Energy Management System In Utility Grid Solar Cell And Battery For Power Stability

Novid Ari Rahmawan[1], Machmud Effendy[2], Nurhadi[3]

Authors

[1]Electrical Department, Engineering Faculty, Muhammadiyah University of Malang, Jalan Raya Tlogomas No. 246, Malang and 65144, Indonesia, novid2019@gmail.com

[2]Electrical Department, Engineering Faculty, Muhammadiyah University of Malang, Jalan Raya Tlogomas No. 246, Malang and 65144, Indonesia, machmud@umm.ac.id

[3]Electrical Department, Engineering Faculty, Muhammadiyah University of Malang, Jalan Raya Tlogomas No. 246, Malang and 65144, Indonesia, nurhadi@umm.ac.id

Corresponding: machmud@umm.ac.id

Abstract

Power plants with higher power capacity were needed along with the increasing human populations and the development of technology. The use of renewable energy could act as an alternative way to solve the growing load demand. However, renewable energy faced an obstacle because electrical power could not be continuously built to fulfill the load's requirement. Transferring energy could help balance the energy and the system. Thus, the Energy Management System was needed to meet the stable and continuous load requirement. In this research, the Energy Management System was chosen as the scheduling system for DC's grid with the PV as the renewable energy. The PV was connected on-grid to the utility network; thus, the power could be exchanged with the utility grid. A battery was used as the extra reserve energy supply when the highest loads happened. Based on the results, the filling schedule of power was conducted by importing power when the load power requirement was less than 25 kW and no energy was generated from the PV. Furthermore, when there was power generation in the PV, the EMS would schedule the power at the incoming PV to meet the load when the generated power was higher than the required. The use of batteries as a backup energy source was utilized when the load requirement was greater than 25 kW because the battery here served to meet the power requirements when peak loads occur. The results also followed the EMS scheme, where the load's demand was fulfilled entirely with precise scheduling. Finally, the strain on the DC bus was successfully maintained at 48 VDC to avoid energy decreasing.

Keywords
Renewable Energy, Energy Management System, Power, DC Grid, On The Grid.

1. Introduction

The growth of population and industrial development demands a higher power generator. Renewable energy could act as an alternative to solving the increasing load demand. Many types of research and literature discussed the renewable energy source. The development of microgrid is useful to study, particularly DC microgrid. Renewable energy with DC microgrid has many advantages compared to AC microgrid. The DC microgrid has lesser power disadvantages and could distribute 1.41 times electrical power than AC microgrid in a similar configuration [1]

A microgrid can operate in two modes: connected to the utility grid and islanded method or unconnected to the utility grid. In the connected mode, the DC grid is connected to the utility grid so that the power could be exchanged with the utility grid. In the islanded mode, the microgrid is not connected with the utility grid, and thus, there is no power exchange [2][3]. Problems during power transfer could influence power balance so that there needed an energy management system (EMS) scheme. Generally, EMS aimed to minimize the energy exchange in the grid, to maximize the economic income for energy sales that are generated by the renewable plants in the local energy system, and to minimize outside purchase costs. Besides, an efficient energy management system could lessen the power peak on the grid to reduce congestion on distribution and transmission lines, to reduce power imbalances between expected and measured power profiles and cost imbalances [4][5][6]

The utilization of storage devices such as batteries could improve the power transfer and accelerate the power flow if there is a deficit on the primary energy source. The battery is a popular storage device and can be utilized as a renewable energy source. Battery system control should be able to control the DC bus voltage and produce stable grid operation to operate the microgrid in both networks that are connected to the utility and islanded grids [7].

This paper discussed the PV model that was connected on-grid with the utility grid using the battery as the backup energy source to fulfill the peak power requirement and maintain the power stability in the micronetwork. A DC-DC converter was used as the interface to control the bus voltage by charging/releasing energy storage during power fluctuation. The case scheme that was provided here had to meet the power requirements and voltage stability of the DC bus when the microgrid network operated.

