VOL. 11, NO. 22, NOVEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

SETTING UP A REMOTE ACCESSING OF A PV PLANT AND ITS ANALYSIS

Wong Hoong Wei, Syed Ihtsham Ul-Haq Gilani and Hussain Al-Kayiem
Mechanical Engineering Department, Universiti Teknologi Petronas, Bandar Seri Iskandar, Perak, Malaysia

ABSTRACT

The growing interest and increasing installation capacity of photovoltaic (PV) power plants have raised the awareness of the necessity and importance of better managing the PV power plant system in order to harvest the optimal energy yield from PV power plant. To accomplish the above objectives, sufficient supervision and monitoring the health and performance of the PV system are necessary. This paper presented a remote PV plant in UTP to be monitored remotely. The performance ratio of the PV power plant is evaluated based on the data collected through Sunny Portal. The result obtained shows that the low performance ratio of the PV power plant not only as a result of less power demand from the load but also due to the state of charge of the battery bank. The PR of the PV power plant varies between 12.90% and 29.74%.

Keywords: PV power plant, remote monitoring, insolation, temperature, PV modules, performance ratio.

INTRODUCTION

Energy is the essential driving force for development, modernization and economic foundation of our civilization and its demand is escalating globally. However, as current global energy sources primarily rely on burning fossil fuels, they have been the main contributing factors to the greenhouse emissions, global warming, and drastic climate change. Moreover, they are non-renewable and they will definitely end in the near future. The upraising concerns towards the environmental impact and depletion of available fossil fuels have driven the governments and industries from all over the globe to move towards green energy and producing energy from renewable energy sources, which are abundant and free to access.

As agreed by Mekhilef, S , Safari, A, Mustaffa, WES, Saidur, R,Omar, R, Younis, MAA (2012) [1], solar energy has always been considered as one of the most promising alternative energy. It is naturally available and a clean energy source, which is extracted from the sun and can be used directly to generate electricity. It has the least impact on the environment and will not deplete as natural fossil fuels do. Photovoltaic (PV) cells are used to capture the sun radiation and directly convert the sunlight into electricity. A PV module is a combination of PV cells and a PV array system is formed by connecting several PV modules connected in series or parallel. Having the property to absorb sunlight, PV cells are able to capture photon and produce free moving electrons. As explained by K. L. Ray (2010) [2] , "when the electron gain sufficient energy from the sunlight and move freely in the PV cells, a potential barrier is built up and assists these free moving electrons to produce voltage, which is used to drive a current through the circuit".

Malaysia is a tropical country and located in Southeast Asia, between the longitudes of 100 to 120 degree due East of Meridian and between 2 to 7 degree due North [3]. Due to the strategic location of Malaysia, high solar irradiance is available throughout the entire year. Nearly 88,467 MW of PV is installed in Malaysia in the year of 2014 [4]. S. C. Chua and T. H. Oh (2012) [5] anticipated that the future of solar energy is auspicious and is anticipated to outshine others renewable energy sources in Malaysia by the year of 2050 .

The growing interest and increasing installation capacity of photovoltaic (PV) power plants have raised the awareness of the necessity and importance of better managing the PV power plant system in order to harvest the optimal energy yield from PV power plant. To accomplish above objectives, sufficient supervision and monitoring the health and performance of the PV system are necessary. In comparison to huge PV power plant, which can afford to have complicated PV monitoring systems and dedicated personnel available on site for continuous monitoring and maintenance, small-scale PV plants installed for residential or commercial and remote area usage are often insufficiently monitored after installation.

Setting up a remote monitoring system for a PV power plant enable the operators to have real-time monitoring to conduct data analysis on the performance of the system to give prominent to potential defects of the power supply design, hence permitting the use of proper countermeasures without being onsite. Among the benefits of remote monitoring systems for PV plants include (i) enabling PV plant operator to acquire real-time information of their PV panels with the corresponding economic advantage of making the ideal trade off by switching between electrical and solar power supply, (ii) instant problem pinpointing as well as pre-emptive resilience to failure enabling trained technician to fix the problem quickly, (iii) self- repairing of the PV system through monitoring software when possible [6].

