiation can be absorbed by solar cell (400-1200 nm) the rest turns to heat. This problem besides a vast number of other parameters such as environmental issues and electronic components failure requires solar system monitoring and efficiency tests.

All the previous researches have presented various methods for monitoring and optimization of the PV panels performance. Several approaches exist for monitoring the performance of parameters such as panel and components aging, failure detection, etc. [3-7]. In general, there are two types of architectures used for monitoring purposes; a) connecting the monitoring device on each PV panel, b) allocating one monitoring device for an array of panels. Selection of the right architecture depends on the overall system topology and most importantly the target which the device has been designed for. System complexity and cost are two major elements which must be considered, especially when installation consists of large number of panels. Intelligent and smart systems are playing an important role when large numbers of panels are involved. Fuentes et al [8] presented a portable data-logger using the Arduino to monitor the PV systems in remote areas. İnner [9] also used Raspberry Pi 3 to continuously monitor energy production via the Bluetooth. In his study, the environmental issues such as temperature, rain etc. did affect the signal quality, therefore wireless data transfer has been recommended over Bluetooth. Papageorgas et al. [5] proposed a design methodology for monitoring PV panels using wireless network. However, their characterization device which is embedded in each PV panel, is connected through the serial bus to the local gateway. They used open source platforms for web-publishing of energy data. This paper presents the novel secure monitoring module, embedded into the solar panel itself. The contribution is towards the use cases and application of this system which is mainly designed to enable the Blockchain technology for secure and easy online trading in the future.

In this paper, we consider smart embedded solar panel systems designed to mitigate elements of fraud problems and a secure means of data transfer. This is based on the author Colin Mallett's patent [10] in which the key invention lies in embedding secure processors and communications circuits directly into solar panels.

The proposed system contains of two units namely; Measurement unit and Management unit. The Measurement unit, called Module 500 (M500) is embedded inside each PV panel. The management unit, called Module 400 (M400) is one unit per installation, this means an array of PV panels will share their produced metering data with the Module 400. The M500 attached to each PV panel, securely measures the power output and sends metering data to Module 400 via Wi-Fi. On the other hand, The M400 connects to the cloud for transferring the energy production data. This turns the Module 400 into a self-powered blockchain node which generates cryptographic proof that submitted data has not been altered. Figure 1 shows both smart modules and their connection topology; The key requirement of this system is to embed the module 500 with its processors and communications circuits directly into the solar panel. Hence, this module cannot be removed or changed without being destroyed.

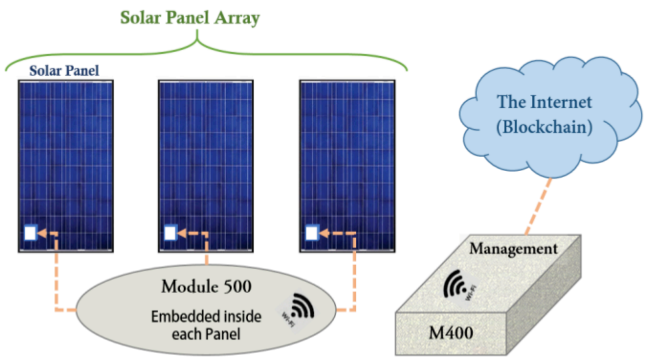

Figure 1. The Smart Trusted PV modules.

2. System Description

This section presents the implementation of Module 500 and Module 400 (Monitoring and Management units) of the Smart solar system which has been proposed in [11]. There are independent security processors on each of the modules M500 and M400. In terms of the physical location, Module 400 can be located in close proximity of the solar roof so that WI-FI communication can be made possible with each PV panel. Both modules will be embedded in weatherproof containment. The basis of Module 500 is illustrated in figure 2 (Appendix A). The voltage and current produced by the panel is monitored and measured with the sensors and then these data are sent to an ADC and ESP. This data is then passed to the Multos chip for security and encryption, which can then be converted into a TCP/IP stack by the ESP8266. Finally, this secured data will be sent to the Management unit (M400) wirelessly.