2. Main Theory or Related Current Research

PV is a system to exchange the solar energy into electrical energy. The amount of converted energy by the solar cell depends on the radiation intensity and surrounding temperature that influence the solar cell itself. Based on a standard condition, the sunlight contains 1000 W/m2 energy at 25-degree temperature. Thus, the radiation amount and surrounding temperature become the determining factors of how much energy a solar cell produces [8]. The amount of power from a solar power plant is vital to be calculated correctly to get a suitable and efficient power plant. Determining the PV capacity can be calculated using the equation below:

$$\mathrm{V_{dc}} = \mathrm{N}_{Seri} \times V \quad (1)$$

$$\mathrm{P_{out}} = \mathrm{N}_{Seri} \times \mathrm{N}_{Parallel} \times W \quad (2)$$

Where:
Vdc : PV output voltage (V)
Pout : PV output power (W)
N_{ser} : Number of panels arranged in series
$N_{parallel}$: Number of panels arranged parallel

The boost converter acted as a step up for the output voltage to produce a larger voltage output than the given input. In its usage in a solar power plant, this converter acts to increase the output voltage from the MPPT to obtain the required output. Besides, from the battery side, the converter acts as a discharge when the battery functions as the load supply [9]

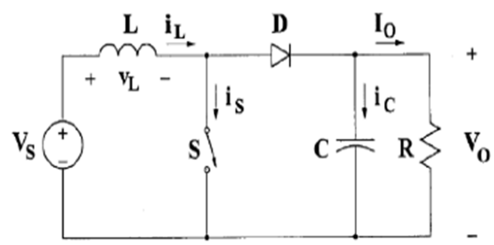

Figure 1. Boost converter network

The equation below was used to determine the amount of duty cycle and the value and component of inductor and capacitor:

$$D = 1 - \frac{V_{out}}{V_{in}} \quad (3)$$

$$L = \frac{V_{in}(V_{out} - V_{in})}{d_i \, x \, f_s \, x \, V_{out}} \quad (4)$$

$$C = \frac{I_{out} \, x \, D}{fs \, x \, dv} \quad (5)$$

Where:
D: Duty Cycle
V_{out}: Output converter voltage (Vdc)
V_{in}: Input converter voltage (Vdc)
L: Inductor value
Fs: Switching frequency (Hz)
C: Capacitor value (F)
d_v: Output voltage ripple (V)
I_{out}: Output current (A)

The loading section uses a buck converter interface as voltage reduction and voltage stabilizer in the DC bus. Buck converter is a type of DC-DC converter that produces smaller output compared to the input voltage [7].

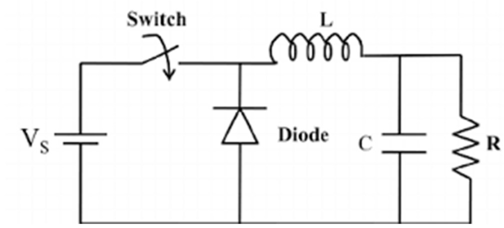

Figure 2. Buck Converter Network

The component values in Figure 2 was obtained using the equation below:

$$D = \frac{V_{out}}{V_{in}} \quad (5)$$

$$L = \frac{(V_{in} - V_{out}) x Vout}{\Delta I_L \, x \, fs \, x \, Vin} \quad (6)$$

$$C = \frac{\Delta I_L}{8 \, x \, fs \, x \, \Delta Vout} \quad (7)$$

Where ΔI_L is the current ripple and ΔV*out* is the voltage ripple.

3. Method

3.1. DC Microgrid System Scheme

In grid-connected mode, microgrid gives or receives power from the utility grid depending on whether the microgrid can fulfill the required local load. When microgrid is unable, the utility grid would work and supplied the power to the load through the DC/AC converter. The utility grid could enter the network at noon when PV could not fulfill the loading requirement or at night when PV does not operate, and the battery could not fulfill the loading requirement. In the microgrid operational strategy, for utility grid mode, the bus voltage was controlled by the primary grid through controlling the switching of the electronic power converter. The PV distributed the loading power through a DC-DC converter that was connected to the DC bus. Next, the battery was connected with the DC bus through the boost converter. When the PV supplied the power, the power was transferred to the load through the buck converter. The residual was sent to the utility grid.