PV'S SYSTEM CONFIGURATION

The 10kWp PV power plant installed in UTP Solar Research Site consists of 40 pieces of PV panels from Canadian Solar, (Model:CS6P-250P). The UTP PV power generation system has two subarrays. One subarray with 2 parallel strings of 10 PV modules connected in

VOL. 11, NO. 22, NOVEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

series and connected to one PV inverter and another one with 10×2 linked the other inverter as illustrated in Figure-1. The PV modules are positioned in a fixed direction facing southwest at an inclined angle of 5°. Each of the PV modules consists of 60 solar cells which able to generate 250W. The details of the PV panel are shown in Table-1.

Table-1. Electrical data of the PV modules provided by Canadian solar Inc (2012) [7], Measured under "Standard test conditions (STC) of irradiance of 1000 W/m^2, spectrum AM 1.5 and cell temperature 25 °C".

STC	Canadian Solar CS6P-250P
Nominal Maximum Power, (P_{max})	250 W
Optimum Operating Voltage,(V_{mp})	30.1 V
Optimum Operating Current, (I_{mp})	8.30 A
Open circuit Voltage, (V_{oc})	37.2 V
Short Circuit Current,(I_{sc})	8.87 A

The PV system utilizes two different types of inverters: two bidirectional inverters (SMA Sunny Island 8.0 H) and two PV inverters (SMA Sunny Boy 5000TL-21). The two PV inverters are connected to the PV arrays to convert the DC PV output to supply 230 V_{AC} to the AC load and 48V_{Dc} to a DC load while the remaining energy is used to charge the battery bank via the two bidirectional inverters.

The two bidirectional inverters are also connected to the load, PV inverters and battery bank. They have two functional modes, which are charging mode and discharging mode. They convert excess AC power generated by the inverters to DC and charge the battery bank during the charging mode. However, the inverters can also use the energy stored in the batteries to provide 230 V_{AC} and 48 V_{DC} output during the discharge mode. Thus, the connected loads can operate stably even when solar energy is not available and yet electricity demand still exists. The two parallel operation bidirectional inverters are operated in a master–slave-standby configuration. The battery tank comprises of 12 cells, divided into 3 section connected in parallel and in which 4 battery cells are connected in series to provide a 48V_{DC} nominal storage voltage.

The environmental data such solar irradiation (W/m^2), ambient temperature (°C) and wind speed (m/s) are continuously recorded by the Sunny SensorBox and the operation performance data such as power output (kW), state of charge (SOC, %) as well as the electricity consumption at the intervals are recorded by Sunny Remote Control at an interval 1 minute.

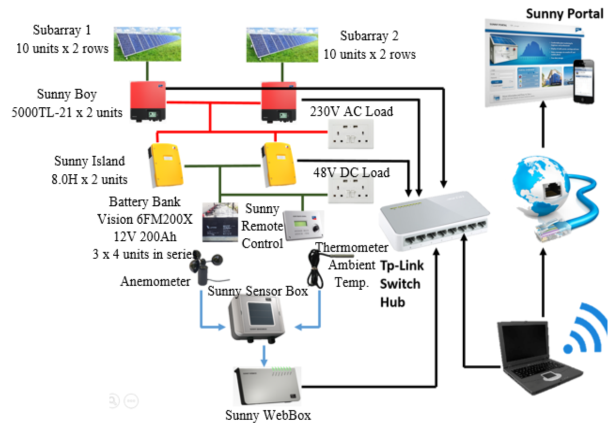

Figure-1. Schematic diagram of the UTP PV power plant system.

METHOD OF EVALUATION

The system performance of the UTP PV power plant is evaluated based on the power generated by PV arrays, inverters and the SOC of battery bank of the PV plant. Normalized parameters and energy performance indices (efficiencies/ratio) were used to evaluate the overall performance of the system [8]. Tao Ma and Hongxiang Yang (2013) [8] suggest that the normalized performance parameters are commonly used as indicators to compare different PV systems' performance. These indicators in units of kWh/kWp/d are calculated by relating the energies used to the nominal power of the PV array. These parameters are analyzed according to the guideline of IEC Standard 61724 [9].

