The Design of Online Photovoltaic Monitoring (PV) System for Small-Medium Power Consumption

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Abstract- **In order to analyze the performance of PV systems, we have developed a real-time monitoring system using communication gateway that can be remotely accessible from anywhere in the world using an internet portal. The development of the system is able to monitor, supervision and control of PV systems installed over wide area and at the same it can collect current data which can be stored in the database or server for future analysis. Based on the analysis of several remote monitoring technology projects that exist nowadays, this project aimed to design, construct and integrate with others to build a comprehensive system that can be applied whether for household application or large scale Photovoltaic (PV) plant. This project is developed to innovate the green technology mainly in solar energy to be more efficient and reliable source of future energy used by the household users and an industry. By doing so, the monitoring system needs to be flexible and accessible anywhere to make sure early detection of any malfunction can be alerted.**

Keywords- **PV Monitoring, Solar panel, Online / remote monitoring.**

I. INTRODUCTION

Live monitoring system is widely used in many areas especially in power plant and agriculture industry. It is used to analyze and monitor current performance of the equipment measured. In modern agriculture sector some critical plant such as vegetables and flowers need to critically monitored 24 hours to collect valuable data of growth. In power plant, it is important to collect the data for further analysis such as power consumption, voltage and temperature. This type of monitoring needs to be autonomous and continuously monitored, so that it can provide early fault occurrence and early restoration can be provided to avoid major problem.

II. SYSTEM DESCRIPTION

This project monitoring system ensures, with the modular concept, that every plant operator can individually determine the extent of their energy management. This applies for existing and new PV plants with small or large PV power generation capacity. The following modules are some of the solution of PV Solar monitoring.

- The basic solution for intelligent energy management and live remote monitoring
- Flexible storage solution for new and existing PV plants: Flexible Storage System

The system installed configuration for basic intelligent solution with remote monitoring system can be shown in the picture below:

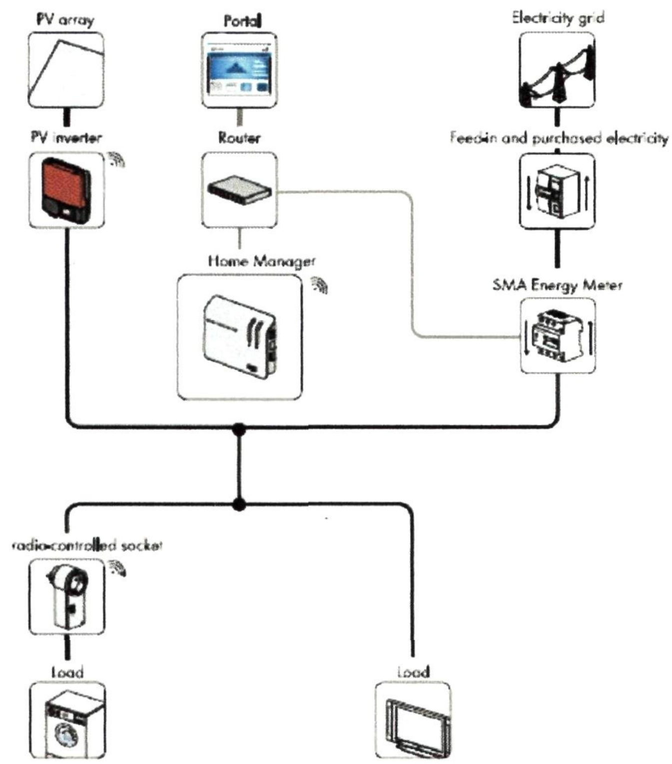


Fig. 1 Example PV Solar Monitoring with Grid-Connected system and Power Load Management.

Main Components of Monitoring System:

2.1.1 Input Signal (PV- Solar Panel & Inverter)

In this project we use 2 types of PV Solar panel which identify by system 1 and system 2. The purpose is to see the difference of performance of this 2 solar panel and compare the end result. The solar panel characteristics and parameters is being identified as table below [1] :

System I: Polycrystalline-Silicon GC System

For polycrystalline (p-Si), the detailed characteristics of the system I as tabulated in Table 1.

