Design and Performance Analysis of Solar PV DC Power System for Disaster Relief Centre using PVsyst

T M N T Mansur\textsuperscript{1,2}, N H Baharudin\textsuperscript{1} and R Ali\textsuperscript{1}

\textsuperscript{1}School of Electrical System Engineering, Universiti Malaysia Perlis, 02600 Arau, Perlis, MALAYSIA
\textsuperscript{2}Centre of Excellence in Renewable Energy (CERE), Universiti Malaysia Perlis, 02600 Arau, Perlis, MALAYSIA

tunkunizar@unimap.edu.my

Abstract. One of essential elements at disaster relief camps is electricity supply. Categorized under disaster preparedness, it is required to support humanitarian aids, provide security and convenient for the victims involved. The objective of this project is to design a standalone DC power system for a disaster relief camp at Kota Bharu, a capital for Kelantan State located at east coast of Peninsular Malaysia from renewable energy resource which is solar PV. The methodology of the project are configuring DC load demand, sizing PV array and battery bank from solar energy resource and load demand and lastly simulation of the design system by using PVsyst. In general, a relief camp will consist of basic electrical appliances such as lightings, fans and hand-phone chargers while in common area could be equipped with flood lightings, air-conditioning unit and refrigerator to store foods and medicine. The solar PV array, battery bank and DC bus regulator power rating are designed accordingly to the local meteorological data and load profile based on desired operating schedule. The system operates in stand-alone mode in which the power is fully supplied in DC voltage. The energy generated from solar array will be stored in the battery bank while the operation and management of the system is controlled and coordinated by local controller to ensure energy optimization system. The amount of user’s load demand is 8,820Wh per day. Based on solar energy resource, the optimum PV array size is 3.0kWp while the battery bank size is 900Ah at 48V which is designated for 4 days of autonomy. The system could meet up to 99% of load demand throughout the year except for December with 62.3% performance ratio. The loss to the system is contributed by the temperature effect to the PV module ohmic wiring loss, unused energy because of battery full, convertor efficiency and battery efficiency.

1. Introduction

In 2014, Malaysia was hit by one of the worst flood disaster in history where more than 100,000 victims have been moved to evacuation centre. In Kelantan area, there are extreme cases where victims have to live without food, clean water and electricity for more than 40 hours due to the severity of floods that prevented delivery of aids [1].

Electricity supply is one of elements required to support humanitarian aids such as disaster relief centre or camps. So far, electricity technology for disaster relief centre is not given serious attention since government’s building are normally been used as a centre where electricity is already available. In the meantime, outdoor camps only focused on traditional fuel such as wood, biomass, agricultural waste and conventional fossil fuels for heating, cooking, lighting and fuel driven electric generators for power [2]. However, based on the extreme case during 2014 flood disaster, backup power supply
especially portable that could support basic loads such as for lighting and communication devices should be considered.

Motivated by environmental and economic conditions, renewable energy resources such as from solar photovoltaic (PV) is currently popular technologies used especially for remote and rural electrification. In recent years, tremendous improvements in efficiency and cost effectiveness of solar PV technology have been made [3]. In addition, there have been intensive efforts to utilize DC in distribution system to supplement the traditionally used AC system [4]. Moreover, many of today’s consumer loads are available at low voltage DC such as LED lightings and hand phone's charger [5]. The advancement achieved in power electronics has made the DC voltage regulation a simpler task and better efficiency. Today’s solid-state switching DC converters have a power conversion efficiency in the range of 95% [6]. Compared to AC system, the energy conversion losses of DC system is minimized [7] since there is no reactive power [8].

2. Methodology

The objective of this project is to design a standalone DC power system for a disaster relief camp from renewable energy resource which is solar PV. The methodology of the project are configuring DC load demand, sizing PV array and battery bank from solar energy resource and load demand and lastly simulation of the design system by using PVsyst. PVsyst is professional software used to design and simulate the performance of the system related to solar PV.

The project site that has been chosen is Kota Bharu (6.17°N, 102.28°E), a capital for Kelantan State which located at the east cost of Peninsular of Malaysia. This area is severely affected by the heavy flood in 2014. This research is expected to give benefit to the authorities involved in disaster management in the affected area.

2.1. Solar Energy Resource

Information on solar energy for Kota Bharu is obtained from Meteonorm 7.1 which provided monthly meteorological data that has been preloaded in PVsyst. The annually global solar irradiation is 1,705kWh/m² and the average ambient temperature is 27.2°C. Figure 1 below shows the monthly global solar irradiation and average ambient temperature for Kota Bharu.