A. Module 500

The enabler for a solar panel to become smart is the addition of a custom-made circuit board. The circuit board is embedded into each panel for monitoring the power production, this trusted metering data is encrypted on-board and then transferred over Wi-Fi to a management unit of the solar panel array. The circuit board architecture is shown in figure 3. The PCB is separated into two sections with the section on the left solely for power regulation. The voltage input from the solar panel selected is up to around 40 V and the PCB on the right, which contains the main sensors and processors, operates at a voltage of 3.3 V, this circuit achieves this voltage stepdown to provide consistent reliable power. As it can be seen in figure 3 there are two solar inputs, this is due to one input being for power regulation and the other is a direct feed into the current and voltage sensors which enables the ability to read the data using an analogue to digital converter. Solar output is the connection required to connect a load to the circuit. The current and voltage sensors are used as the data sources to feed into the ESP via ADC. The processing of the data is carried out using the ESP8266, this module has the additional benefit of wireless capabilities which is being utilized to send the processed data to a management module. The separate Multos security chip is used for encrypting the datagram which it is passed by the ESP8266.

B. Module 400

Part two of the system architecture is the management unit (M400). The processor on the module 500 has limited internal storage memory, therefore a management unit is needed to collect data from all solar panels in its array; this data is uploaded to a cloud platform where it is stored in a database. The selected hardware for this module 400 is a Raspberry Pi 3, there are many benefits for using this device such as, low price, low power usage, the ability for expandable memory via an SD card, good processing power and an onboard Wi-Fi chip.

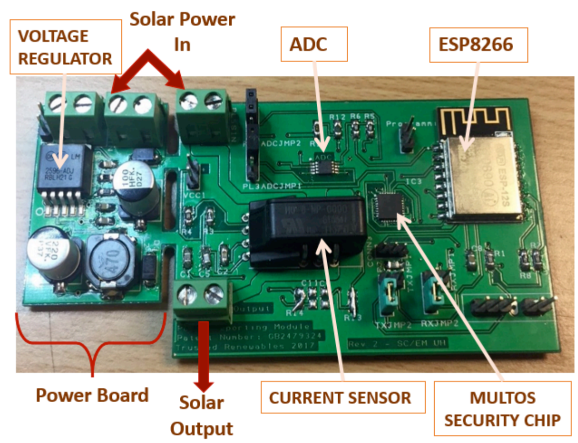

Figure 3, The PCB Design of Measurement Unit (Module 500)

3. The Implemented Software System

The software architecture consists of two separate entities. The Module 500 and Module 400.

I. Module 500: Attached to the solar panel. Responsible for sampling the power and energy generation of the solar panel.
II. Module 400: In close proximity to a number of module500's (Wi-Fi range). Collects and handles data received from the Module500's.

The overall system flow for initial testing can be found in Figure 4 (Appendix B).

The Main processor on the Module500 is the ESP8266; the 8266 supports Arduino allowing the writing and deployment of flexible C++ programs. The backbone of the M500 code is taking readings from an analogue-digital converter (ADC), converting these back to correct input scale for volts and amps using predetermined formulas, and calculating the Energy in watt-seconds. It also has to handle the connection to the Module400's Wi-Fi network as well as maintain an MQTT (Message Queue Telemetry Transport, it is a standard publish-subscribe-based messaging protocol) connection with the M400. Speed is extremely important in the Module500, therefore all operations that are not part of sensor reading such as sending MQTT messages, are asynchronous. This implies that non-speed critical operations are processed only when the main program is paused between readings.

The Pi3 has multiple useful capabilities including acting as a Wi-Fi access point. The powerful processor can handle a lot of work, giving the ability to handle the incoming data from multiple Module500's. Using the windows IoT operating system on the raspberry pi supports the deployment of powerful UWP (Universal Windows Platform) apps written in C#. The Module400 hosts both an MQTT broker as well as a client, keeping the MQTT connection within the local network. The client program receives and sorts messages published by the Module500; maintains a queue and processing threads for each Module500; performs any additional processing before passing the data off to other systems.

Energy Calculation:

The Module500 samples the voltage and current every 10 ms, calculating the watts ($V \times I$) for each sample. For every second that passes, i.e. 100 samples, the integral of watts generated for each sample is taken to give the watt-seconds generated over that period (Equation 1).