TABLE I. SYSTEM CHARACTERISTICS

Type of System	Grid Connected
Nominal Power(w)	6.11 kWp
Inverter	1 unit X SB5000TL
Mounting	Retrofitted
PV Module	Polycrystalline (13 units x 235Wp)
Array Configuration	1 string x 13 series

In addition, the picture of system I with 6.11 kWp using p-Si technology is shown in Figure 1.

Fig. 2 Example of a 6.11 KWp GC system installed at GERC, UiTM Shah Alam, Selangor Darul Ehsan, Malaysia.

System II: Monocrystalline-Silicon GC System

For mono-crystalline (m-Si), the detailed characteristics of the system II as tabulated in Table II.

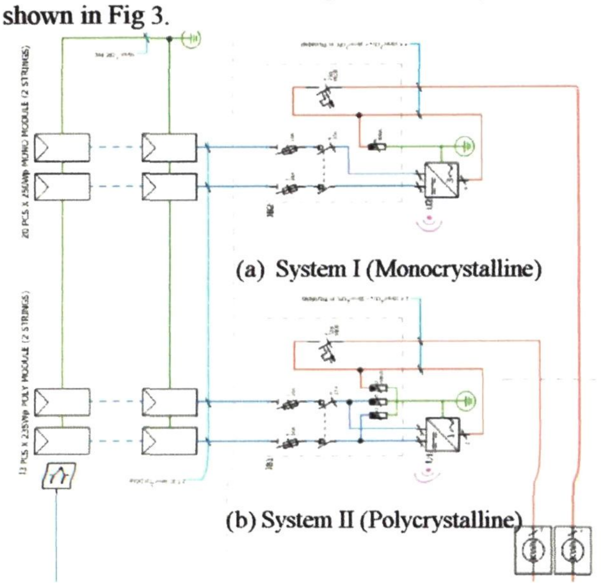
TABLE II. SYSTEM CHARACTERISTIC II

Type of System	Grid Connected
Nominal Power(w)	10kWp
Inverter	1 unit X STP8000TL
Mounting	Retrofitted
PV Module	Mono-Crystalline (20 units x 250Wp)
Array Configuration	2 string x 10 series

Furthermore, system II has equipped with 10 kWp using m-Si technology is illustrated in Figure 2.

Fig. 3 Example of a 10 kWp GC system installed at GERC, UiTM Shah Alam, Selangor Darul Ehsan, Malaysia.

In addition, the schematic diagram for GC system I and II as shown in Fig 3.



(a) System I (Monocrystalline)

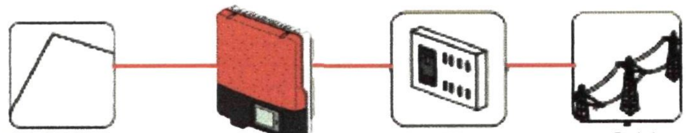
(b) System II (Polycrystalline)

Fig. 4 Schematic diagram of GC systems installed at GERC, UiTM Shah Alam, Selangor Darul Ehsan, Malaysia.

2.1.2 Inverter

The inverter used in this project is Sunny Boy PV inverter[2], which converts the direct current of the PV array to grid-compliant alternating current and feeds it into the electricity grid or being used by household electrical equipment.

The basic configuration of an inverter to solar panel as below:



This inverter used as it is one of efficient inverter which has higher 750 volt maximum input voltage that can be connected to this inverter in one time. It effected the design which can reduce module string is needed because more modules now can be connected or switched on in a series.

