Control of Microgrid with Hybrid Energy Storage System

Suganthi.N, P. Usha
Dayananda Sagar College of Engineering,
suganthin-eee@dayanandasagar.edu,pu1968@yahoo.co.in

Abstract.

This paper proposes the energy management system for DC side of the microgrid which consists of PV system, wind energy system, along with hybrid energy storage system consist of battery and supercapacitor. Solar and wind systems are implemented with maximum power point control to extract maximum power. To improve the power output and to manage its intermittent nature of these sources hybrid energy storage devices is implemented with appropriate control strategy . Hybrid energy storage system with high energy density and high-power density is implemented to reduce the fluctuation in DC link voltage and to maintain power balance in DC microgrid. The control strategy proposed fulfills the need of transient power and average power requirements of the load. The proposed DC microgrid is realized in MATLAB Simulink and the performance of the system is verified for different cases.

Keywords. Wind, Solar, PV, Energy, Storage, battery, super capacitor.

1. INTRODUCTION

In the current scenario as power demand is increasing and fossil fuel is getting depleted need for alternate energy sources and also distributed generation-based grid is increasing.[1] Renewable energy sources are the promising solution for these energy needs. Among the several renewable energy sources wind and Solar are the prominent sources as it available in plenty and it is a clean energy. Microgrids with wind and solar are evolving. [2] To handle the variable nature these sources and to increase the penetration of these devices in to main grid energy storage devices are required. Battery is the most commonly used energy storage system [3]. Some loads such as refrigerator, Air conditioner, require high starting current and sizing the battery for such requirements proved to be costly.[4] In situations such as sudden load change /generation change to handle the momentary as well as regular current requirements combination of high power and high energy density devices are required [5]. Most commonly used combinations are flywheel and battery, battery and supercapacitor, fuel cell -flywheel, pumped hydro-battery and etc. [6]-[7] However, battery -super capacitor is an effective solution, as flywheel suffers with rotor failure, pumped hydro system requires large area, fuel cell responds slowly to fast load variations.[8]. In microgrid with hybrid energy storage devices such as battery and supercapacitor meeting the load demand by maintaining the SOCs of the storage devices is challenging. Therefore, designing a control strategy for energy management plays a important role in the continuous, stable and reliable operation of the microgrid. In [9]-[11] an energy management system is proposed with battery as the storage device. In these system DC link voltage rating and Battery voltage rating should be kept same. Any load /generation disturbances must be buffered by the battery. This places high stresses on the battery and also this reduces the life cycle of it. [12]. A perfect storing system in a DC microgrid must be able to supply together high-power density and energy density needs to manage the circumstances such generation, load, and climate changes. By applying battery and supercapacitor (SC) hybrid combination battery life time, reduction in battery size, reduction in cost of the battery can be achieved. Several types of control approaches been reported in the literature for energy management Model predictive control, neural networks, decision tree, fuzzy logic and etc [13]-[17] However, these methods involve large data storage requirements and extensive computations. And the disadvantage of the Model predictive Controller method is itrequires large mathematical computations.

Potential development in battery life time is quantified in [18]-[19] In[20] advantages of addition SC to battery storage system in wind energy conversion systems is been verified. The basic concept of all the above-mentioned energy management strategies is that battery provides a low frequency current requirement and transient current component is handled by super capacitor momentarily and the battery slow response is not compensated. This proposed paper is based on dividing average current requirement and high frequency current requirement for generating reference current for battery and SC. The battery error component is utilized to generate current reference for supercapacitor along with high frequency current component to compensate the slow response of the battery, to achieve faster voltage regulation.