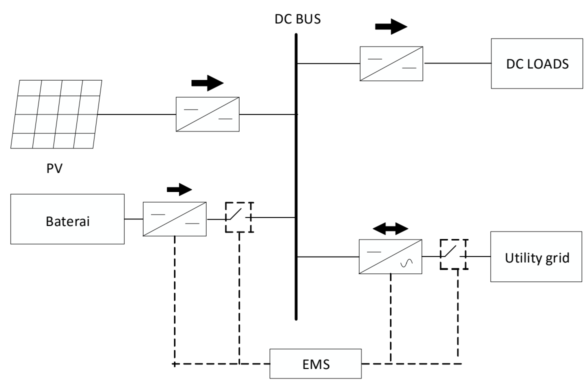

Figure 3. Flow diagram of DC microgrid with EMS

3.2. Load Profile

The data in Figure 4 is the load data in DC smart home that was taken in Chicago, the USA in July. The chart shows that the load peak occurred at night. The load characteristic was used to set the mode for power stability and determining the required power from the generator and battery capacity.

In the research, the load entered the system at 0.2 seconds. Then, every 0.2 seconds represented 1-hour loading, so it needed 0.2+(0.2x24)=5 seconds in the simulation.

The EMS determine between using the two modes or to the battery backup power when connected into the utility grid depending on the power balance and utility availability. The inputs shown are explained under each operating mode [8].

Figure 5 presents the proposed EMS flow diagram. In priority mode, the export of excess power from PV is used to supply the power to the load. The EMS checks the power converter, and then, it monitors the possibility of exporting available power to the utility network. If there is a surplus of energy from the utility grid converter interface, the EMS will schedule the export of power into the AC utility grid.

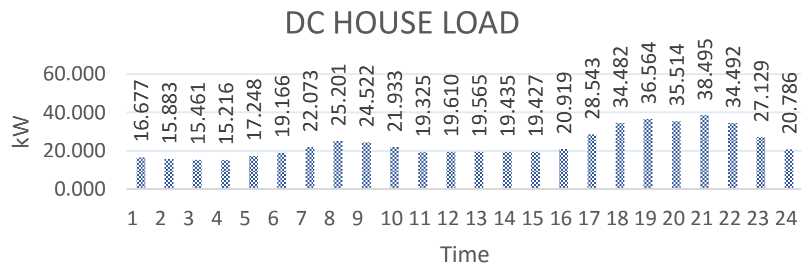

Figure 4. Loading chart

In grid-connected mode, if the total local load is more than the PV generator, the EMS switches into import priority mode. The controlled rectifier is scheduled to import the power from the utility grid; or, the battery interface converter is expected to release and supply the power to stabilize the power in the DC microgrid. In this mode, scheduling is performed following the import power from the utility grid. When the battery exceeds the determined minimum SOC, the rectifier works to supply the power from the utility grid to the load.

