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Wireless Monitoring Prototype for Photovoltaic Parameters

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ABSTRACT

Photovoltaic (PV) parameters monitoring is very important for the implementation and optimum utilisation of solar energy as electricity source. This work proposes a design of simple, cost-efficient, and low consumption wireless PV monitoring system enhanced by a driving software for recording the PV system parameters. The circuit is designed with a minimum number of components to manage four types of sensors to measure four parameters that are essential for real-time analysis and prediction of PV performance. Only pair of XBee RF modules as an active components, while othera are passive, includes resistors and capacitors for PV current, and voltage those for signal conditioning, temperature and irradiance sensors were also involved. The paper presents a prototype system for high voltage series connected PV array in the range (100-310) V and 3 ampere as a maximum current, while the sampling frequency can be configured up to 14 sample/Sec in applications of the short period for data logging for the four channels. The proposed system succeeds in providing real-time monitoring with lower cost and can be extended for more functions such as controlling tracking system and failure diagnosis.

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1. INTRODUCTION

Raising energy demands and climate changes are the main global issues. To overcome the energy limitations and environmental pollution, the world is widely focusing on alternative and cleaner energy utilisation. Minimum environmental effects, a long life and abundance of availability make the PV more popular amongst clean energies. However, there are few problems associated with PV technology which hinder its development, i.e., high cost and low efficiency [1]. Also, the optimum reliability is considered as an additional issue in this technology [2]. Recent research [3] showed that by using a PV module in outdoor application in accordance with the manufacturer specification gave errors and may cause a system failure later on. It is realised in Virtuani et al. (2011) and Petrone et al. (2008) that the monitoring of PV parameters in realistic condition is very essential for reliability, cost and performance improvements of a PV system. Also, the PV parameters monitoring is essential for evaluation, implementation and in returns on investment analysis of PV systems [4].

Many advantages in utilizing the microcontroller-based circuits and accessing new sensory strategies into PV monitoring applications, but the complexity and cost also need to be taken in a count. Microcontroller-based monitoring system and sensors can be found in everywhere industrially, commercially, and in residential applications. These electronics are designed to be matched directly by the microcontroller, which simplifies modification and the circuit design. A software driver facilities also play a significant role in decreasing the dependency on hardware components allowing engineers or programmer to access the attained data in a sophisticated method with more complex features that could strongly support the application. Many technical descriptions of wireless monitoring systems were presented with pointing out on the disadvantages and advantages of each strategy as well as the its availability on the market, challenges, and future trends of that technologie discussed in [5].

A wireless data acquisition system that helps to estimate solar energy potential considering the remote region's energy requirement has been proposed in [6]. A system for the remote monitoring and control of complex stand-alone photovoltaic plants has been described in [7]. This system records and periodically reports the overall performances. In case of incorrect behavior, the system will immediately inform the operator. Some researchers also develop a monitoring system for current-voltage characteristic of PV module. For example a system in [8] that is capable of continuously monitoring the I-V characteristics of seven modules. Also [9] has developed a computer-based instrumentation system for PV module characterization that allows drawing of the I-V characteristics of a PV module in real meteorological test conditions. The temperature and solar irradiance are the common parameters observed by monitoring systems [6][7][8][9].

These are the parameters that affect the energy produced by a PV system. The deviation of temperature or solar irradiance on PV array changes all PV array parameters [6] [9]. The monitoring of PV array characteristics will enable an analysis of performance, degradation and failure of PV systems [8] [9]. I-V characteristics are also monitored by monitoring systems [8]. Monitoring the I-V characteristics can be used to investigate and compare the actual power produced by the modules under realistic operating conditions [7].

The general advantages of such monitoring devices can be briefly listed as follows:

1. Efficient and cost effective technologies in wireless network that serve future green source of energy.
2. Although the RF modules have a low rate data transmission, but they are quite sufficient to monitor the harvested energy and weather parameters.
3. They can use broadly in device control, building and home automation, remote monitoring, fault diagnosis, and other applications. Several studies can be tabled to summarize the state of art in this field as in Table 1.