2. DC MICROGRID ARCHITECTURE

The DC micro grid considered contains of PV power generation system, wind energy system (WES) along with battery and ultra-capacitor Hybrid Energy Storage System (HESS) is shown in Fig.2.1. In the represented Microgrid system, Photo Voltaic with the boost converter implemented with MPPT controller utilizing peturb&obseve algorithm to increase the output power of the PV system. The output pulses from MPPT controller are supplied to the boost converter that is linked to DC bus. WES consists of wind turbine coupled with PMSG generator. The AC power generated from WES system is converted into DC power using AC -DC converter. HESS is employed to handle the transient as well as the regular load necessities. The energy storage devices super capacitor and battery is parallelly attached to DC bus via bi-directional DC-DC boost-buck converter. A DC-AC converter is employed to convert DC power from the PV, battery and SC to AC power and supply to ACload and is represented in Fig.2.1. Proposed system constitutes the DC microgrid.

2.1. Wind Energy Conversion System

In the wind turbine wind's dynamic energy is changed into mechanical energy and is given in equation (2.1) below

$$P_W = \frac{1}{2}\rho\pi r^2 C_p(\lambda,\beta)V^3 \tag{2.1}$$

Where Cp is the co-efficient of power (Betz), ρ is density of air in kg/m^3, V is the velocity of wind in m/s, r is the length of the blade in m. Equation (2.2) gives the wind turbine's aerodynamic torque.[22]

$$T_W = \frac{P_W}{\omega} \tag{2.2}$$

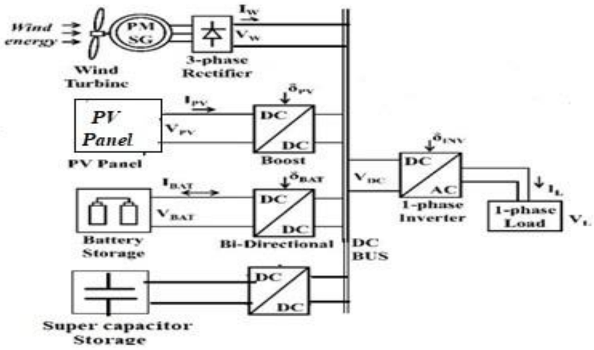


Figure 2.1. Configuration of Hybrid Energy sources with HESS

Where ω is the rotor speed in radians per second. The generated mechanical energy is changed in to electrical energy in Permanent Magnet Synchronous Generator. The diode rectifier converts the three-phase AC voltage of the PMSG into DC voltage.

2.2. PV System Model

The single -diode equivalent circuit of PV cell is shown in the Fig:2. This cell can be symbolized as an ideal Photovoltaic cell with a diode connected parallel to the current source.[23]. To prevent the reverse power flow, the bypass diode is used.

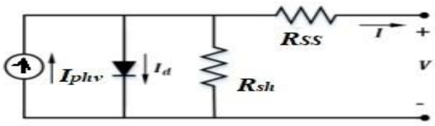


Fig:2.2 Equivalent circuit of PV cell[23]

$$I_{pvv} = I_{phv} - I_d \qquad (2.2.1)$$

and Current of diode ($\boldsymbol{I_d}$) is represented in idyllic form as follow

$$I_d = I_0(e^{\frac{qVocpv}{\eta p K_p T_p}} - 1) \qquad (2.2.2)$$

$$Ipvv = Iphv - I_0(e^{\frac{qVocpv}{\eta p K_p T_p}} - 1) \qquad (2.2.3)$$

Where I_d, $Iphv$, V_{oc}, q, ηp, and T_p denote the current (diode), Photo current, output potential of PV, total Charge, factor of ideality, Boltzmann constant and temperature in Kelvin accordingly. Shunt resistance (Rsh) is negligible as it has less effect on I-V features of the Photovoltaic cell. Therefore equation (2.2.1) can be simplified to (2.2.3). Detailed specifications of the model is given in the table (2.2.1) below and the model used is WAAREEEnergiesWU-120. Boost converter design is similar to that reported in [7].