Take P to be a list of discrete watt samples (P_n) of length N, samples at interval Δt.

E is the integrated total of those points

$$E = \Delta t \sum_{n=1}^{N} Pn \qquad (1)$$

Module 500 samples every 10ms and sends a result every second, a set of 100 samples.

$$\text{Therefore } \Delta t = \frac{10ms}{1000\ ms/s}, \text{ and } N = 100$$

$$E = \frac{10}{1000} \sum_{n=1}^{100} Pn$$

The system hardware and software design and implementation has been discussed in above sections, the following section will explain the utilization of the smart solar system to be used within the distributed ledger by block chain algorithms.

4. Blockchain and Distibuted Ledger

A digital energy currency called SolarCoin has been introduced by Gogerty et al [12] and the SolarCoin Foundation (SCF) [13] with a vision to build a worldwide solar energy value transfer network that can be converted into money. These coins are ready to be credited to digital wallets for every 1 MWh of verified solar electricity generated by a registered solar system owner. Distributed ledger technology based on block chains can record every transaction made by every participant in a decentralized system and consequently can create a secure renewable database shared across multiple sites to prevent fraud and hijacking electric supplies. They also support "smart contracts" [14].

The flexibility offered by the module 400 opens up new notions for this work; it allows more sophisticated usage of the data, which in this instance can be used to integrate a block chain algorithm. Each solar panel will have a unique identifier with this added intelligence and the data secured, this allows the potential for power from individual panels to be traded.

Recent advances in block chain technology have allowed persisted information to be distributed which is trustable and verifiable. As work in progress, suitable platform architectures would be investigated which allows this technology to be used to facilitate flexible, frictionless low-cost trading. The research approaches the use of block chaining from the viewpoint of future economies that would advance towards energy and energy-assets trading at ultimately an individual level. For this purpose, trusted data about the energy source is required at a more refined resolution than currently available. Block chaining has the potential to provide this data more efficiently and at a lower cost than existing solutions. The development of a smart solar allotment system allows crucial data for trading to be collated and transmitted to a distributed ledger platform responsible for maintaining the blockchain data. As the case with distributed platforms, it is envisaged that functions can be portable and as such, the platform can be a virtual one. Part of the investigation would be an evaluation as to more efficient physical embodiments of the platform.

Trading with cryptocurrencies via Blockchain in this system means that all the transactions are signed by using a private key already embedded in the solar panel inside M500. The solar panel manufacturer doesn't see or reveal these private keys, however they publish the trusted public key for the panels in the central energy authority. Solar panel owner secures its ownership in the block chain by the panel public address (key). The panel can be purchased after that, both seller and buyer (which both have their own private keys) will sign the smart contract online and then publish the updated ownership information on the block chain. In a matter of seconds panels can be bought and assembled into a portfolio at next to no cost. Compare this to the traditional mechanisms of investment which takes days and can cost 1-3% to trade.

After the panel is sold, the buyer (identified by a public key) is linked to the panel in a secure and open way. The panel then begins to generate power and meter readings are then signed by the panel using its private key. All transactions are recorded in the block chain and unspent transactions outputs are calculated and held in a separate database.

Figure 5 (Appendix C) shows a number of rooftop solar systems made up of panels which all contain secure Measurement unit (M500), the outputs of which are collected by a panel management unit (M400) which contains secure communication lines. This improves resistance to cyber-attacks and manages strong encryption of the various communications links. Without any additional external hardware, each rooftop solar system act as a secure blockchain node and transfer the power data directly to the distributed ledgers using a cryptographic root of trust close to where the power is generated.

All the Module 400 are connected as different block chain nodes and are securely linked together as a peer-to-peer local network which records the status of each installation in a secure distributed ledger. This is currently a work in progress and will be implemented and tested in the future.

5. Conclusion

The design of two smart modules for monitoring the energy metering data and managing the power remotely has been presented in this paper. The modular set up has been examined with two different voltage rated solar panels (One with 24V and one with 40V) and the measurement and communication section are all tested successfully.