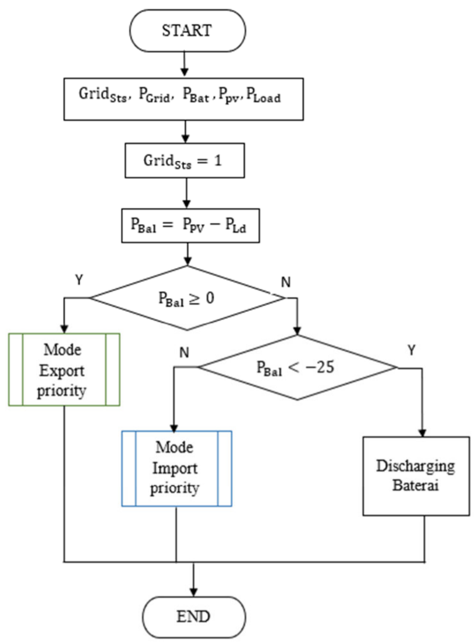

Figure 5. The proposed EMS flow chart

3.3. Energy Management System

The EMS primary purpose is to stabilize the microgrid power. The proposed EMS was implemented as a real-time operating algorithm. Before starting the algorithm, a set of the variable was initiated into the EMS scheduling. Before picking the suitable operational mode, EMS algorithm checked the utility grid status beforehand to determine the microgrid in connected grid mode ($Grid_{Sts}$=1). Then, it checks the power balance (P_{Bal}) between the solar PV (P_{PV}) and the load of PV (P_{Ld}) using the equation below:

$$P_{Bal} = P_{PV} - P_{Ld} \tag{8}$$

It is necessary to have an EMS for the desired scheduling, as seen in Figure 6, to determine the mode of how to meet the desired load request. This matter aimed to determine from which of three sources (PV, utility grid, and battery) to be used. If the power from the utility network is used to meet the load, then the mode is said to be a power import mode. However, when the energy from PV is higher than the load power, the export mode will work. From Figure 7, $P_{balance}$ is the difference between the PV output power compared with the load power demand.

If the $P_{balance}$ value is more than 0, then switch1 will show the value of 1 and the import mode will work. The power from the PV will be used to meet load requirements, and the rest will be sent to the utility network.

If the $P_{balance}$ value is less than 0, the PV power is not enough to meet the load requirements. The switch1 will turn into 0, so the import mode will apply. The energy from the PV will be used to meet the load requirements, and the rest will be sent to the utility network. If the $P_{balance}$ value is less than 0, the PV power is not enough to meet the load requirements, and switch1 will turn into 0, so the import mode will apply. The energy from the utility network will be used to meet the load. When a $P_{balance}$ is less than -25, this means that the power required by the load is higher than 25 kW, so the switches will be worth 1 to discharge the battery, and thus, the battery supports the peak load.

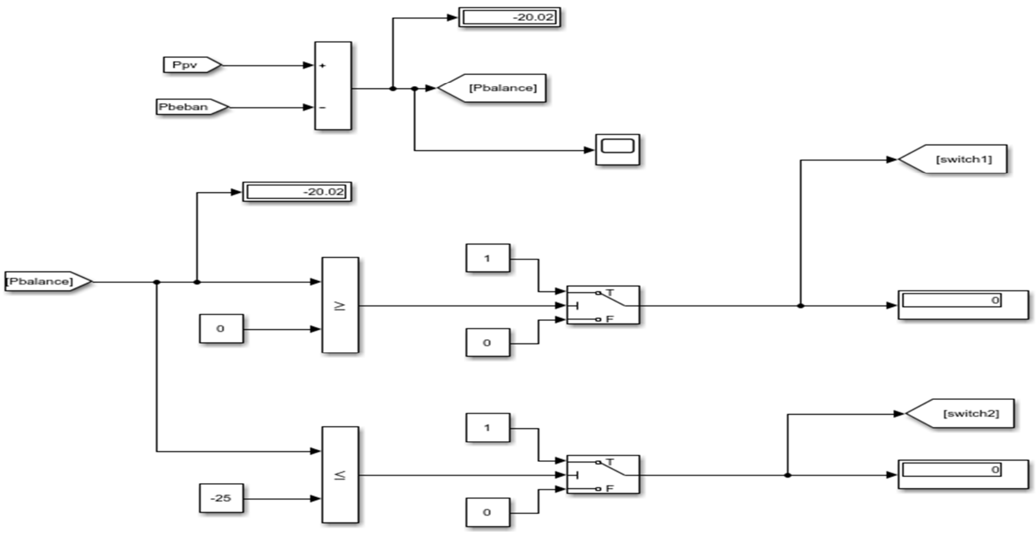

Figure 6. EMS model in Matlab

4. Result

4.1. PV System Test

Here, the input parameters were irradiance (*ir*) and temperature (*T*). The temperature was assumed constant with the value of 25 degree, whereas the radiance changed, as seen in Figure 7. At 1.6 seconds, the irradiance value increased following the irradiance input until the 3.2 seconds.