S.No	Solar cell Details		
	Constraints	Symbol	Value
1	Highest power	Pmm	120W
2	Highest voltage	Vmm_P	17.1V
3	Highest current	Immp	7.1A
4	Short circuit current	Ishh	8A
5	Open circuit Voltage	V_{open}	21 V

Table 2.2.1 Details of PV System

Wind Energy system Details			
S.No	Parameter	Variable	Value
1.	Base rotational speed	ω	1.2pu
2.	Maximum power atbase speed	Pw	0.85 pu
3.	Nominal output power	Pout	1Kw
4.	Wind turbine rated Velocity	V	12m/s
5	Turbine radius	R	1.1m

Table2.2.2 Details of WECS

The boost converter is realized with MPPT control implemented with P&O algorithm. There various types of MPPT algorithm [24] stated in the literature. Amid various types, Perturb and Observe procedure is simple to employ, and is used to increase the photovoltaic system

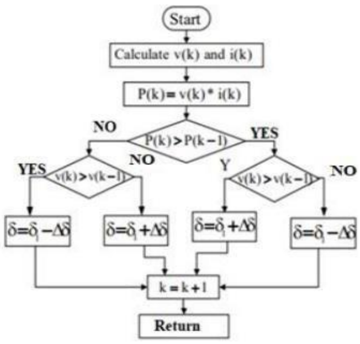


Fig.2.2.1.P&OMPPTAlgorithm

Systems	Storage system Requirement
Battery	Li-ion-24 V,14Ah
SC	32V,29F
Two-way DC-DC converter	L_{bat}=0.03mH, Lsc=0.352mH, C=400µF, Vo=50v, R=5Ω, f=16KHZ
gains for controller of HESS	Kbp=0.004, Kbi=0.9, Kscp=0.55, Ksci=16800, Kppv=1.58, Kiiv=4097.

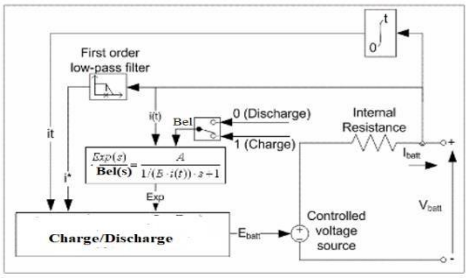
Table.2.3.1Storage system

power output and also to rise the system effectiveness of the photovoltaic system.[25]. The P&O algorithm flow chart is presented in Fig.2.2.1. This algorithm is used to give pulse input to the boost converter. This algorithm disturbs the voltage and relative change in power is calculated and is compared with previous power value. The operating point will be traced towards MPP if the power change is positive and away from MPP if the change in power is negative. This process will be repeated until maximum peak is obtained.[26]

2.3. Battery &super capacitor Modeling

In the DC microgrid system Li -ion battery model obtainable in MATLAB /Simulink 2018 is been considered. Equivalent circuit of the Li-ion is shown in Fig.2.3.1. The Battery model represents the different variations of battery and its features. Battery is modelled as current source with some inbuilt resistance, according to the SOC level of the battery charges and discharges.

When battery works in charging mode battery voltage rises and when it works in discharging mode the current rises.



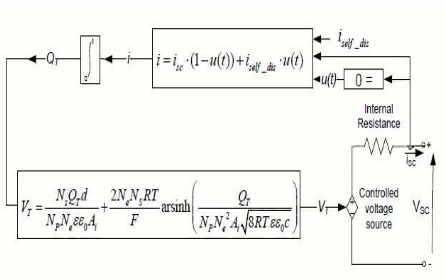


Fig.2.3.1 Battery Model [27] Fig2.3.2 Supercapacitor model [28]

The DC microgrid system also utilizes Stern -Tafel model of the ultra-capacitor which is obtainable in Simulink (Mat lab) is depicted in Fig.2.3.2. It is established as the voltage source that can be controlled with inbuilt resistance. The ultra-capacitor model performance depends on the numerous constraints such as ultra-capacitor's inbuilt resistance, ultra-capacitor rated capacitance and net stored charge.