The proposed module 500 is embedded inside the PV panel as shown in Figure 6 (with the help of GB-SOL solar panel manufacturer). Design considerations include a very thin and small PCB to be embedded within the PV panel. Therefore, the large components such as current sensor have been taken out of the PCB and connected to the system via their designed interfaces. The external components were connected to the panel via ribbon cable. Besides these hardware design considerations, the prototype needs significant field testing and calibration with solar panels arrays. Further testing is required to discover bandwidth tolerances; i.e. how many nodes can be connected to a single module 400 management unit which is dependent on Wi-Fi capability.

There is a demand that renewable energy owner should be able to sell their excess power using peer-to-peer (P2P) or local smart connected networks by trading energy assets via smart contracts [15]. The smart solar system presented in this paper can enable the new way of trading the solar power using cryptocurrencies. In addition, this paper studies the technical potential of using block chains and distributed ledger technology to improve energy security. Therefore, the other possibilities this work presents is data security as data can be securely stored for the power generation of each solar panel.

The presented infrastructure provides the platform to implement block chain technology to simplify low cost trading in a secure way.

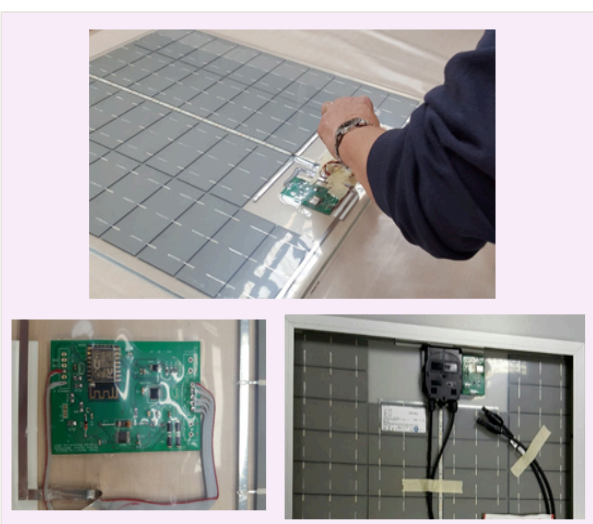

Figure 6. Embedded Module 500 in the Solar Panel

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APPENDIX A

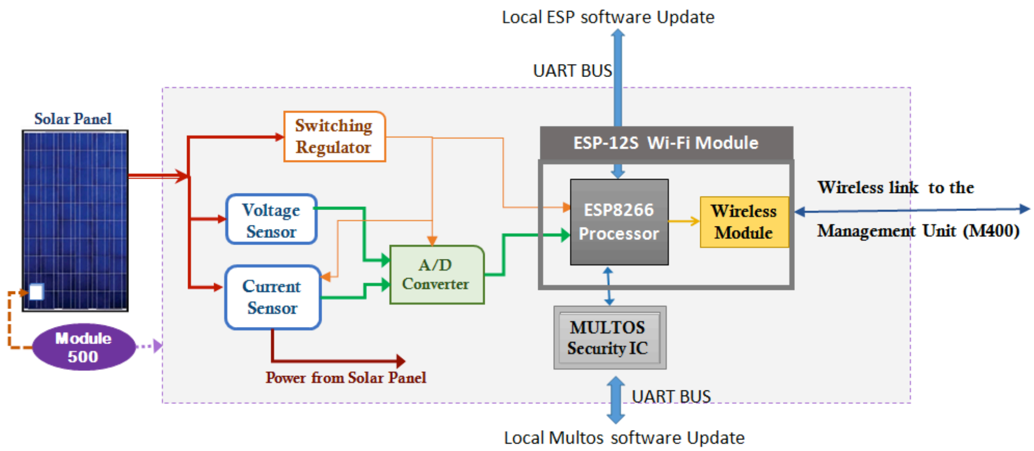

Figure 2. The Block Diagram of Module 500

APPENDIX B

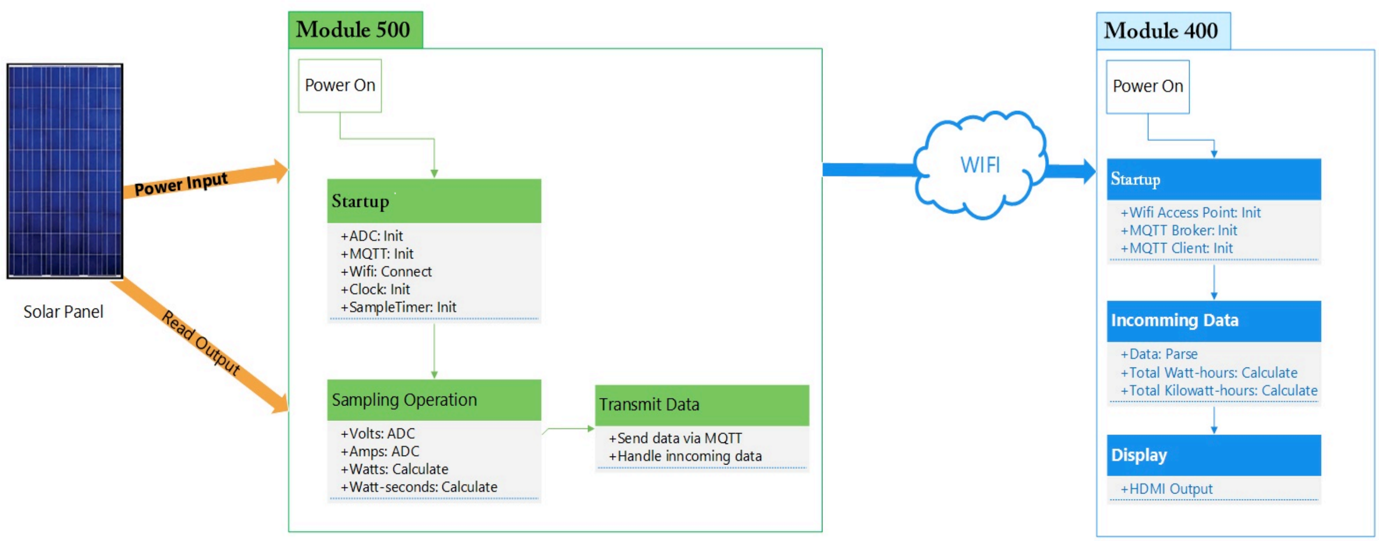

Figure 4. Overall System Flow

Appendix C

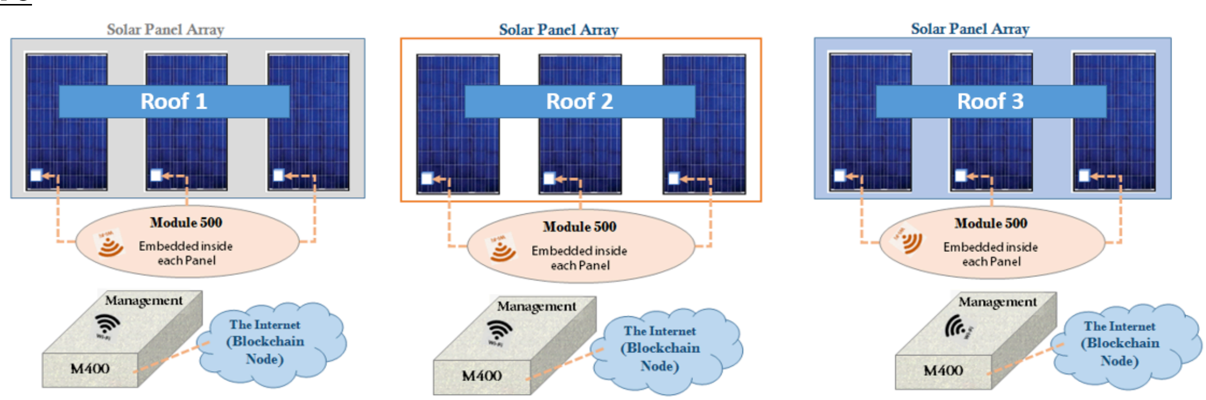

Figure 5. Distributed energy resource asset management system