The currently available technologies of a weather system and PV parameters are still costly and need sometimes for a complex configuration or restrictions on their install, even those that called lower cost circuits if they used for lower levels of power generation. Other technologies are based on the onboard web server to process the data via Ethernet. These systems are constrained by lower memory to store large amounts of measurements, and the clients only view limited data.

This work presents a very low cost circuit and prototype for wireless and real-time measurement of photovoltaic array parameters using XBee pro s2 as a data processor and transceiver within sensor network. The circuit design and the performed measurements were chosen based on their simplicity, availability, and lower price. The two weather parameters were measured using Light Dependent Resistor (LDR) for irradiance, it is a Non-RoHS Photoconductive cadmium sulphide, which is a light dependent resistor housed in a case of clear lens window, its resistance value decreases as the weather light falling on its window increases [10]. LM35 has been used as a temperature sensor. The two electrical parameters, load current and PV voltage were measured by a custom resister-based current sensor and voltage divider respectively, those two sensors have been used successfully and basically, but an option of using the low cost ACS 712 5A current sensor [11] and voltage sensor also tested and possibly. A full daily measurements of a 150Wp solar panel series connected PV system 50 meter out the Lab where monitoring was conducted to test the real-time measurement system. The sampling time has been selected for a 1 second so as to capture the sudden change in weather that sometimes required for further analysis. The attained data from the PV are further processed, displayed over a MATLAB-based Graphical User Interface (GUI) and stored in the PC disk. Therefore, the method has the advantages of fast processing and offers an easy-to-use graphical weather that permits the system users to deal easily the collected data with no limit and can be used in large power capacity in renewable systems. The proposed circuit can be clearly described in Figure 1.

Table 1. Comparison among different wireless sensor designs in monitoring applications.

Ref.	Descriptions and Main Features	Hardware Components/ node	No of input node	Sampling time	Network
[12]	A set of sensors for logging meteorological parameters (humidity, pressure, solar radiation, wind speed & direction, temperature, rain fall,etc.).	Microcontroller PIC16F877, MAX232, Power Supply, TX5002 and RX5002 chips from RF Monolithic. LABView	5	Not mentioned	Wireless
[13]	A set of sensor nodes for collecting real-time DC-voltage Current, temperature and solar radiation parameters	AD microcontroller converter, MCP3909, NXP-Jennic microcontroller, voltage transformer (toroidal MCFM32/12), optocoupler, SFH615, ACS712 sensor, temperature probe sensor (PT1000), op-amp.	4	1min	Wireless
[14]	Remotely monitoring by wired (Ethernet cable) or wireless connection (radio transmitter) to evaluate in real time the performance of the solar cells and weather conditions.	Solar Cell Test Station (SCTS) includes: (1) dye sensitized solar cells and pyranometer for sun irradiance; (2) control circuit for battery charging (3) data storage and transmission.	3	4min	Wireless
[15]	Real-time measurement of photovoltaic system using Zigbee sensor networks. The measurements were performed using sensors that are chosen based on their simplicity and lower price	OPT101 photodiode for Irradiance, DHT22 for temperature and humidity, ACS 712 5A as a current sensor, voltage sensor modules, Arduino, and Zigbee	3	3 - 4 Sec	Wireless
[16]	Low cost Data acquisition system DAS applied to decentralized renewable energy (RE) plants with an USB interface	USB interface microcontroller , real time clock (RTC), an external EEPROM, which communicates using an I2C twin wire, TTL/RS-232 transceiver, which can be used as interface in GSM/GPRS modems and a TTL/RS-485 transceiver for use in Modbus devices networks.	2	10min	Wire
[17]	Real-time monitoring system for 6-parameter tropical environmental elements and the energy performance of 3 types of Photovoltaic (PV) generator systems with the total capacity of 10kW	cRIO as means of Data Acquisition and Real Time Monitoring (DART) system LabVIEW software and	6	30min	Wire
[18]	Energy-saving urban mobility monitoring system based on wireless sensor networks (WSNs)	Bluetooth sensor and a Zigbee transceiver, Microcontroller (Arduino Uno R3), Zigbee shield, Zigbee module (Xbee Pro), Bluetooth reader (HC-05), Storage card, Mini PC (Raspberry Pi-B), Battery pack.	1	Not mentioned	Wireless
[19]	DAS using PIC12F675 microcontroller for real time, temperature and humidity monitoring.	Serial adapter BAFO BF-810, PIC12F675, MAX232, LM35 Temp sensor, TPS00715 humidity sensor, OP-Amps, PICkit2 programmer. USB to serial adapter BAFO BF-810, Visual Basic 6	4	30min	Wire
[20]	Real-time monitoring system by short text Message Service (SMS). Through a GSM network	(1) 16F877 Microcontroller (2) External 24C32A EEPROM memory (3) LF398 Integrated Circuit (4) MAX 232 drivers/receivers (5) DB 9F connector (6) Power supply (7) LM016L LCD (8) Hall-Effect Sensor (9) Sensor Outputs	5	1 hour	Wireless