2.4. DC Microgrid System with Two-way Converter control

In the presented DC microgrid, energy storage devices ultra-capacitor and battery are linked to the DC bus parallel to each other using individual two-way converters which can transfer the power in both directions. Depending on the switching pulses received from the energy management control system the converters of the battery and ultra-capacitor either discharges(supplies) or charges(absorbs) power depending on the power flow direction. Converter construction is depicted along with microgrid system simulation in Fig.2.4.1. In case of boost mode, the switches SW-bb1 and SW_SCC1 is switch to on condition and in buck mode SW-bb2 and SW_SCC2 is switch to on condition**.**

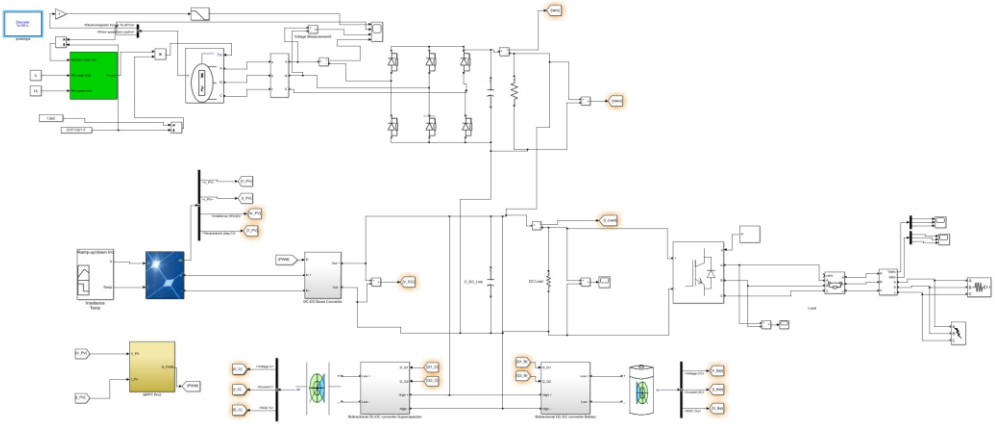


Fig.2.4.1. Simulation circuit of DC Microgrid with HESS

3. *ENERGY MANAGEMENT ALGORITHM*

In this proposed energy management algorithm basically works on the net current required from storage devices which is obtained from the feeding difference between DC bus voltage and actual available voltage to Proportional Integral controller. PI regulator ‘s output current signal is further split into high frequency current component and average current component using filter controller. The average current component is obtained as follows

$$I_{B\,av} = F(I_{Tot}) \qquad (3.1)$$

$$I_{Berr} = I_{B\,av} - I_{Bat} \qquad (3.2)$$

This obtained average current component ($I_{B\,av}$) is compared with the available battery currentI_{Bat}, and the error signal (I_{Berr})obtained as in equation (3.2) is supplied to the PI regulator to produce duty ratio. Then duty ratio is converted in to switching pulses by means of pulse width modulator (PWM), using these signals the switches SW1 and SW2 are operated. The transient current necessities (II_{Hf}) are attained from the net current necessities(I_{Tot})by deducting the low frequency current requirement ($I_{B\,av}$) as follows

$$I_{Hf} = I_{Tot} - I_{B\,av}. \qquad (3.3)$$

In order to compensate the slow response of the battery, and to compensate uncompensated($Punc$) power by the battery for first few seconds uncompensated power is calculated as follows,

$$Punc = (I_{B\,av} - I_{Bat})\, V_b \qquad (3.4)$$

Where V_b is the voltage of the battery. The current reference given to the super capacitor includes the uncompensated current component of the battery and high frequency current component. In the equation 3.5 second part represents the uncompensated current of the battery.

$$I_{SCRef} = I_{Hf} + (I_{B\,av} - I_{Bat})\,\frac{Vb}{Vsc} \qquad (3.5)$$

The reference current for the supercapacitor is obtained by subtracting actual supercapacitor from current obtained from equation (3.5) and the variance obtained is provided to PI regulator to produce duty ratio and the switching pulses are generated from PWM and is given to the supercapacitor bi-directional converter switches (SW3&SW4) as shown in the figure 2.4.1. In order to maintain the constant DC link voltage, super capacitor and battery will either act boost/discharge mode or in buck /charge mode. Energy management strategy is shown in figure.3.1.