![Figure 1. Global solar irradiation and average temperature for Kota Bharu.](image)

2.2. Load Demand

In general, a relief camp will consist of basic electrical appliances such as lightings, fans and hand phones charger while a common area could be equipped with flood lightings, air-conditioning unit and
refrigerator to store foods and medicine. These loads will be divided according to their power rating where the high power loads will operate at higher voltage level which is 48V while the low power appliances operates at low voltage level which is 12V. List of loads with their respective power rating and their daily energy requirement is shown in Table 1 while Figure 2 shows the hourly energy demand from the loads. From there we can summarize that loads will operate at night only for 6 hours with total daily energy demand is 8,820 Wh.

**Table 1. Daily Energy Consumption for Disaster Relief Centre.**

| Appliances          | Quantity (Unit) | Power (W) | Hours (hr) | Energy (Wh) |
|---------------------|-----------------|-----------|------------|-------------|
| LED lighting        | 10              | 12        | 6          | 720         |
| Fan                 | 10              | 12        | 6          | 720         |
| Charger             | 10              | 5         | 6          | 300         |
| Flood lighting      | 10              | 30        | 6          | 1,080       |
| DC Air-conditioner Unit | 1           | 1,000     | 6          | 6,000      |

**Figure 2. Hourly Energy Demand for Disaster Relief Centre.**

2.3. **Sizing of PV Array**

Solar PV array is sized to meet the required energy demand. The output energy of PV array is a function of peak sun shine hours and temperature. The estimation of energy generated from PV array is simplified and calculated based on Equation (1) below [9].

\[
E_{array} = P_{array} \times PSH_{period} \times f_{temp}
\]

where \( E_{array} \) is PV array yield in kWh, \( PSH_{period} \) is Peak Sun Hour and \( f_{temp} \) is temperature de-rating factor. The temperature de-rating factor, \( f_{temp} \) is given by the Equation (2)

\[
f_{temp} = 1 + \left( \frac{\gamma_{pmp}}{100} \right) \times \left( T_{cell\_ave} \times T_{stc} \right)
\]

where \( \gamma_{pmp} \) is temperature coefficient for \( P_{mp} \) in % per °C, \( T_{cell\_ave} \) is average daily maximum cell temperature and \( T_{stc} \) is cell temperature at standard test condition which is 25°C. The average cell temperature, \( T_{cell\_ave} \) is given by Equation (3)

\[
T_{cell\_ave} = T_{amb\_ave\_max} + \left( \frac{NOCT - 20}{800} \right) \times G_{amb\_ave\_max}
\]
where $T_{\text{amb, ave, max}}$ is average daily maximum ambient temperature in °C, NOCT is nominal operation cell temperature in °C, $G_{\text{amb, ave, max}}$ is average daily maximum solar irradiance in Wm$^{-2}$.

The PV module used is Yingli Solar YL250P-29b which is preloaded in the PVsyst database. Selected parameter and their value for the PV module is shown in Table 2 below.

#### Table 2. PV Module specification

| Parameter                        | Value at Standard Test Condition (STC) |
|----------------------------------|----------------------------------------|
| Power output, $P_{\text{max}}$   | 250.0 Wp                               |
| Voltage at Pmax, $V_{\text{mpp}}$| 30.23 V                                |
| Current at Pmax, $I_{\text{mpp}}$| 8.27 A                                 |
| Open-circuit voltage, $V_{\text{oc}}$| 37.73 V                      |
| Short-circuit current, $I_{\text{sc}}$| 8.83 A                        |
| Module efficiency               | 15.40 %                                |
| Temperature coefficient at Pmax, $\gamma_{\text{mpp}}$| -0.42 % / °C  |

2.4. Sizing of Battery Bank

The amount of charge required is based on Equation (4) below

$$C_{\text{Ah, req}} = \frac{E_{\text{req}}}{V_{\text{sys}}} \times k_{\text{storage}} \times \frac{DOD_{\text{max}}}{T_{\text{aut}}}$$  \hspace{1cm} (4)

where $C_{\text{Ah, req}}$ is charge storage capacity required in Ah, $V_{\text{sys}}$ is the system voltage, $k_{\text{storage}}$ is the battery efficiency, $DOD_{\text{max}}$ is maximum depth of discharge allowed and $T_{\text{aut}}$ is number of autonomy days.

The system voltage is set to 48V, battery efficiency is set to 97%, number of autonomy days is set to 4 days and maximum depth of discharge is set to 80%.

3. Result

PVsyst software is used to simulate the performance of the system. Summary of the system configuration is shown in Figure 3.