The PV cell operating temperature, TC of the PV panels are not being measured by using any sensor attached to the PV panels as the data logger is located out of the range of effective transmission and accuracy of the measurement would be affected. Yet it is an important parameter to evaluate the performance of a PV system.

According to J. A. Duffie, W. A. Beckman, and W. Worek (1994) [10], the cell temperature of the PV panels was estimated by using the following equation:

$$T_c = (T_{NOCT} - T_{a,NOCT})\left(G_T/G_{NOCT}\right)\left(9.5/(5.7 + 3.8V)\right)\left(1 - \eta_c/\tau\alpha\right) \quad (1)$$

where:
NOCT is the nominal operating cell temperature [10];
$\tau\alpha$ is estimated to be 0.9;
V is the local wind speed in meters per second

Array Yield (Y_A) is defined as the number of hours per day that the array would need to operate at its nominal power, P0 to contribute the same quantity of energy to the system [8] . It is the annual or daily energy output by the system divided by the peak power output as the equation stated below [11] :

$$Y_A = E_A/P_0 \ (kWh/kWp) \quad (2)$$

where:
E_A is the hourly array energy output (kWh);

VOL. 11, NO. 22, NOVEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

P_0 is the PV array peak power (kW_p).

Final yield (Y_f) is referred as the usable amount of energy derived from the entire PV power generation system. The yield is delivered to the load per kilowatt peak of installed photovoltaic array.

According to T. Ma, H. Yang, and L. Lu (2013) [8] , it is stated as:

$$Y_F = E_{PV}/P_0 \; (kW\,h/d/kW_p) \tag{3}$$

where:

E_{pv} is the actual energy amount delivered to the load by the PV system;

P_0 is the PV array peak power (kW_p).

Reference Yield (Y_r) is defined as the ideal amount of energy produced by the PV plant. It also recognized as the expected nominal efficiency tested under Standard Test Conditions (STC) of PV modules [8]. It is derived as:

$$Y_R = A.\eta_{STC} \int G_i\,dt/P_0 \; (kW\,h/kW_p) \tag{4}$$

where:

A is the total area of the PV array;

G_i is the irradiance incident on the tilted PV array (W/m2); η_{STC} is the nominal efficiency of the PV module at STC according to the specification provided by the manufacturer.

Energy losses show the amount of time during which the array would be required to operate at its nominal power, P_0 to produce power for the losses [8]. The losses mainly include the two parts: system losses (Ls) and array capture losses (Lc). The equation to calculate system losses and array capture losses are as follow [8] :

Capture Losses:

$$L_C = Y_R - Y_F \tag{5}$$

System Losses:

$$L_S = Y_A - Y_F \tag{6}$$

The performance ratio, PR is defined as when the Yf compares against with the Yr. With the expected output of power generation by considering the amount of insolation of the system received compare against the actual power generated by the system. It accounts for the overall effect of losses on the rated output due to inverter inefficiency, wiring mismatch, and other losses such as transforming the DC. to A.C. power, PV module temperature, incomplete use of irradiance because of the reflection from the module top surface; soiling; snowing; system downtime; and component failures [8] . It is stated as:

Performance ratio:

$$PR = Y_f/Y_r \tag{7}$$

RESULTS AND DISCUSSION

a) PV array performance analysis

Figure-2, 3 and 4 show the active power output of the SMA Sunny Boy PV inverters and the global irradiance for a cloudy day, which noted as Day 1, a mid-cloudy day noted as Day 2 and sunny day noted as Day 3. It can be observed that the sun radiation is only available at around at 0745 and stop at around 1945 for the three specific days. As the insolation level of Day 1 is fluctuating greatly, it is classified as a cloudy day. However, the insolation level is low before 1400 on Day 2 indicating that it is mid-cloudy but the sky is clear out in the afternoon with the increase of insolation level detected. As expected from a sunny day, Day 3 has a smooth bell-shaped insolation curve as being shown in Figure-4.