- Highly flexible design reduces cabling requirements
- Maximum efficiency of 97 percent ensures top solar yield

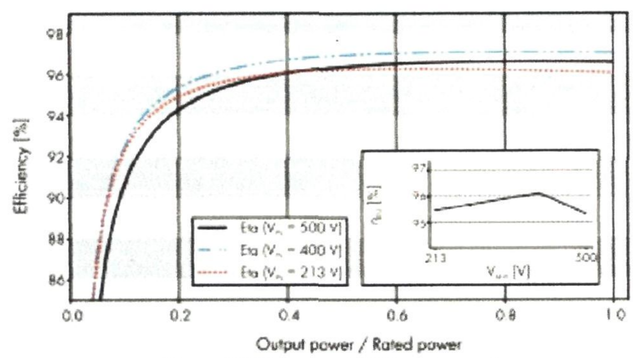


Figure 5 Efficiency of PV Inverter used

The specification of inverter used is as below :

DC INPUT

Maximum DC power at cos φ = 1 3,200 W
Maximum input voltage* = 750 V
MPP voltage range = 213 V to 500 V
Rated input voltage = 400 V
Minimum input voltage = 125 V
Initial input voltage = 150 V
Maximum input current = 15 A
Maximum input current per string = 15 A
Number of independent MPP input = 1
Strings per MPP input = 2

OUTPUT AC

Rated power at 230 V, 50 Hz 3,000 W
Maximum apparent AC power = 1 3,000 VA
Rated grid voltage = 230 V
AC nominal voltage = 220 V / 230 V / 240 V
AC voltage range* = 180 V to 280 V
Nominal AC current at = 220 V 13.6 A
Nominal AC current at = 230 V 13.1 A
Nominal AC current at = 240 V 12.5 A

Maximum output current = 14.6 A
Maximum output current in case of faults 14.6 A
Total harmonic factor of output current at
AC total harmonic factor < 2%,
AC power > 0.5 nominal AC power ≤ 4%
Rated mains frequency = 50 Hz

2.1.3 Communication module

As the central communication interface, the communication module connects the PV plant and its operator. This is the gateway that collects and documents all data of the connected devices, thus permitting interruption-free monitoring of the PV plant. The communication module provides the operator with all recorded data via an Internet connection. In this project we use sunny WebBox as our gateway

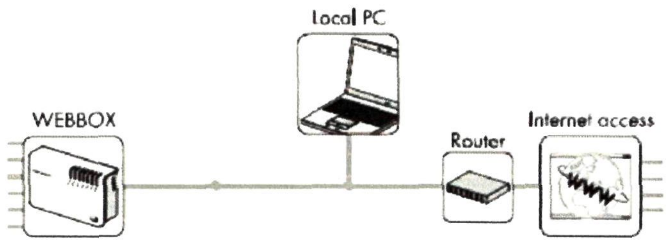


Fig. 6 Example position of communication module in PV monitoring system

The WebBox is also a powerful tool for operators when configuring plants or performing remote diagnostics via computer. It allows continuous monitoring of the PV plant and early detection of disturbances. Thus, the WebBox helps to optimize PV plant yields.

Specification of Communication Module WebBox [2]:

Table 3: Specification of Communication Module

Communication	
Inverter communication	RS485, 10/100 Mbit Ethernet
PC communication	10/100 Mbit Ethernet
Modem	Analog (optional), GSM
Max. number of devices	
RS485 / Ethernet	50 / 50
Max. communication range	
RS485 / Ethernet	1,200 m / 100 m
Power supply	
Power supply	External plug-in power supply
Input voltage	100 V - 240 V AC, 50 / 60 Hz
Power consumption	Typ. 4 W/ max. 12 W

Environmental conditions in operation
Ambient temperature -20 ° C to +65 ° C
Relative air humidity 5 % to 95 %, non-condensing

Memory
internal 8 MB circular buffer
external SD-card 128 MB / 512 MB / 1 GB / 2 GB

The environment Sensor allows the user to further expand the plant via the WebBox. The environment sensor records the environmental data relevant to performance monitoring at the PV plant. For this purpose, the environment has an integrated irradiation sensor as well as an external module temperature sensor. The user can also connect an optional ambient temperature sensor and a wind sensor to the sensor.

