STM JOURNALS

Trends in
Electrical Engineering

https://journals.stmjournals.com/tee

ISSN: 2249-4774 (Online)
ISSN: 2321-4260 (Print)
Volume 14, Issue 1, 2024
January–April
DOI (Journal): 10.37591/TEE

Review TEE

Energy Management Using Hybrid Energy Storage System in DC Microgrid: A Review

Ruchi M. Sadhu[1],*, Kinjal R. Patel[2], Jagrut J. Gadit[3]

Abstract

The purpose of this paper is to study the power management of a hybrid energy storage system in a DC microgrid. The energy storage system for microgrids is bound to face several challenges, such as a lack of conventional power sources and load imbalance. There are many losses in using household energy Management system (HEMS) that require a microgrid to optimize performance and extend hybrid energy storage systems. The hybrid energy storage system (HESS) incorporates a battery energy storage system (BESS) and a supercapacitor (SC) to cater to high energy and power demands. The HESS, with the proposed controller and energy management strategy (EMS), admits improved time response to sudden and slowly varying load demands, resulting in reduced battery stress and an improved battery life span. The challenges are to develop systems that can accurately predict energy usage, minimize losses, enhance the efficiency of the HESS, and improve the overall system cost. This ensures the reliability of the overall system. Hybrid energy storage systems (HESS), especially in the context of DC microgrids, have emerged as a workable solution to these problems. This article examines the idea of employing HESS for energy management in DC microgrids, emphasising its advantages, elements, and best practices.

Keywords: Energy management system, hybrid energy storage system, photovoltaic (PV) system, DC microgrid

INTRODUCTION

Renewable energy resources (RER) are used in place of fossil fuel-based power facilities to minimize greenhouse gas emissions as a result of concerns about climate change and global warming. It may be challenging to manage, control, and defend distribution networks effectively because of the intrinsic erratic nature of major RERs, such as wind and solar power plants. A microgrid is a system composed of dispersed generators, various loads, energy storage systems (ESS), and a control unit. It develops in response to these complications. By using a communication system, a microgrid can work in tandem with the utility grid (grid-connected mode) to exchange electricity or autonomously (islanded mode) to provide neighborhood loads [1].

The instantaneous power generation and load circumstances in a freestanding microgrid determine the large variations in power flows in and out of ESS elements. Power exchanges within ESS can be broadly classified into two types: low-frequency components, which include the natural behavior of RER; and high-frequency components, which include sudden surges in power demand or intermittent solar power generation on cloudy days. Low-frequency power exchanges demand high-energy-density ESS components, but high-frequency power exchanges often require ESS elements with a quick reaction time [2].

***Author for Correspondence**
Ruchi M. Sadhu
E-mail: sadhuruchi4@gmail.com

[1]Researcher, Department of Electrical Engineering, The Maharaja Sayajirao University of Baroda, Gujarat, India
[2]Research Scholar, Department of Electrical Engineering, The Maharaja Sayajirao University of Baroda, Gujarat, India
[3]Associate Professor, Department of Electrical Engineering, The Maharaja Sayajirao University of Baroda, Gujarat, India

Received Date: February 23, 2024
Accepted Date: April 04, 2024
Published Date: April 10, 2024

Citation: Ruchi M. Sadhu, Kinjal R. Patel, Jagrut J. Gadit. Energy Management Using Hybrid Energy Storage System in DC Microgrid: A Review. Trends in Electrical Engineering. 2024; 14(1): 25–31p.

Because the energy provided by renewable energy sources (RESs) such as wind and solar cells is dependent on the weather, the integration of RESs such as these is still a typical source of voltage swings in standalone direct current micro-grid (DCMG) systems. Energy storage devices (ESDs) are used in standalone microgrids to manage the balance between generation and load demand, address these problems, and enhance the power quality of the microgrid system [3]. An artificial neural network (ANN) controller was utilized to regulate the bidirectional DC/DC converter connecting the battery and DC bus in a freestanding microgrid that combines photovoltaic technology with a battery as an ESD to balance the demand-generation gap in the face of uncertainty. Because of its poor power density, the battery is under more stress even with the use of a quick ANN-based controller, making it unable to handle rapid swings in PV generation and load demand [4].