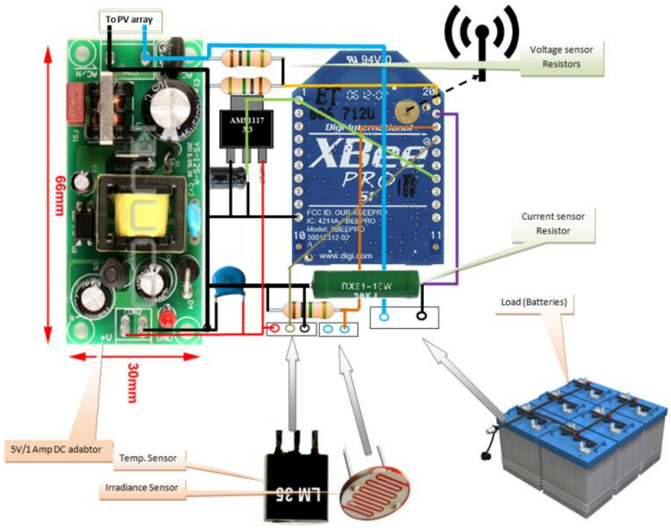


Figure 1. Proposed circuit diagram

2. RESEARCH METHOD

The proposed wireless weather system is composed of a remote node and base station. The remote node is solar powered through High voltage DC-DC supply which is available elsewhere and commercially known as a 5V DC adapter, and this one of the reasons that makes this system is lower in cost. The base node or station receives and buffers the transferred data and then transmitted it via the UART adaptor card and identical XBee Pro module to a connected PC for processing.

2.1. PV Measurements

The accuracy of PV measurements is influenced by the sensor circuits and software code. The PV parameters that usually monitored and logged; for weather are: irradiances and temperatures, while for electrical measurements are voltage, and current. A low cost XBee Pro S1 module with a voltage divider as a voltage sensor has been used to indicate the PV output voltages. This sensor module is based on resistance points principle to reduce the input voltage of 10 times from original voltage value. The XBee module chip has an 10 bit analog to digital converter or can convert the values between 0-1023, therefore the resolution is 0.003226 V (3.3V/ 1023). The input voltage of the XBee as a maximum range is limited by the voltage at the Vref pin of the module, which is fixed at 3.3 in our case. The PV voltage calculated by equation (1) as follows:

$$V_{PVout} = \left(\frac{3.3}{1023}\right) V_{XBee}.1/\,Ratio \quad (1)$$

Where V_{XBee} is the analogue signal (0-1023)

$$Ratio = 1/10 \quad (2)$$

As an option, ACS712 current sensor is used as a current module to measure the PV current, which provides precise and economical solution for such applications. ACS712 current sensor converts the current value into a relevant voltage value. The design suggests to supply a power of 5V instead of 3.3 to benefit from higher range. By default, the middle sensing voltage is 2.5V at no current sensing. The PV current then calculated using equation (2).

$$I_{PVout} = \left(\frac{5}{1023}\right).V_{XBee2} - 2.5/0.185 \quad (3)$$

The overall setup of the PV monitoring system, with all interconnections among sensors and Zigbee network can be seen in Figure 2. The PV array were a series modules that measured on Electrical and Electronics/ Engineering Faculty, UPM Malaysia.