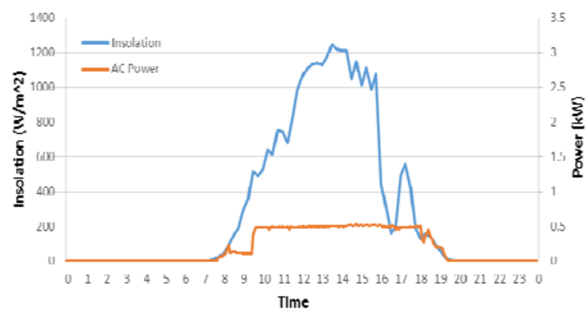

Figure-2. AC power output vs insolation for cloudy day.

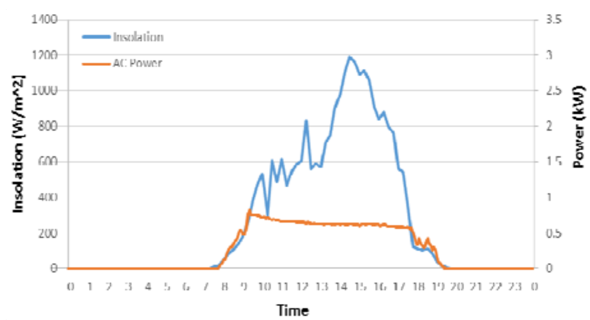

Figure-3. AC power output vs insolation for mid-cloudy day.

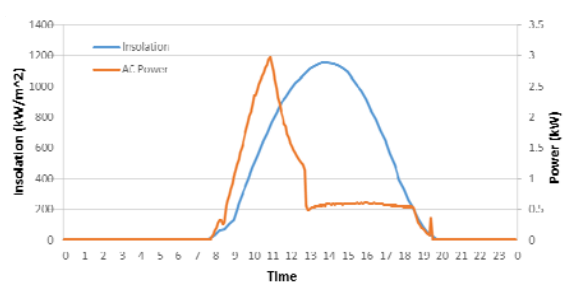

Figure-4. AC power output vs insolation for sunny day.

VOL. 11, NO. 22, NOVEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

From the figures, we can observe that the active power generated do not follow the instantaneous changes in the insolation for the days especially on Day 3 due to the power regulation control by the bidirectional inverter. As can be observed from Figure-4, Day 3 has a sharp drop of active power generation after 1050 while the insolation level after 1050 is high. As discuss in [8], in spite of the high levels of insolation, the observed drop in the active power generation is because of the means of the bi-directional inverter managed the frequency of the power generation system. As we can observe in the following section, the PV inverters are instructed to reduce the power output by changing the local grid frequency once the battery bank is reaching its maximum SOC and the power demand from the load is low during the day time.

b) Effect of power management mode on performance ratio

The bidirectional Sunny Island inverters are responsible for the power management of the PV plant system. The bidirectional inverters regulate the power flow of the system by using droop mode control [12, 13]. Jaehong Kim, Josep M. Guerrero, Pedro Rodriguez, Remus Teodorescu and Kwanghee Nam (2011) [13], states that droop control is widely considered to be a good choice for managing the power flows between micro-grid converters in a decentralized manner. Using this mode of control, the bidirectional inverters are able to vary the grid frequency depending on its active power [13] as can be observed in Figure-5. The figure presents the battery bank SOCs (Figure-5. a), the AC power generated by one of the PV-inverter (Figure-5. b) and the frequency (Figure-5.c) for Day 3.

As discussed in [13], with the droop mode control, the bidirectional inverter will raise the frequency of the system when there was more solar energy is present than the load required and the batteries are fully charged whereas the bi-directional inverter will lower the grid frequency if less solar energy is present than the load is in demand and the batteries are not fully charged to trigger the inverters to raise the energy output.

As can be observed in Figure-5, the SOC of the battery is low as the batteries are discharged at the previous night, the bidirectional inverters lowered the grid frequency of the system to 49 Hz to trigger the system to generate AC power once the solar energy is available. While the solar energy is available and the batteries are being charged, the bidirectional inverters start to raise the frequency of the system. As the SOC of the batteries has reached around 91 %, the bidirectional inverters raise the system frequency to 51 Hz to limit the power flow. The PV inverter decrease its power output as a result of the rise in grid frequency between 12 h and 18 h for this day as shown in Figure-5.

c) Overall system performance

From Table-2, we can observe that the performance ratio (PR) of the PV power plant is low. The PR of the inverters varies only between 12.90 % to 29.74 %. The total power fed to the PV system is the highest for Day 3. As the power losses are the lowest on Day 3, most of the power generated by the PV system is used to charge the battery bank and consumed by the load. In spite of having the highest reference yield and array yield, Day 2 also experienced the largest amount of power loss, which results in having the lowest performance ratio (PR) of only 12.90 %. In the contrary, the mid-cloudy day, Day 1 has the lowest reference yield and array yield, yet it has obtained a higher performance ratio than Day 2.