Currently, the control layer is the focus of most studies research. Little research has s been conducted on how the energy storage state of charge (SOC) and charge and discharge power constraints affect the best way to allocate energy storage capacity based on technical and economic variables [5]. Based on distinct goals, there are two categories of hybrid energy storage capacity allocation research: technical, aiming to guarantee system reliability, and economic, aiming to achieve system profitability. Meanwhile, the arrangement under the first two goals is not without its drawbacks. The subsequent cost of investment according to the Ragone curve of the energy storage component is considered from the perspective of the overall life cycle cost of an energy storage system. The scheduling cost model considers the battery capacity loss and sets the lowest scheduling cost per unit duration as the optimization objective. An energy storage system minimum capacity allocation model aimed at mitigating wind power variations in microgrids, a composite model of energy storage costs based on the total economic advantages of microgrids, and the effect of microgrid operating aims on the entire life cycle of energy storage is considered [6].

PROPOSED MODEL

The DC microgrid architecture, shown in Figure 1, was examined in this study. Supercapacitors, batteries, and photovoltaic (PV) arrays constitute the system. A DC/DC converter connects these components to the DC bus. Power transmission is limited to the PV array on the bus, and power flow in the other direction is not permitted. The DC/DC converter connects the PV system to the DC bus. With the help of this converter, the microgrid's PV-generated power of the microgrid can be effectively

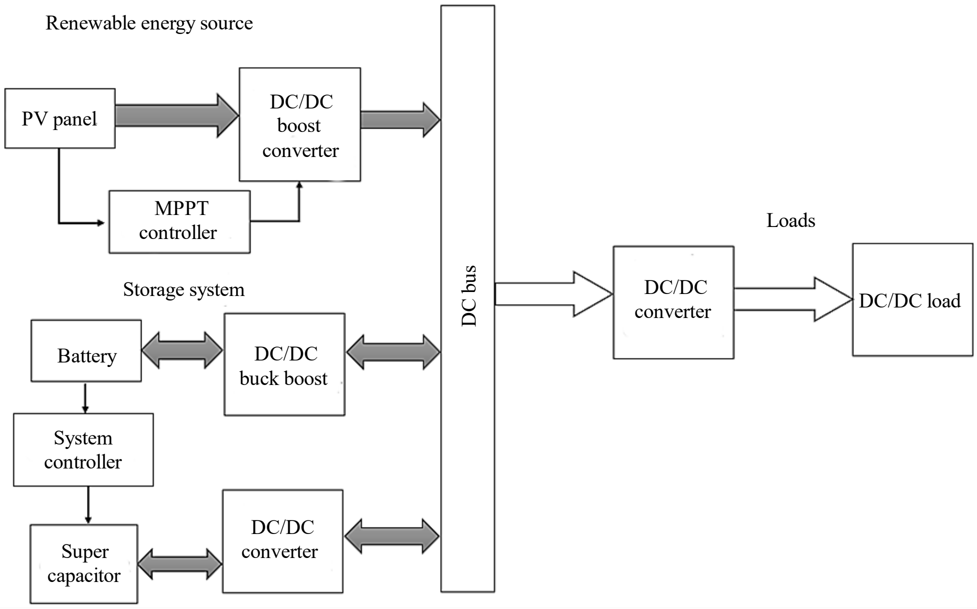

Figure 1. Model of energy management.

integrated. Bidirectional DC/DC converters connect the supercapacitor and battery to the DC bus. Charge and discharge of ESDs are made possible by these converters, which allow energy to flow in both directions. The batteries and supercapacitors that constitute the hybrid energy storage system (HESS) are linked to the DC bus through bidirectional DC/DC converters. This configuration allows for flexibility in microgrid management and power transmission. Buck-boost converters, also known as bidirectional DC/DC converters, are devices that allow power transmission in two modes: charging and discharging. When the batteries and supercapacitors are in charging mode, the converters allow electricity to flow to them from the PV system or other sources, allowing them to store energy. When the microgrid is in the discharging mode, the converters allow the batteries and supercapacitors to store energy to be released, powering the loads and other components. When the electricity produced by the photovoltaic source and the load demand inside the microgrid are out of balance, the system functions to preserve the balance. A microgrid uses energy storage components, such as batteries and supercapacitors, to fulfill the load demand and maintain a steady supply of electricity if it surpasses the amount of energy provided by photovoltaic cells. The extra energy will be used to charge the HESS if, on the other hand, the load demand is less than the energy generated by the PV source [7]. Storage for future use or balancing out variations in the microgrid's energy supply and demand permits the efficient exploitation of excess energy [8]. All things considered, the microgrid actively corrects energy imbalances by using energy storage components to compensate for shortfalls in power production or store extra energy for later use, guaranteeing optimal system stability and utilization.