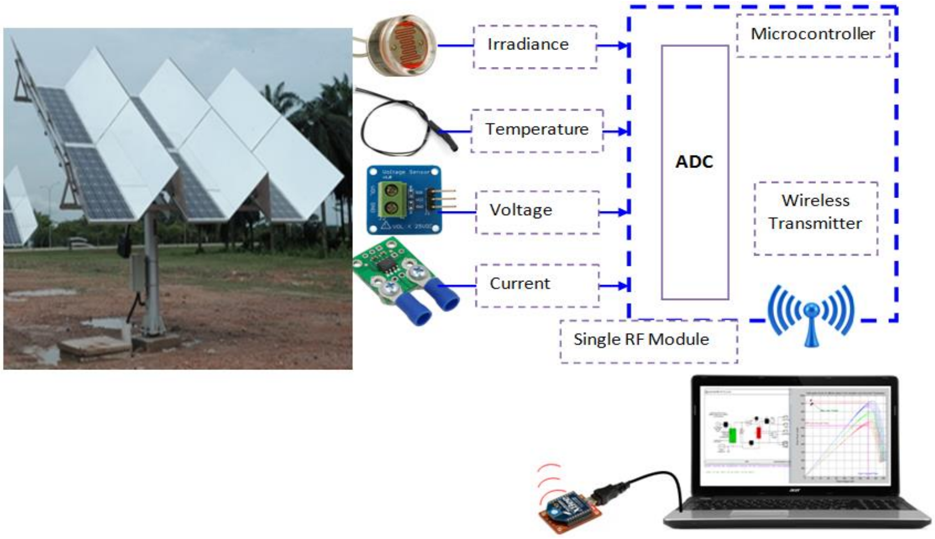


Figure 2. Overall system setup

2.2. Software work

Since this paper propose a new 4 parameters monitoring circuit, which is recognized by the dispense of additional Microcontroller such as Ardiuno, Raspberry Pi brand, BeagleBone Black, and BeagleBone Black, in a traditional monitoring system of such application. Therefore, the proper functioning of data acquisition system firmware was developed to access the Xbee's microcontroller and manage the data processing though it and all was prepared in MATLAB.

2.2.1. Communication Protocol

The communications technique through the serial bus to access the data can be defined as the serial interface protocol. XBees configuration is in transparent mode by default. But this work utilized Application Programming Interface API, one of the two XBee modes. The API mode provides a structured interface where data is communicated throughout the serial interface in structured packets. This will help to enable to create complex communication between XBee base module and Xbee end device or remote module without the need to define the protocol.

The algorithm starts with creating a frame-based API to extend the level to which a host application can interact with the networking capability of the module. The received data by the USB serial input is queued up for the radio transmission process, then data received wirelessly is sent as it exactly received to serial output, without further information. When API mode is enabled, (AP = 1), the UART data has a frame structure defined as shown in Figure 3.

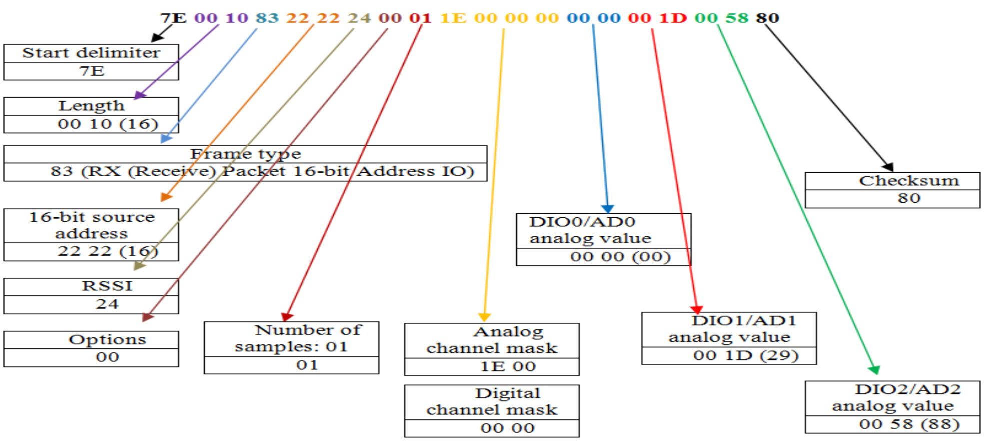


Figure 3. Frame structure when API mode is enabled, (AP = 1)

This work also involves the command mode of XBee operation. Command mode is a state in which the firmware interprets incoming characters as commands. Command mode provides the project to adjust the device's firmware by changing the parameters that can be set using AT commands.