Table-2. AC power generated, yields and loss parameter for the specific days.

	E (kWh)	Y_R (h)	Y_A (h)	Y_F (h)	L_S (h)	L_C(h)	L_C+L_S (h)	PR (%)
Day 1	12.82	6.33	6.04	1.28	4.76	0.29	5.05	20.26
Day 2	9.50	7.33	6.91	0.95	5.97	0.42	6.38	12.90
Day 3	22.763	7.72	7.19	2.29	4.90	0.52	4.78	29.74

Where:

E	Generated Power
Y_R	Reference Yield
Y_A	Array Yield
Y_F	Final Yield
L_S	System Loss
L_C	Array Capture Loss
L_S+L_C	Total Loss
PR	Performance Ratio

The low values of the PR achieved for the days are because of less power delivered to the system as shown in Figure-5 as a result of the way the activated power are regulated by the bi-directional inverter. The decrease of power will start once the battery bank is reaching its maximum SOC shown in Figure-5. b and Figure-5. c. At this instance, the bidirectional inverters raise the frequency of the system as shown in Figure-5.c and the PV inverters will start to limit its AC power generation. We can also observe the same trend of effect on power regulation as discussed in [12, 14].

However, as discuss in [2, 10], the cell operating temperature could also be one of the many factors that affect the performance of the power plant. According to the PV module manufacturer, the module efficiency would drop –0.43 %/ °C when the cell operating temperature are above 45 °C [7].

From the interpreted result, we can deduce that the PR of the PV power plant not only affected by the system loss but also the state of charge of the battery bank as well as the power demand from the load and cell temperature because of the local grid control mode.

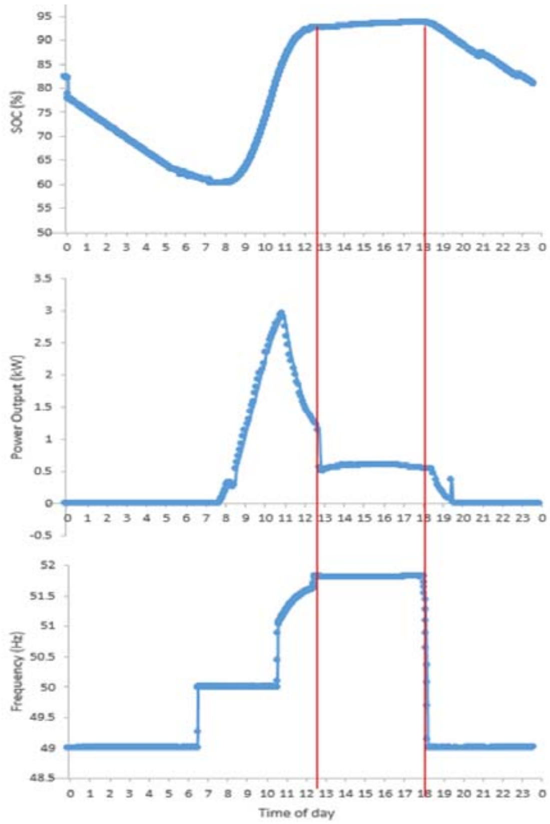

Figure-5. (a) SOCs of battery bank, (b) The AC power generated and (C) the voltage frequency for day 3.

CONCLUSION AND RECOMMENDATION

This aim of this project is to set up an online monitoring system to monitor the photovoltaic power generation system remotely and make a thorough analysis to evaluate the performance of the system. Setting up an online monitoring system could ease the researchers to study and monitor the performance of the photovoltaic power generation system. The students would not be required to be on-site to record data, as the data could be recorded by the data logging device, Sunny WebBox at all time. The data collected by the Sunny WebBox will be transmitted to the Sunny Portal. Students are then able to view the data collected on Sunny Portal.