MODEL OF PHOTOVOLTAIC SYSTEM

A photovoltaic (PV) system, [9] battery energy storage system (BESS), supercapacitor (SC), and power electronic converters constitute a DC standalone. The primary energy resource in the system that is intended to fulfill the greatest load demand during the day is the photovoltaic system. To deliver the net output power into the network and adjust the PV output power (mostly to track the maximum power point), a boost converter is employed [10]. With a separate DC-DC bidirectional converter for every storage source, the HESS is connected to a single DC bus. To balance any imbalances between generation and load, a HESS is used to control the DC voltage (Vdc) at the common DC connection [11]. There are two ways in which a DC-DC bidirectional converter can operate. There are two modes of operation: 1) charging mode when the power generation exceeds the load demand and 2) discharging mode when the generation falls short of the load need. The HESS described here can satisfy transient power fluctuations for brief periods, in addition to the typical power requirements for extended periods [12]. The photovoltaic cell for the equivalent circuit is shown in Figure 2.

For Equivalent Circuits for Photovoltaic Cells

The voltage-current characteristic equation of a solar cell [13],

Module photocurrent

$$I_{ph} = [I_{sc} + K_i(T - 298)] \times \frac{I_r}{1000} \quad (1)$$

Here, I_{ph}: photocurrent (A), I_{sc}: short-circuit current (A), K_i: short-circuit current of the cell at 25°C and 1000 W/m^2, T is the operating temperature (K), I_r: solar irradiation (W/m^2).

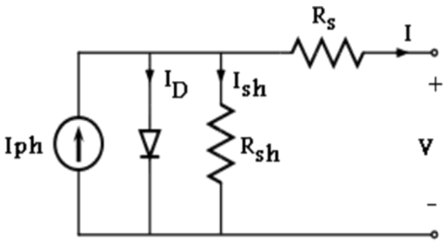

Figure 2. PV equivalent circuit.

Module reverse saturation current I_{rs}:

$$I_{rs} = I_{sc}/[exp(qV_{OC}/N_s k_n T) - 1] \tag{2}$$

Here, q: electron charge, = 1.6 × 10^{-19}C; V_{OC}: open-circuit voltage (V), N_s: number of cells connected in series, n: ideality factor of the diode, k: Boltzmann's constant, = 1.3805 × 10^{-23} J/K.

The module saturation current I_0 varies with the cell temperature, which is given by

$$I_0 = I_{rs}\left[\frac{T}{T_r}\right]^3 exp\left[\frac{q \times E_{g0}}{nk}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right] \tag{3}$$

Here, T_r the nominal temperature = 298.15 K; E_{g0} is the bandgap energy of the semiconductor, = 1.1 eV; The current output of the PV module is:

$$I = N_p \times I_{ph} - N_p \times I_0 \times \left[exp\left(\frac{\frac{V}{N_s} + I \times \frac{R_s}{N_p}}{n \times V_t}\right) - 1\right] - I_{sh} \tag{4}$$

with

$$V_t = \frac{k \times T}{q} \tag{5}$$

and

$$I_{sh} = \frac{V \times \frac{N_p}{N_s} + I \times R_s}{R_{sh}} \tag{6}$$

Here: N_p: number of PV modules connected in parallel; R_s: series resistance (Ω); R_{sh}: shunt resistance (Ω); V_t: diode thermal voltage (V).

MODEL OF SUPERCAPACITOR

The application of SC would cause problems with power quality and thermal stability when dealing with loads that fluctuate and require more immediate power. Including SC helps to enhance and alleviate most of these challenges. This method establishes shifting loads using controlled switches to link several power loads in parallel. The ordinary capacitor and BESS were connected via a supercapacitor (SC). Because of its small capacitance (a few hundred farads) and fast reaction time, SC is a good choice for temporary applications. Supercapacitors are high-density power-storage devices that can be used to increase the current required by induction machines when turned on. Therefore, they cannot be used independently because of their poor energy densities. Hence, they are suitable for use in BESSs. Despite the low voltage of most SCs, when they are employed in situations where the voltage level is higher than that of a single capacitor, they must be connected in series. The SC is connected in parallel to increase potential energy storage [14].

Modeling, evaluation, and simulation of an SC module for energy system (ES) application

$$\eta_{eff} = e^{-\frac{2R_{ESR}C_{TOTAL}}{t_{dch}}} \tag{7}$$

where η_{eff}: energy efficiency, R_{ESR}: total equivalent series resistance, C_{TOTAL}: total capacitance, t_{dch}: discharge time.

$$V_c(t) = V_o e^{-\frac{t}{R_T C_{total}}} \tag{8}$$

and

$$v(t) = v_C(t) + v_{R_{ESR}}(t) \tag{9}$$

where $V_c(t)$: voltage of the supercapacitor, V_o: voltage at the initial condition, and t is time.