Since the XBee Module support ADC (Analog/digital conversion) as well as the digital I/O line passing. The proposed work used the maximum available 6 analogue channels for the temperature, currents and voltages while using the digital I/O lines to control appliances status. The flowchart of the proposed system can describe the driving steps of data processing and displaying as can be seen in Figure 4

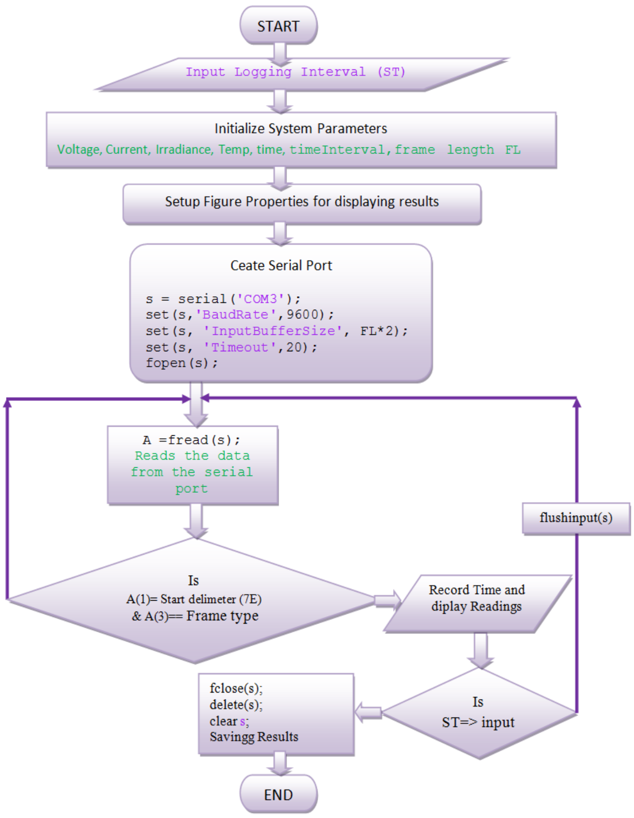


Figure 4. Flowchart of the proposed system

2.2.2. XBees Initial configuration

At the beginning, the Xbees (base and remote) configured with the proper parameters, so that they will communicate each other. In both XBee radios, XCTU is utilized to load the initial parameters as listed in Table 2

The designing of such wireless network, the XBee RF node acts as a transceiver and has three different categories; a coordinator, end node or a router. A coordinator XBee performs as an access point and receives all incoming data packets from end device or router one. In contrast, the end device node XBee collect, process, and transmits data packets to a coordinator sensor. It may use a router XBee to act both as a transmitter and receiver to hand the data packets from-two adjacent end device nodes or routers.

The settings of the XBees configure the remote RF module to set AD0, AD1, AD2, and AD3 as analogue input and sampled once each every 20ms. Then sending to the base RF module. The base must accordingly receive a 24-Byte transmission (12 Bytes of data and 12 Bytes framing) every 20ms.

The characteristic curves of the weather parameters have been formulated and adopted in the analysis software at the base station, those curves can be seen in Figure 5.

Table 2. Parameter configurations of the remote and base modules.