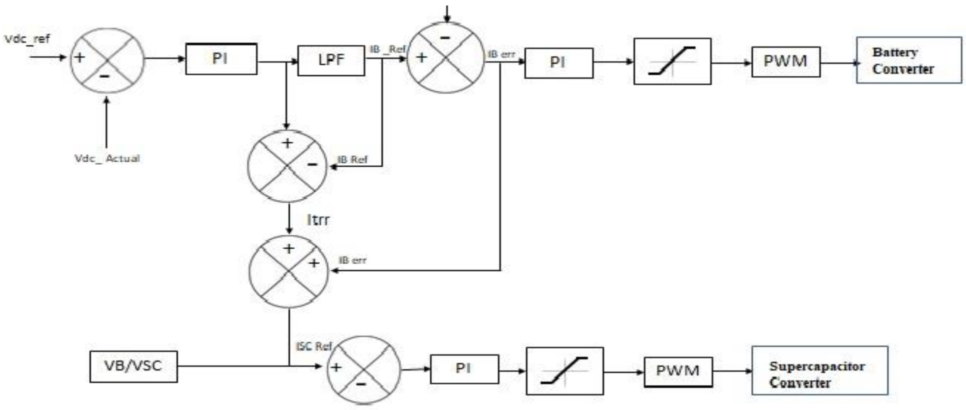


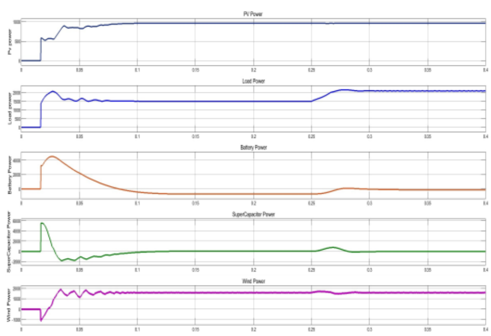
Fig.3.1 Energy Management Strategy of DC Microgrid

4. *SIMULATION AND ANALYSIS*

The DC microgrid system is analyzed for load variation and generation variation and the results of two cases are discussed below

4.1 Case1: Load Variation

To analyze the load variation, generated power is kept constant, and load is varied as from 1500W to 2000W at 0.25 sec. Before 0.25 sec power from is wind power 1300Wand solar power is 1000W which is more than the load requirement, and the extra power is been absorbed by battery(700W) upto 0.25 sec as shown in figure4.1, sudden rise in load power at 0.25 sec is momentarily satisfied by super capacitor and average power requirement is satisfied by battery. It is also verified that the DC link voltage is kept constant(50V) regardless of load change as observed in figure4.2



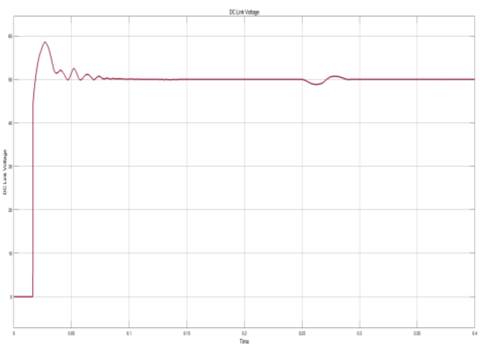


Fig4.1 Power response for load variation

Fig4.2DC Link Voltage

Case4.2: Variation in Generated Power

DC microgrid is analyzed for variation in generation by keeping load power requirement constant at 1500W. In this case wind power generation is kept at 1000W and PV power is varied by varying irradiance. At starting power generation from PV system is 500W and it increase to 1000W at 0.2. Upto 0.2 sec the power generation from PV and wind systems is equal to the load demand of 1500W. After 0.2 sec PV power is increased to 1000W, now power generation form PV and wind is more than the load requirement. The extra power of 500W is absorbed by supercapacitor momentarily for few microseconds followed by battery as shown in figure 4.3 And also from figure 4.4, it is verified that DC link voltage is sustained constant regardless of generation deviation.