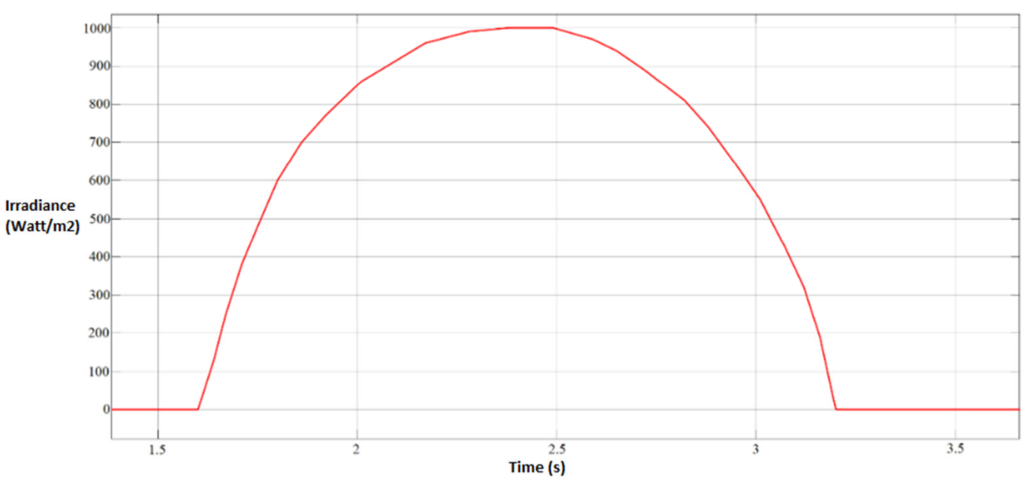

Figure 7. Irradiance input signal

Table 1 shows the results using the optimization method as proposed by optimizing P&O. The desired maximum PV power was 51.28 kW to fulfill the load requirement and utility grid. Using the optimization method resulted in more than 95% efficiency. Thus, the output was high, which means close to the ideal power generated by the PV.

TABLE 1
RADIATION POWER, MEASURED POWER, IDEAL POWER, AND PV EFFICIENCY

Hour	Time	Efficiency (%)	PPV (kW)	P_{ideal} (kW)	Irradiance (Watt/m^2)
8.00	1.6	0	0	0	0
9.00	1.8	96.7	29.47	30.74	600
10.00	2	97.4	42.33	43.57	850
11.00	2.2	97.5	48.41	49.64	968
12.00	2.4	97.6	50.15	51.28	1000
13.00	2.6	97.6	48.28	49.48	965
14.00	2.8	97.4	41.3	42.35	826
15.00	3	96.6	27.97	28.96	565
16.00	3.2	0	0	0	0

4.2. Overall System Test

The whole system test aimed to find the results from the applied EMS scheme. Figure 8 displays whether the mode worked as desired by observing the current character from the inverter side. The system was stable at 0.2 second time, and the load entered at the 0.2 second time. If the current chart were located below the 0 axis, import mode would be applied. The negative current direction meant that there was a current entering the DC bus imported from the utility network. If the current chart were more extensive or similar to 0, the export model would work. The export model works when the PV-generated power is larger than the required load, and then, the residual power would be transferred to the utility grid. When the PV power exceeded the loading requirement, the current direction moved from negative to positive to export the power to the utility grid. When the inverter current graph was stable at 0, it meant that no export or import mode took place because the load power requirements were met by the battery as a backup power store.