Parameter	Remote Configuration	Base Configuration
CH Channel	C	C
ID PAN ID	3332	3332
DL (Destination Address Low)	DL = 0x1111	DL = 0x2222
MY (Source Address)	MY = 0x2222	MY = 0x1111
BD Interface Data Rate	115200 [7]	
API Operation	API disabled[0]	API disabled[1]
Analog- to- Digital Converter, DIO = Digital Input/output	D0= D1= D2= D3= D4= D5= ADC[2];	N/A
IR (Sample Rate)	IR = 0x14	N/A
CE Coordinator Enable	N/A	Coordinator [1]
IU (Enable I/O Output)	Enabled [1]	Enabled [1]
IA (I/O Input Address)	N/A	0xFFFF
End Device Association		0100b [4]

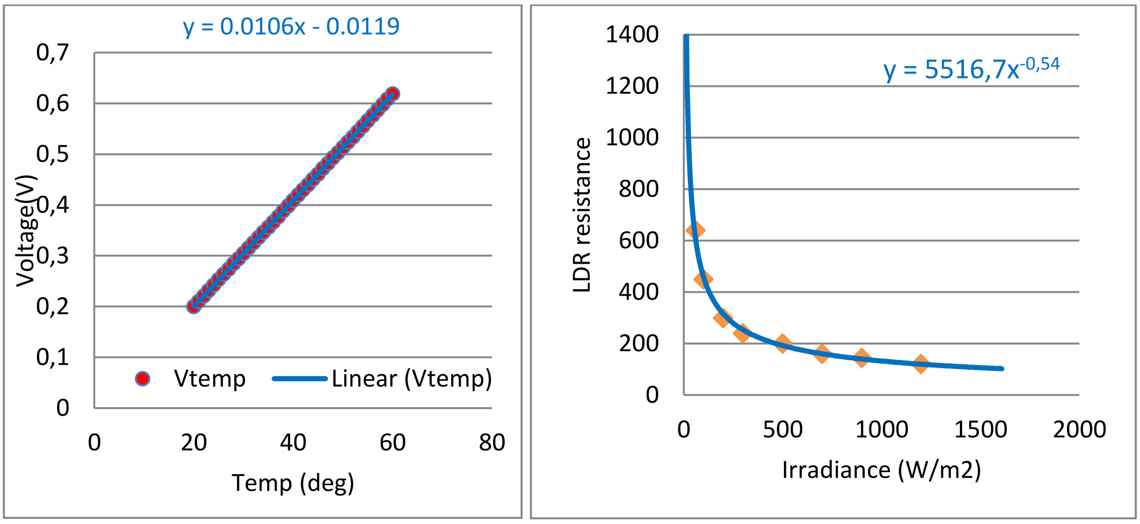
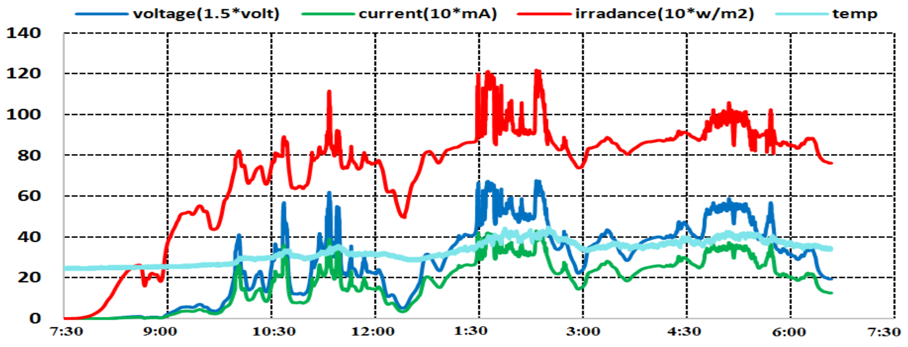


Figure 5. The characteristic curves of LM35 and LDR.

Figure 5, shows also the formulas of each sensor individually, where the temperature sensor acts linearly, while the LDR has a power modeling equation with respect to irradiance variation.