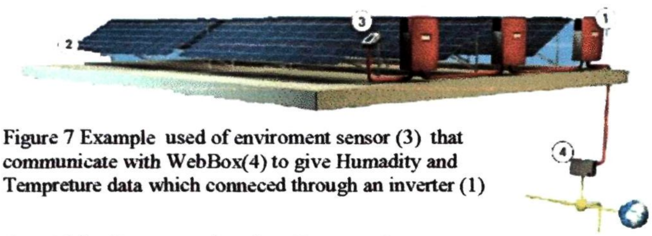


Figure 7 Example used of enviroment sensor (3) that communicate with WebBox(4) to give Humadity and Tempreture data which conneced through an inverter (1)

2.1.3(a) Communication Protocol
JavaScript Object Notation (JSON)

For this project we used WebBox as communication module unit. This project use Java Script Object Notation (JSON) language as the programming language for the communication module which also called as API (Application Programming Language). JSON is light-weight programming language, easy to use and can be intercommunicate with other existing programming language such as Python, C++,C, PHP etc.

A description and explanation of JavaScript Object Notation (JSON) can be found on the website [3].

The following example shows an illustration of a device list. It defines an object made up of the values "totalDevicesReturned" and "devices".

"totalDevicesReturned" is a figure with the value 4. The array "device" has 2 fields, each having one device object), which in turn contains nested device objects.

```
RPC={
"totalDevicesReturned":4,
"devices":
[
{
"key":"SCC250H9:1390148531",
"name":"Sunny Central E1",
"children":
[
{
"key":"SCBFS016:8945",
"name":"Sunny BFS E1",
"children":null
},
{
"key":"SMU8b004:2567",
"name":"String Monitoring Unit E1",
"children":null
} ] },
{
"key":"SCC250H9:1390148538",
"name":"Sunny Central E2",
"children":
{
"key":"SCBFS016:8956",
"name":"Sunny BFS E2",
"children":null
},
```

"key":"SMU8b004:2534",
"name":"String Monitoring Unit E2",
"children":null }] }] }

2.1.4 Monitoring Portal

Monitoring Portal is an Internet portal for the monitoring of plants as well as the visualization and presentation of plant data.

In order to use Monitoring Portal, we need a product that can record your plant data and send it to the Portal Depending on which product sends the data to Monitoring Portal, various functions are available in the Portal.

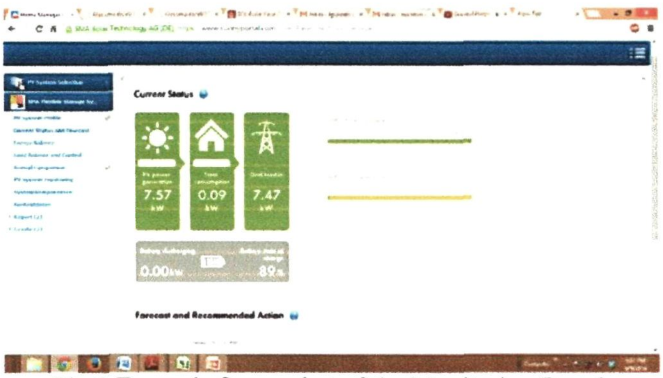


Fig 8 Example Screenshot of the Monitoring Portal

The specification, requirements and data available and accessible to view using the portal is as below:

Table 4: System requirements and specification

System requirements	
Supported operating systems	All / optimized access for mobile devices
Plant information	
Plant description	Overview of the key properties of the PV plant
Annual comparison	Quick yield overview of the entire operating period
Energy balance	Overview of purchased and fed in power and self-consumption, if applicable (power Meter integration via Meter Connection Box)
Plant log book	Access to messages regarding plant events
Device overview	Properties and parameters of the devices in the PV plant
Software	
Recommended browsers	Firefox, Internet Explorer, version 7 and later, Safari
Other	JavaScript and cookies enabled
Supported data logger	WebBox, Home Manager
Access	
Website	http://pvmc.uitm.edu.my/gerc/gerc.php
Monitoring	
Inverter comparison	Fully automatic and ongoing inverter yield comparison and e-mail alarms
Communication monitoring	Ongoing monitoring and, when necessary, alarms for the connection between the Portal and the WebBox
Status reports	
Information reports	Daily or monthly reports on energy yield, maximum output, temp
Event reports	Hourly or daily reports on information, warnings, faults and errors
Report format	Text, PDF, HTML

III. METHODOLOGY

In order to monitor the current data feed (power generated by PV Solar Panel) through the communication gateway every 15 minutes from the PV we have setup the a method to integrate the data received into the local server to the internet and publish to the website. The data publish need to be sync with the hardware every 15 minutes and stored at the server in SQL format.