So that, voltage V(t)

$$V(t) = V_o\left(1 + \frac{R_{ESR}}{R_T}\right)e^{-\frac{t}{R_T C_{total}}} \tag{10}$$

Voltage discharge ratio

$$d = \frac{v(t)}{V_o} = \left(1 + \frac{R_{ESR}}{R_T}\right)e^{-\frac{t}{R_T C_{total}}} \tag{11}$$

And solving for the discharge time from the above equation

$$t_{dt} = -(R_{ESR} + R_{Load})C_{total} ln\left[\frac{(R_{ESR}+R_{Load})}{2R_{ESR}+R_{Load}}\right] \tag{12}$$

Where, R_{Load} is a function of voltage(v) because the current(i) during discharging was set to be constant.

MODEL OF BATTERY ENERGY STORAGE SYSTEM

Owing to the sporadic nature of renewable energy sources, times when solar energy production is low or nonexistent require the use of a battery storage system. Battery storage systems are used in combination with solar PV systems to reduce the uncertainty surrounding the availability of renewable energy sources [15]. The energy stored in the battery system can be used to provide the necessary power during peak and non-peak hours. The dependability and stability of microgrid power systems will be improved by the battery storage system, which will also balance out the effects of power fluctuations from available renewable energy sources. The battery efficiency and performance are contingent upon several factors, such as the surrounding temperature, charge level, voltage fluctuations, and charging and discharging rates [16]. Battery durability was also determined by these variables. However, the effects of these variables vary according to battery type. Lithium-ion batteries were utilized in this study because of their long lifespan and superior efficiency compared to other battery types [17, 18].

$$V = E_0 - K\left(\frac{Q}{Q-it}\right)i - R_0 \cdot i + A \cdot e^{(-B \cdot it)} \tag{13}$$

Here,
E0 represents the open-circuit voltage of the battery at full capacity (V).
K is the polarization resistance coefficient (Ω);
Q is the battery capacity (Ah);
i is the battery current (A);
R_0 is the internal resistance (Ω);
it = ∫ idt is the removed charge (Ah);
A and B are empirical constants (V), (1/Ah).

$$V = E_0 - K\left(\frac{Q}{Q-it}\right)i^* - K\left(\frac{Q}{Q-it}\right)it - R_0 \cdot i + A \cdot e^{(-B \cdot it)} \tag{14}$$

$$V = E_0 - K\left(\frac{Q}{it-0.1Q}\right)i^* - K\left(\frac{Q}{Q-it}\right)it - R_0 \cdot i + A \cdot\ e^{(-B \cdot it)} \tag{15}$$

$$V_{full} = E_0 - R_0 \cdot I + A \tag{16}$$

$$V_{exp} = E_0 - K\frac{Q}{Q-Q_{exp}}\left(Q_{exp} + I\right) - R_0 \cdot I + A \cdot e^{\left(-B \cdot Q_{exp}\right)} \tag{17}$$

$$V_{nom} = E_0 - K\frac{Q}{Q-Q_{nom}}(Q_{nom} + I) - R_0 \cdot I + A \cdot e^{(-B \cdot Q_{nom})} \tag{18}$$

$$E_0 = \frac{E_{exp}C_{nom} - E_{nom}C_{exp}}{\left[\left(1-e^{(-B \cdot Q_{nom})}\right)C_{exp} - (1-e^{-3})C_{nom}\right]} \tag{19}$$

$$K = E_0\left(\frac{1-e^{-B \cdot Q_{exp}}}{C_{exp}}\right) + \frac{E_{exp}}{C_{exp}} \tag{20}$$

$$A = V_{full} - E_0 + R \cdot i \tag{21}$$

$$B = \begin{cases} \frac{2}{Q_{exp}}, for\ LFP\ cell \\ \frac{4}{Q_{exp}}, for\ NMC\ cell \end{cases} \tag{22}$$

CONCLUSION

In conclusion, maximizing performance, prolonging battery life, and lowering overall system costs depend on the power management of a HESS in a DC microgrid. To accomplish these objectives, it is necessary to integrate microgrids powered by renewable energy, hybridize storage devices, and accurately estimate energy consumption. Reduce energy losses in future research by utilizing energy storage system prediction data to minimize the total cost of the system.