This paper presented a remote PV plant in UTP to be monitored remotely. The performance ratio of the PV power plant is evaluated based on the data collected through Sunny Portal. The result obtained shows that the low performance ratio of the PV power plant not only as a result of less power demand from the load but also due to the state of charge of the battery bank. The PR of the PV power plant varies between 12.90% and 29.74%. The low PR value of the system is mainly due to the system losses. Fathi, A. El; Nkhaili, L; Bennouna, A; Outzourhit, A (2014) [14] suggest that this parameter will be further improved by using all the available PV energy through the use of a dump load such as mechanical pumps or motors.

It is recommended that the PV power plant should be monitored for a year in order to have a better evaluation of its performance. The PV system would also be connected to a DC and AC loads instead of just AC load alone so that we can better determine the performance of the battery bank and the inverters. Factors such as shading and wiring mismatch should be further studied as they are not covered in this project. As suggested in [15], pyranometer or crystalline silicon reference sensors should be used to compare the insolation reading detected by the a-Si cell . A stable internet connection device such as a modem or WLAN connection should be installed at the UTP Solar Research Site instead of using broadband as a mean for internet connection.

REFERENCES

[1] S. Mekhilef, A. Safari, W. Mustaffa, R. Saidur, R. Omar, and M. Younis, "Solar energy in Malaysia: current state and prospects," Renewable and Sustainable Energy Reviews, vol. 16, pp. 386-396, 2012.

[2] K. L. Ray, "Photovoltaic cell efficiency at elevated temperatures," Massachusetts Institute of Technology, 2010.

[3] S. S. A. A. M. Omar, "The Malaysian Building Integrated Photovoltaic Project: Country Report."

[4] S. E. D. A. Malaysia, "National Survey report of PV Power applications in Malaysia 2014," 2014.

[5] S. C. Chua and T. H. Oh, "Solar energy outlook in Malaysia," Renewable and Sustainable Energy Reviews, vol. 16, pp. 564-574, 2012.

[6] M. Nkoloma, M. Zennaro, and A. Bagula, "SM 2: Solar monitoring system in Malawi," in Kaleidoscope 2011: The Fully Networked Human?-Innovations for Future Networks and Services (K-2011), Proceedings of ITU, 2011, pp. 1-6.

[7] C. S. Inc., "CS6P 235/240/245/250/255P," ed, 2012.

[8] T. Ma, H. Yang, and L. Lu, "Performance evaluation of a stand-alone photovoltaic system on an isolated island in Hong Kong," Applied Energy, vol. 112, pp. 663-672, 2013.

[9] Z. Glasnovic and J. Margeta, "Vision of total renewable electricity scenario," Renewable and Sustainable Energy Reviews, vol. 15, pp. 1873-1884, 2011.

[10] J. A. Duffie, W. A. Beckman, and W. Worek, "Solar engineering of thermal processes," ed: American Society of Mechanical Engineers, 1994.

[11] E. Kymakis, S. Kalykakis, and T. M. Papazoglou, "Performance analysis of a grid connected photovoltaic park on the island of Crete," Energy Conversion and Management, vol. 50, pp. 433-438, 2009.

[12] J. Kim, J. M. Guerrero, P. Rodriguez, R. Teodorescu, and K. Nam, "Mode adaptive droop control with virtual output impedances for an inverter-based flexible AC microgrid," Power Electronics, IEEE Transactions on, vol. 26, pp. 689-701, 2011.

[13] B. Panahandeh, J. Bard, A. Outzourhit, and D. Zejli, "Simulation of PV–wind-hybrid systems combined with hydrogen storage for rural electrification," International journal of hydrogen energy, vol. 36, pp. 4185-4197, 2011.

[14] A. El Fathi, L. Nkhaili, A. Bennouna, and A. Outzourhit, "Performance parameters of a standalone PV plant," Energy Conversion and Management, vol. 86, pp. 490-495, 2014.

[15] Woyte, M. Richter, D. Moser, N. Reich, M. Green, S. Mau, *et al*., "Analytical monitoring of grid-connected photovoltaic systems," IEA-PVPS T13-03, vol. 2014, 2014.