The data loggers which is communication gateway which in this project we used WebBox continuously record all the data of a PV plant. This is then averaged over a configurable interval and cached. The data can be transmitted at regular intervals for analysis and visualization.

Using the WebBox RPC interface, selected data from the PV plant can be transmitted to a remote terminal by means of an RPC protocol (Remote Procedure Call protocol). To do this, the WebBox provides a pool of service procedures that can be accessed from the remote terminal by means of a Remote Procedure Call protocol (RPC protocol) via a network or RAS (Remote Access Service) connection. The data exchange format used here is the JavaScript Object Notation (JSON).

3.1 Remote Procedure Call (RPC) via HTTP

Data exchange takes place by means of the Hypertext Transfer Protocol via a TCP/IP connection to the web server port configured in the WebBox.

Both the client-side implementation effort and the resource requirements are relatively high. As a general rule, communication takes place via the standard port 80, which means that there is no need to make any changes to active firewalls.

- The default setting is port 80.
- The URL for all requests is: http://IP address/rpc
- The IP address in each case is the currently configured IP address of the WebBox.
- The default setting is 192.168.0.168.

Hence, the default URL is the following: http://192.168.0.168/rpc.The request is transmitted via HTTP POST in the body of the HTTP request as a serialized JSON object according to the conventions established.

Both the client-side implementation effort and the resource requirements are relatively high. As a general rule, communication takes place via the standard port 80, which means that there is no need to make any changes to active firewalls.

IV. RESULT AND DISCUSSION

Graph in Figure 9 shows the power energy yield in DC input represented by Watts (W) versus hour generated by the system 1: polycrystalline PV Solar panel throughout the day. The graph shows that generated power on a day is around 11AM to 1 PM every day.

This graph in a form of mean power displaying by is automatically generated by the system based on lived feed data from the communication gateway every 15 minute to the server and then being displayed to monitoring portal.

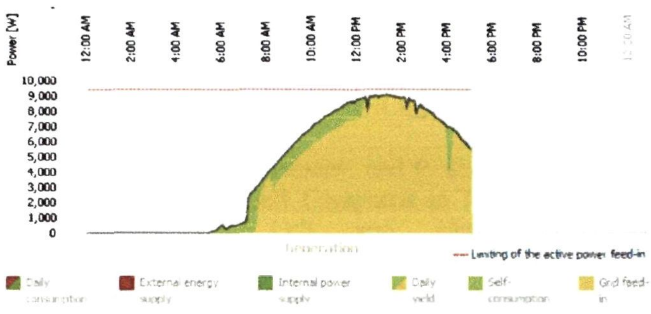


Fig. 9 Solar Power Generated for PV Solar panel

Graph in Figure 10 below shows the power energy consumption used by electrical equipment in a household. The consumption of electrical power normally lower then power generated by the PV Solar panel during morning. The access power generated normally will be stored in a battery to be used when the power generated is lower on afternoon and at night

The integrated power supply between the Solar Panel, Battery and the Grid connected have make the electrical used is very effective and save cost

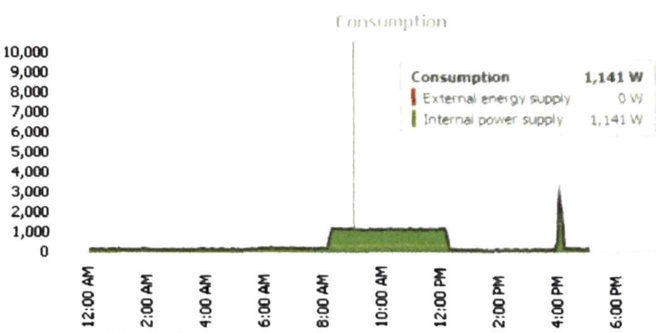


Fig. 10 Power consumption by electrical equipment

The monitoring portal can also displaying the ambient temperature and irradiance based on the measurement using environment sensor that being integrate with the communication gateway.