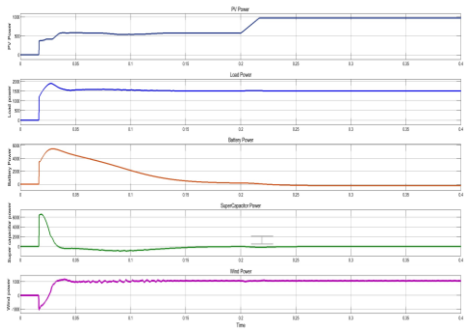


Fig 4.3 Response to PV generation variation

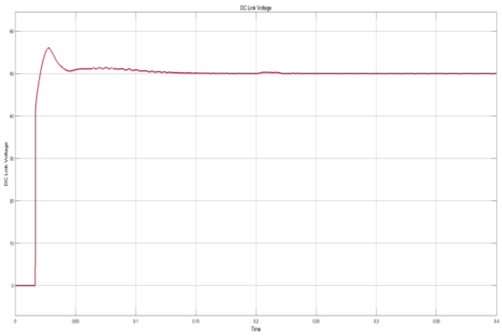


Fig 4.4 DC link Voltage

Similarly when wind velocity is changed at 0.2 sec, the wind power generation changes from 1000w to 500W along with variation in solar irradiance introduced at 0.2 sec from $1000W/m^2$ to $400w/m^2$, due to this total power generation becomes less than the load demand of 1500W. Momentary power deficit of 600w is supplied by the super capacitor for 0.008 sec followed by the battery as shown in figure 4.5.Form the figure 4.6 ,it is clear that DC link voltage remains constant irrespective of generated power variation. All simulation results are tabulated and presented in table4.1 below

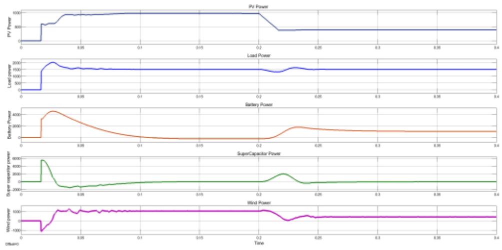


Fig 4.5 Response to PV&Wind generation variation

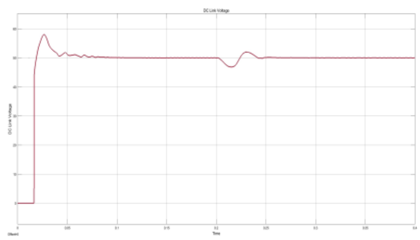


Fig 4.6 DC link Voltage

Different Scenarios	DC link voltage Variation		
	Overshoot	Steady state - time	Disturbance recovery time
Load Variation	58V	0.007 sec	0.004 sec
PV Generation Variation	55V	0.006 sec	0.001sec
PV &Wind Generation Variation	58V	0.007	0.004 sec

Table4.1 Summary of Simulation and Analysis results

5. CONCLUSION

Hybrid Energy Storage system along with two renewable energy sources are effectively utilized in the presented energy management control strategy. The main goal of the proposed energy management algorithm is to sustain thedc link voltage constant irrespective of load changes and the generation variation. The proposed system is simulated and analyzed and is also verified that dc link voltage is sustained at constant value irrespective of change in wind velocity, variation in irradiance and load variation and also the stability of the system is maintained.