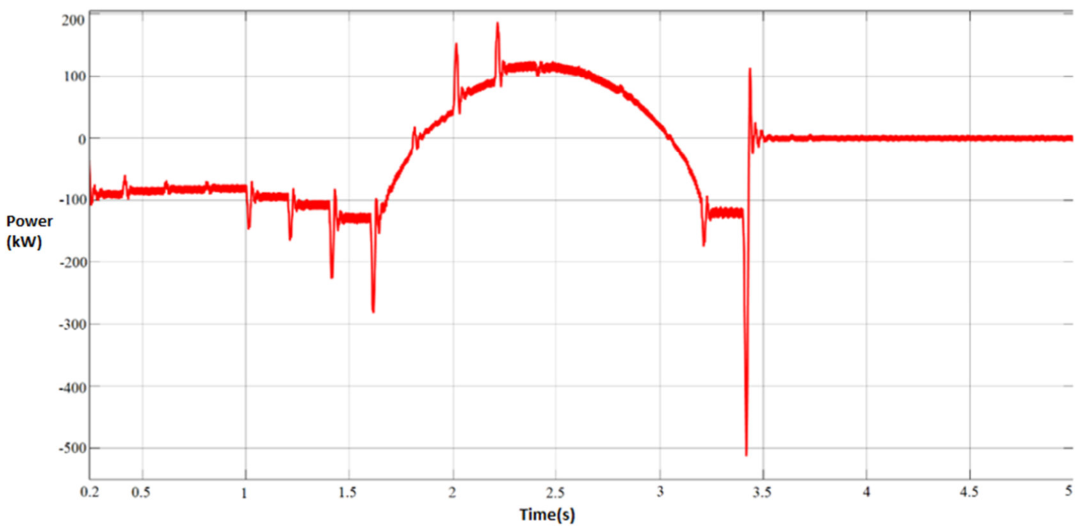

Figure 8. Inverter current characteristic char

Figure 9 depicts the simulation result from the applied EMS. Here, when the load requirement entered the 0.2 second time (at 01:00), the utility power grid fulfilled the import power requirement. When the irradiation appeared at 1.6 seconds (at 08:00), there would be a power that was generated by the PV. Next, when the PV power was more considerable or similar to the load power, at 1.8 seconds (at 09:00), the EMS scheduled load power demand supplied by PV and excess power to be exported to the network.

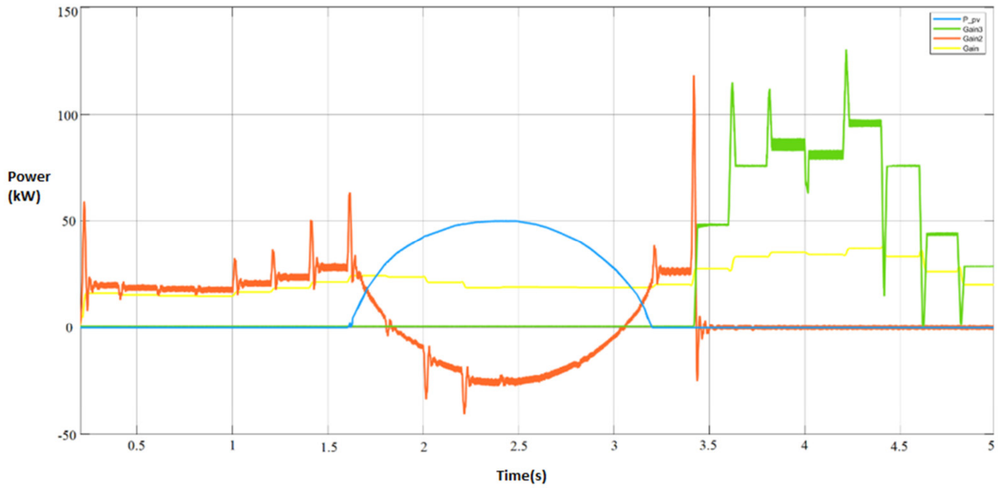

Figure 9. Load power requirement (yellow) and PV consumption power (blue), grid (orange), and battery (green)

The decrease in sun radiation also reduced the PV-generated power so that the EMS scheduled the utility grid to supply the power back on at 3.2 second time (at 17:00). Battery utilization to store the backup power was used when the load requirement was more substantial than 25 kW. Thus, during the peak load, the system would condition the battery to fulfill the load requirement. The battery started to supply the load at 3.4 seconds (at 17:00) which means at that moment, the $P_{balance}$ was larger or equal to -25, or the required power was 25 kW so that the system transfers the power supply from the grid into the battery. Voltage stability in the load was maintained at 48 volts. Buck converter played a role in voltage stabilization on the DC bus.