The graph in Figure 11 shows the relationship of ambient temperature and irradiance to the voltage and current produce by the solar panel. The ambient temperature and irradiance is used in analysis of the performance ratio of the solar panel. The data collected from the environment sensor is being stored in the database at the server same as the data of the power generated and power consumption. This data is very useful in comparative studies and performance evaluation of the solar panel.

As shown in the graph we can see that the ambient temperature is directly proportional to power generated by the Solar Panel.

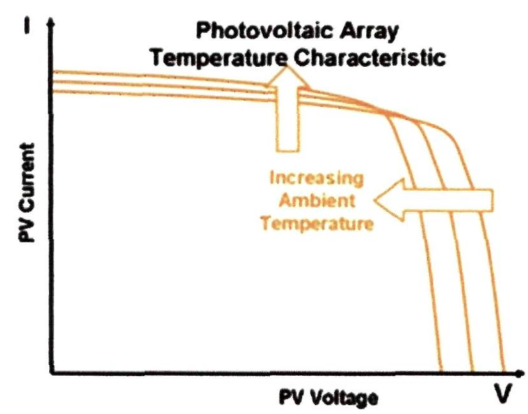


Fig. 11 Effect of ambient temperature on module voltage and current

The monitoring system also can shows forecasting of power generated based on location setting by the user and the system will calculate based on whether data provided in the internet. Shows in figure 12 the forecasting made and gives an over-view of expected PV power generated by the solar panel and recommendations given on the manual switching-on of loads.

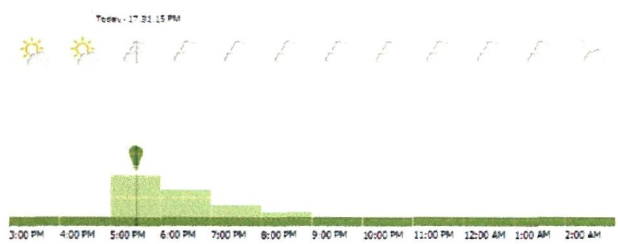


Fig 12: Example of forecasting based on environment data sensor

The data collected by the system will be stored in a database for future references and further studies of power generation of the plant or household consumption. The table below shows the example of data collection between system 1 using polycrystalline and system 2 mono-crystalline as studies in [4] shows the effectiveness of PV solar panel made from polycrystalline slightly more efficient then the other ones

TABLE 5: ENERGY AND MODUL EFFICIENCY

			Total		Monocrystalline		Polycrystalline	
			Total		10 kWp		6.11 kWp	
		Irra.						
	Month	kWh/m2	kWh	Eff.	kWh	Eff.	kWh	Eff.
2013	May	139	1779	11.8%	1097	12.0%	682	11.5%
	Jun	143	1664	10.8%	1138	12.2%	695	11.4%
	Jul	133	1698	11.8%	1079	12.4%	674	11.9%
	Aug	136	1781	12.1%	1094	12.3%	687	11.9%
	Sep	140	1756	11.7%	1081	11.8%	675	11.4%
	Oct	144	1798	11.6%	1103	11.7%	694	11.4%
	Nov	129	1608	11.6%	984	11.7%	623	11.4%
	Dec	123	1576	11.9%	901	11.2%	566	10.8%
2014	Jan	137	1718	11.6%	981	10.9%	675	11.6%
	Feb	112	1428	11.8%	871	11.9%	557	11.7%
	Mar	153	1940	11.8%	1186	11.9%	743	11.4%
	Apr	131	1688	12.0%	1029	12.0%	658	11.8%
		1620	20436	11.7%	12545	11.8%	7929	11.5%

Table 5 above is sample data collected by the PV Monitoring system that stores the power output of the 2 systems mono-crystalline and poly crystalline in a period of 1 year. This data are stored in Sql database format in the server and used to analysis and studies for PV Solar panel material efficiency.

ACKNOWLEDGEMENT

The authors wish to acknowledge Faculty of Electrical Engineering, especially the Green Energy Research Centre, Research Management Institute (RMI), UiTM Sunny Solar for providing the System to Faculty of Electrical Engineering, UiTM in order to complete the project by sharing the data and facilities.

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