6. REFERENCES

[1] Punna, Srinivas & Manthati, Udaya. (2020). Optimum design and analysis of a dynamic energy management scheme for HESS in renewable power generation applications. SN Applied Sciences. 2. 10.1007/s42452-020-2313-3.

[2] S. Kotra and M. K. Mishra, "Design and Stability Analysis of DC Microgrid With Hybrid Energy Storage System," in IEEE Transactions on Sustainable Energy, vol. 10, no. 3, pp. 1603-1612, July 2019, doi: 10.1109/TSTE.2019.2891255.

[3] S. Augustine, M. K. Mishra and N. Lakshminarasamma, "A Unified Control Scheme for a Standalone Solar-PV Low Voltage DC Microgrid System With HESS," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 8, no. 2, pp. 1351-1360, June 2020, doi: 10.1109/JESTPE.2019.2916421.

[4] D. Das, M. J. Hossain, S. Mishra and B. Singh, "Bidirectional Power Sharing of Modular DABs to Improve Voltage Stability in DC Microgrids," in IEEE Transactions on Industry Applications, vol. 58, no. 2, pp. 2369-2377, March-April 2022, doi: 10.1109/TIA.2022. 3144653..

[5] Suganthi.N, Dr.P. Usha, "Overview of Micro grid Controllers and Energy Storage Systems", 6th International E-Conference on Latest Trends in Science, Engineering and Technology (ICLTSET'20) on April 13,2020.

[6] Sangeeta Modi, Dr.P. Usha published paper on "Mathematical Modelling, Simulation and Analysis of Microgrid: A Pre-requisite for Devising a Controller" GIS Science Journal, ISSN NO : 1869-9391, Dec.2021, Vol.8, issue12, page no.433-461.

[7] Suganthi. N and P. Usha, "Modeling and Analysis of Dynamic Energy Management of DC Microgrid Using HESS," 2021 5th International Conference on Electronics, Communication and Aerospace Technology (ICECA), 2021, pp. 23-29, doi: 10.1109/ICECA52323.2021.9676105

[8] K. Kevin, S. Modi and P. Usha, "Micro Grid: An Energy Efficient Approach for Modern Power System," 2019 IEEE International Conference on Distributed Computing, VLSI, Electrical Circuits and Robotics (DISCOVER), Manipal, India, 2019, pp. 1-5

[9] A. K. Podder, O. Chakraborty, S. Islam, N. Manoj Kumar and H. H. Alhelou, "Control Strategies of Different Hybrid Energy Storage Systems for Electric Vehicles Applications," in IEEE Access, vol. 9, pp. 51865-51895, 2021, doi: 10.1109/ACCESS.2021.3069593.

[10] M. Rezkallah et al., "Coordinated Control Strategy for Hybrid off-Grid System Based on Variable Speed Diesel Generator," in IEEE Transactions on Industry Applications, vol. 58, no. 4, pp. 4411-4423, July-Aug. 2022, doi: 10.1109/TIA.2022.3174825.

[11] Sangeeta Modi, Ashish Anand and P. Usha, "Microgrid Control: A Comparative Study on Control Strategies for Controlling the Circulating Current", IEEE International Conference on Communication, Control and Intelligent Systems (CCIS), pp 339-343, Nov. 2015.

[12] Nikhil Korada, Mahesh K. Mishra,” Grid Adaptive Power Management Strategy for an Integrated Micro grid with Hybrid Energy Storage”, IEEE Transactions on Industrial Electronics, 64(4),2017, pp. 2884-2892. (Journal).

[13] Z. Zhu, F. Xiao, Z. Huang, J. Liu, P. Chen and Q. Ren, "Bidirectional Power Control Strategy for Super Capacitor Energy Storage System Based on MMC DC-DC Converter," in IEEE Access, vol. 10, pp. 53225-53233, 2022, doi: 10.1109/ACCESS.2022. 3175207..