REFERENCES

1. Ahmed M, Kuriry S, Shafiullah MD, Abido MA. DC microgrid energy management with hybrid energy storage systems. In: 23rd International Conference on Mechatronics Technology (ICMT); 2019; Salerno, Italy. IEEE Publications; 2019. p. 1–6. DOI: 10.1109/ICMECT.2019.8932147.
2. Jing W, Lai CH, Wong SHW, Wong MLD. Battery-supercapacitor hybrid energy storage system in standalone DC microgrids: A review. IET Renew Power Gener. 2017;11:461–469. DOI: 10.1049/iet-rpg.2016.0500.
3. Farrokhi E, Ghoreishy H, Ahmadi Ahangar R. Optimization-based power management for battery/supercapacitor hybrid energy storage system with load estimation capability in a DC microgrid. Int J Electr Power Energy Syst. 2024 Jan;155. DOI: 10.1016/j.ijepes.2023.109665.
4. Rajput AK, Lather JS. Energy management of a DC microgrid with hybrid energy storage system using PI and ANN based hybrid controller. Int J Ambient Energy. 2023;44(1):703–718. DOI: 10.1080/01430750.2022.2142285.
5. Taye BA, Choudhury NBD. Adaptive filter based method for hybrid energy storage system management in DC microgrid. e-Prime – Adv Electr Eng Electron Energy. 2023;5. DOI: 10.1016/j.prime.2023.100259.
6. Chu H, Wang X, Mu X, Gao M, Liu H. Research on optimal configuration of hybrid energy storage capacity based on improved particle swarm optimization algorithm. In: IEEE 4th Advanced Information Technology, Electronic and Automation Control Conference (IAEAC); 2019; Chengdu, China. IEEE Publications. DOI: 10.1109/IAEAC47372.2019.8998019.
7. Neelagiri S, Usha P. Energy management of PV wind based microgrid with hybrid energy storage systems. Int J Power Electron Drive Syst (IJPEDS). 2022;13. DOI: 10.11591/ijpeds.v13.i4.pp2128-2138.
8. Shafiullah MD, Refat AM, Haque ME, Chowdhury DMH, Hossain MS, Alharbi AG, Alam MS, Ali A, Hossain S. Review of recent developments in microgrid energy management strategies. Sustainability. 2022;14. DOI: 10.3390/su142214794.
9. Sutikno T, Arsadiando W, Wangsupphaphol A, Yudhana A, Facta M. A review of recent advances on hybrid energy storage system for solar photovoltaics power generation. IEEE Access. 2022;10:42346–42364. DOI: 10.1109/ACCESS.2022.3165798.
10. Gugulothu R, Nagu B, Pullaguram D, Babu BC. Optimal coordinated energy management strategy for standalone solar photovoltaic system with hybrid energy storage. J Energy Storage. 2023;67. DOI: 10.1016/j.est.2023.107628.
11. Sinha S, Bajpai P. Power management of hybrid energy storage system in a standalone DC microgrid. J Energy Storage. 2020 Aug;30. DOI: 10.1016/j.est.2020.101523.
12. Bellia H, Youcef R, Fatima M. A detailed modeling of photovoltaic module using MATLAB. NRIAG J Astron Geophys. 2014;3:53–61. DOI: 10.1016/j.nrjag.2014.04.001.
13. Nguyen XH, Nguyen MP. Mathematical modeling of photovoltaic cell/module/arrays with tags in Matlab/Simulink. Environ Syst Res. 2015 Dec 9;4. DOI: 10.1186/s40068-015-0047-9.

14. Cultura AB, Salameh ZM. Modeling, evaluation and simulation of a supercapacitor module for energy storage application. In: International Conference on Computer Information Systems and Industrial Applications; 2015; Bangkok. Atlantis Press; 2015. DOI: 10.2991/cisia-15.2015.235.
15. 15Garip S, Ozdemir S. Optimization of PV and battery energy storage size in grid-connected microgrid. Appl Sci. 2022;12. DOI: 10.3390/app12168247.
16. Sharma S, Gupta P. Energy management system of standalone DC microgrid. In: Rani A, Kumar B, Shrivastava V, Bansal RC, editors. Signals, Machines and Automation. SIGMA 2022. Lecture Notes in Electrical Engineering, vol 1023. Springer, Singapore; 2023. p. 265–277. DOI: 10.1007/978-981-99-0969-8_13.
17. Campagna N, Castiglia V, Miceli R, Mastromauro RA, Spataro C, Trapanese M, Viola F. Battery models for battery powered applications: A comparative study. Energies. 2020;13. DOI: 10.3390/en13164085.
18. Lili Z, Guoguang Y, Libin Y, Shengpeng Y. Study on optimization of operating parameters of hybrid energy storage system. In: International Conference on Smart Grid and Electrical Automation (ICSGEA); 2017; Changsha, China. IEEE Publications; 2017. DOI: 10.1109/ICSGEA.2017.45.