![Figure 3. Summary of the system configuration.](image)

Table 3 summarized the system performance throughout the year. In general, the system could meet the loads demand for every month except in December due to the lowest solar irradiation compared to the other months. The annual energy requirement is 3,183kWh while the system could supply up to 3,152 kWh which is 99% of load demand.
Table 3. Summary of the system performance.

|        | GlobHor kWh/m² | GlobEff kWh/m² | E Avail kWh | E Unused kWh | E Miss kWh | E User kWh | E Load kWh | SolFrac |
|--------|----------------|----------------|-------------|--------------|------------|------------|------------|---------|
| January| 135.4          | 143.5          | 342.8       | 46.0         | 0.00       | 270.3      | 270.3      | 1.000   |
| February| 135.0         | 137.5          | 330.1       | 71.4         | 0.00       | 244.2      | 244.2      | 1.000   |
| March  | 165.2          | 161.4          | 386.5       | 105.0        | 0.00       | 270.3      | 270.3      | 1.000   |
| April  | 161.3          | 149.5          | 355.4       | 68.7         | 0.00       | 261.6      | 261.6      | 1.000   |
| May    | 156.8          | 138.4          | 332.0       | 45.3         | 0.00       | 270.3      | 270.3      | 1.000   |
| June   | 149.4          | 126.7          | 305.8       | 31.2         | 0.00       | 261.6      | 261.6      | 1.000   |
| July   | 148.8          | 130.8          | 313.8       | 36.0         | 0.00       | 270.3      | 270.3      | 1.000   |
| August | 151.0          | 137.1          | 327.7       | 32.2         | 0.00       | 270.3      | 270.3      | 1.000   |
| September | 149.1       | 139.9          | 333.5       | 57.2         | 0.00       | 261.6      | 261.6      | 1.000   |
| October | 144.3          | 143.9          | 343.7       | 56.4         | 0.00       | 270.3      | 270.3      | 1.000   |
| November| 113.7          | 117.0          | 280.4       | 27.1         | 0.00       | 261.6      | 261.6      | 1.000   |
| December| 102.7          | 105.4          | 254.6       | 0.0          | 30.89      | 239.4      | 270.3      | 0.886   |
| Year   | 1705.6         | 1631.0         | 3906.1      | 575.5        | 30.89      | 3151.9     | 3182.8     | 0.990   |

Figure 4 summarized the performance ratio and solar fraction of the system and Figure 5 summarized the system’s energy loss throughout the year. The nominal PV array energy at STC is 4,893 kWh but only 3,563 kWh is available as output from it. The losses are due to the temperature effect to the PV module (11.6%), ohmic wiring loss (2.3%) and unused energy because of battery full (13.9%). From PV array output, only 3,152 kWh has been supplied to the users where the main losses are from converter efficiency (6.5%) and battery efficiency (4.5%). The overall performance ratio is 62.3%.
4. Conclusion

The DC power system for disaster relief camp powered by solar PV in Kota Bharu has been designed and simulated by using PVsyst. The amount of user’s load demand is 8,820Wh per day. Based on solar energy resource, the optimum PV array size is 3.0kWp while the battery bank size is 900Ah at 48V which is designated for 4 days of autonomy. The system could meet up to 99% of load demand throughout the year except for December with 62.3% performance ratio. The loss to the system is contributed by the temperature effect to the PV module, ohmic wiring loss, unused energy because of battery full, converter efficiency and battery efficiency.

References

[1] Malaymail Online, “Kuala Kairi flood victims trapped without food, water or electricity at shelter,” 26-Dec-2014.

[2] J. Franceschi, J. Rothkop, and G. Miller, “Off-grid Solar PV Power for Humanitarian Action: From Emergency Communications to Refugee Camp Micro-grids,” Procedia Eng., vol. 78, pp. 229–235, 2014.

[3] K. Shah, S. Member, P. Chen, A. Schwab, and K. Shenai, “Smart Efficient Solar DC Micro-grid.”

[4] S. Sidoposko and M. Taufik, “The DC House Project for Sustainable Rural Electrification,” no. November 2012, pp. 2–6, 2013.

[5] A. T. Ghareeb, A. a. Mohamed, and O. a. Mohammed, “DC microgrids and distribution systems: An overview,” IEEE Power Energy Soc. Gen. Meet., vol. 119, pp. 407–417, 2013.
[6] K. Shenai, K. Shah, and S. Member, “Smart DC Micro-grid for Efficient Utilization of Distributed Renewable Energy.”

[7] M. Amin, Y. Arafat, S. Lundberg, and S. Mangold, “An efficient appliance for low voltage DC house,” pp. 334–339, 2011.

[8] E. R. Diaz, X. Su, M. Savaghebi, J. C. Vasquez, M. Han, and J. M. Guerrero, “Intelligent DC Microgrid living Laboratories - A Chinese-Danish cooperation project,” 2015 IEEE First Int. Conf. DC Microgrids, pp. 365–370, 2015.

[9] A.M. Omar, S. Shaari, S.I. Sulaiman, Grid-Connected Photovoltaic Power Systems Design. Sustainable Energy Development Authority Malaysia, 2012.