[14] D. Sun, H. Long, K. Zhou, Y. Lv, J. Zheng and Q. Chen, "Research on SCESS-DFIG DC Bus Voltage Fluctuation Suppression Strategy for Frequency Inertia Regulation of Power Grid," in IEEE Access, vol. 8, pp. 173933-173948, 2020, doi: 10.1109/ACCESS.2020. 3025292..

[15] C. Serrano-Canalejo et al, "Energy management system design and economic feasibility evaluation for a hybrid wind power/pumped hydroelectric power plant," in IEEE Latin America Transactions, vol. 17, no. 10, pp. 1686-1693, October 2019, doi: 10.1109/TLA.2019. 8986447..

[16] Aws saleh et al, Modeling, Control, and Simulation of a New Topology of Flywheel Energy Storage Systems in Microgrid”, IEEE access, Vol.7, Nov 2019. (journal).

[17] Rishi Kant Sharma et al,"Dynamic Power Management and Control of a PV PEM Fuel-Cell-Based Standalone ac/dc Microgrid Using Hybrid Energy Storage" IEEE Transactions on Industry Applications Vol. 54(1), pp.526-538,2018.

[18] P. Mathew, S. Madi Chetty and S. Mishra, "A Multilevel Distributed Hybrid Control Scheme for Islanded DC Microgrids," in IEEE Systems Journal, vol. 13, no. 4, pp. 4200-4207, Dec. 2019, doi: 10.1109/JSYST.2019.2896927.

[19] I. A. Ibrahim, M. J. Hossain, B. C. Duck and C. J. Fell, "An Adaptive Wind-Driven Optimization Algorithm for Extracting the Parameters of a Single-Diode PV Cell Model," in IEEE Transactions on Sustainable Energy, vol. 11, no. 2, pp. 1054-1066,April 2020R.

[20] Timbus, A et al., “Evaluation of Current Controllers for Distributed Power Generation Systems.” IEEE Transactions on Power Electronics, 24(3), 654–664,2009. doi:10.1109/tpel.2009.2012527.

[21] Mohannad Jabbar Mnati et al.,” Review Different Types of MPPT Techniques for Photovoltaic Systems”, International Conference on Sustainable Energy and Environment Sensing (SEES 2018).

[22] Tremblay, O.; Dessaint, L.-A. Experimental Validation of a Battery Dynamic Model for EV Applications. // World Electric Vehicle Journal, 3, (2009), pp. 289-298.

[23] Henry Miniguano et al.,” A General Parameter Identification Procedure Used for the Comparative Study of Supercapacitors Models”, Energies Journal,12,1776.

[24] M.H.Nehrir,C.Wang et al.,"A Review of Hybrid Renewable /Alternative Energy Systems for Electric Power Generation:Configuration,control,and Applications",IEEE Trans.Sustain.Energy,Vol.2,no.4.pp392-403,Oct2011.

[25] S. Singh, S. Manna, M. I. Hasan Mansoori and A. K. Akella, "Implementation of Perturb & Observe MPPT Technique using Boost converter in PV System," 2020 International Conference on Computational Intelligence for Smart Power System and Sustainable Energy (CISPSSE), 2020, pp. 1-4.

[26] S. R. Pendem and S. Mikkili, "Assessment of Cross-coupling Effects in PV String-integrated-converters with P&O MPPT Algorithm Under Various Partial Shading Patterns," in CSEE journal of power and Energy Systems, Vol.8,no.4 pp. 1013-1028, July 2022.

[27] https://www.mathworks.com/help/physmod/sps/ powersys /ref/ battery.html.

[28] https://www.mathworks.com/help/physmod/sps/powersys/ref/supercapacitor.html

[29] Y. S. Perdana et al,” Direct Connection of Super capacitor-Battery Hybrid Storage System to the Grid-tied Photovoltaic System", IEEE Transactions on Sustainable Energy,Vol.10(3), pp.1370 - 1379, 2019.