3. RESULTS AND ANALYSIS

The proposed solution has been assessed through full daily measurements for 150Wp solar panel series connected PV system which is 50 meters far out the Lab where the measurements conducted to test the real-time monitoring system. The sampling time has been selected for a 1 second so as to capture the sudden change in weather that sometimes required for further analysis. The developed sensor node has been attached to a set of Solar panel modules with the intend on collecting both DC voltage and current measurements, as in Figure 2. The weather sensors in the same remote node have been used to measure the environmental parameters (solar radiation and temperature), these parameters are sufficient to estimate the I-V, PV and the daily harvested energy curves for the PV modules. The Collected Data and PV Module Performance for electrical and environmental data was collected by the sensor nodes taking a 1 Sec sampling time. Figure 6 and 7 show examples of two days of the harvested data in UPM PV site, Serdang, Malaysia.



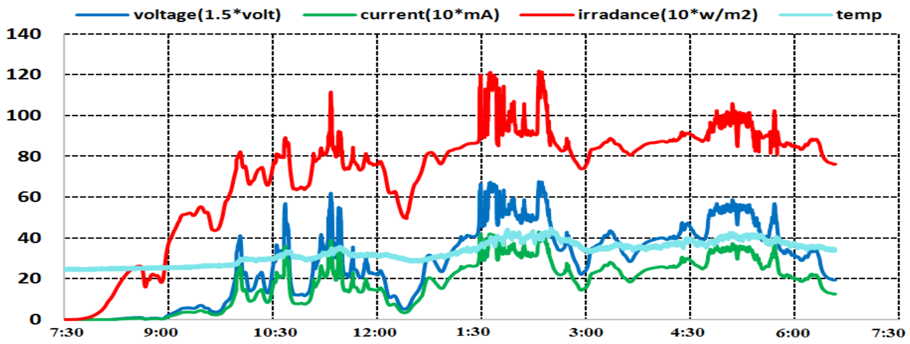


Figure 6. Daily measurements of solar panels on 20/6/2016 in UPM/Malaysia

The proposed monitoring PV system can be also applied to check the range of electrical power generation and compare the results with the expected manufacturer's data-sheet values.

The validation of the monitoring system performance can be evaluated by comparing 4-channels sine wave signals transmitted from the function generator with different amplitudes and phase shifts to be monitored though the proposed monitoring system as can be seen in Figure 7.

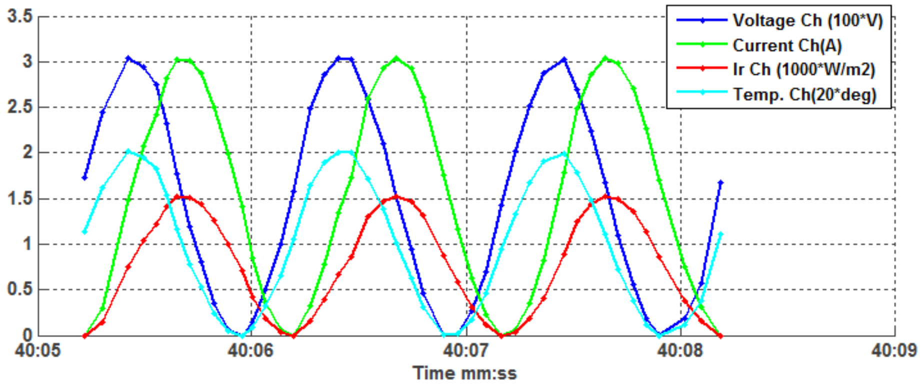


Figure 7. Results validation by sending and received of 4 sinewave signals via the system.

4. CONCLUSION

This work proposes a concept of monitoring the parameters of a PV system that characterized by lower cost and efficient for smart grid applications. Several related work in this concerern enhanced by their products have been reviewed as well.

The presented experimental result highlights that the real-time parameters monitoring for a PV can be implemented via only a pair of Xbees. Commercially power supply is also used as a DC-DC to maintain the power for active devices. The proposed prototype promoses for high quality available monitoring devices to measure the system performance with more energy savings. This work offers valued efforts towards the selection of a more efficient and user-friendly monitoring system in smart grid and integrated solar powered home system [21][22]. However, providing such low cost systems and tailored to fit user profiles is a strong start for offering real-time feedback in easy way. Finally, the designed tool is also useful for the researchers to understand the behaviour of different photovoltaic technologies in natural conditions and for the analysis of degradations in PV modules with respect to age and environmental effects.

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