5. Conclusion

From this study, it could be concluded that the grid-connected mode in the PV, utility grid, and battery was successfully made and was simulated. The specifications were 50 kW PV power, 55 parallel modules, and three series modules to obtain the optimized DC for 164 VDC with 200 Ah battery capacity and 150 VDC nominal voltage. The PV control was simulated using MPPT P&O with more than 95% efficiency, as shown in Table 1. The EMS control was also produced and simulated. The export-import schemes could fulfill the overall load requirement. The utility grid was able to power the load from 0.2 to 1.6 seconds. When the PV entered, the load power requirement was diverted to the PV so that from 1.6 to 3.2 seconds, the load power requirement was supplied by the PV. Furthermore, the grid network functioned to provide the load because the EMS schedule was applied. The battery would overcome the load when the $P_{balance}$ was higher than 25 kW, or during the peak load. The battery started supplying the load in 3.4 seconds when the $P_{balance}$ was greater than 25 kW. On the voltage side, the DC bus was stable at 48VDC. There was an even higher peak when the difference in power demand per hour load was also higher. The system was simulated according to the expectation that all control schemes using EMS to operate to meet the load power requirements and the backup power on the battery could be used when peak load occurs.

References

[1] J. Mirez, "A modeling and simulation of optimized interconnection between DC microgrids with novel strategies of voltage, power and control," *2017 IEEE 2nd Int. Conf. Direct Curr. Microgrids, ICDCM 2017*, pp. 536–541, 2017.

[2] B. Liu, F. Zhuo, Y. Zhu, and H. Yi, "System Operation and Energy Management of a Renewable Energy-Based DC Micro-Grid for High Penetration Depth Application," *IEEE Trans. Smart Grid*, vol. 6, no. 3, pp. 1147–1155, 2015.

[3] H. Mahmood, D. Michaelson, and J. Jiang, "A power management strategy for PV/battery hybrid systems in Islanded microgrids," *IEEE J. Emerg. Sel. Top. Power Electron.*, vol. 2, no. 4, pp. 870–882, 2014.

[4] I. Tank and S. Mali, "Renewable based DC microgrid with energy management system," *2015 IEEE Int. Conf. Signal Process. Informatics, Commun. Energy Syst. SPICES 2015*, pp. 1–5, 2015.

[5] M. Nasir, N. A. Zaffar, and H. A. Khan, "Analysis on central and distributed architectures of solar powered DC microgrids," *Clemson Univ. Power Syst. Conf. PSC 2016*, 2016.

[6] M. Nasir, Z. Jin, H. A. Khan, N. A. Zaffar, J. C. Vasquez, and J. M. Guerrero, "A Decentralized Control Architecture Applied to DC Nanogrid Clusters for Rural Electrification in Developing Regions," *IEEE Trans. Power Electron.*, vol. 34, no. 2, pp. 1773–1785, 2019.

[7] N. Eghtedarpour and E. Farjah, "Distributed charge/discharge control of energy storages in a renewable-energy-based DC micro-grid," *IET Renew. Power Gener.*, vol. 8, no. 1, pp. 45–57, 2014.

[8] A. I. Bandara, P. Binduhewa, L. Samaranayake, and ..., "Novel Energy Management System for a DC MicroGrid," *Int. J. ...*, vol. 5, no. 10, pp. 141–152, 2017.

[9] R. Muhammad, *POWER ELECTRONICS HANDBOOK*, Second. Elsevier, 2007.