Energy management of PV wind based microgrid with hybrid energy storage systems

Suganthi Neelagiri, Pasumarthi Usha
Department of Electrical Engineering, Dayananda Sagar College of Engineering, Bangalore, Karnataka, India

Article Info

Article history:

Received Aug 3, 2022
Revised Sep 3, 2022
Accepted Sep 17, 2022

Keywords:

Energy
Microgrid
PV
System
Wind

ABSTRACT

Power demand all around the world is increasing day by day and conventional energy sources are getting depleted. In order to meet the power demand and to reduce the carbon emission caused by the conventional energy sources, alternate renewable energy sources are important. wind and solar are two reliable energy sources among the various renewable energy sources. In this proposed paper wind and photovoltaic (PV) energy-based direct current (DC) microgrid is proposed with super capacitor and battery hybrid energy storage systems. Constant DC link voltage is the replication of energy balance in DC microgrid. The main goal of the proposed microgrid energy management algorithm is to maintain the constant DC link voltage irrespective of the intermittent nature of the renewable energy sources, load variations and under fault conditions. Energy management system is designed such that battery energy storage system handles the average power requirements and super capacitor handles the transient power requirements caused by the load, renewable energy variation and also caused due to fault conditions. The proposed system improves battery life along with effective DC link voltage regulation. The proposed control algorithm of energy management is compared with conventional energy management system in MATLAB/Simulink and presented for various studies.

Corresponding Author:

Suganthi Neelagiri
Electrical and Electronics Engineering, Dayananda Sagar College of Engineering
Shavige Malleswara Hills, Kumaraswamy Layout, Bengaluru 560078, India
Email: suganthi_neelagiri@yahoo.com

1. INTRODUCTION

In the current scenario the renewable source based electrical power generation systems are evolving. In particularly wind and solar based energy systems. Even though these are the promising alternative solution, these energy sources are intermittent in nature. In order to overcome the unpredictable nature of renewable sources and also to handle the transient power requirements of the some of the loads energy storage devices are required. DC microgrids with renewable energy sources and hybrid energy storage systems are evolving to contribute to the power demand. The challenging issue in microgrid are intermittent nature of renewable energy sources, controllability, and volatility. In order to overcome these issues and to increase the stability of microgrid energy storage devices are required. There different types of energy storage devices are available and are classified into two types like high power density devices and high energy density energy storge devices**.** High energy devices can supply energy for long duration whereas high power density can provide short duration. Battery and fuel cells are some of the high energy density devices. Supercapacitor and flywheel is the high-power density devices.

Various studies shows that when high energy density device is used in combination with high power density devices leads to reduction in stresses placed on the battery and life span of the battery is also improved [1]–[4]. And in DC microgrids the DC link voltage is maintained constant to maintain the power balance. In [5], [6] there are different types of energy management systems are proposed using only battery as energy storage device [7] and in some studies only fuel cell [8] as the energy storage device. Even pumped hydro energy storage system based microgrid systems are proposed [9].

A perfect energy storage system should be capable to provide both high power and high energy density to deal the unpredictable nature of the renewable energy sources and sudden varying load conditions [10]. Different types of control strategy for microgrid been reported in the literature using hybrid energy storage systems like battery and flywheel, or battery, Supercapacitor and diesel generator combinations implemented with fuzzy logic and model predictive control. All reported control strategy only focuses on either Dc link voltage regulation or power balance. Hence an energy management control strategy needs to be devised which ensures the power sharing, DC link voltage regulation, and reduces number of sensors used and improves the storage device life span by reducing the stresses imposed during transient conditions [11]–[15]. To fulfill above said requirement in this paper, an energy management control strategy is designed, such that it handles transient conditions effectively, maintains the DC link voltage constant, and improves battery life by reducing the stresses placed on the batteries.

2. SYSTEM CONFIGURATION

The proposed DC microgrid system consists of hybrid energy sources and hybrid energy storage system. Hybrid energy sources consists of solar and wind energy systems. Battery and supercapacitor form the hybrid energy storage system. Solar energy system is connected to DC bus via DC-DC converter and DC-DC converter is implemented with boost converter which is controlled by Perturb and observe maximum power point tracking algorithm. Boost converter and MPPT algorithm parameters are as given in [16]–[18]. Generic parametric model of super capacitor and dynamic model of battery available in MATLAB 2018 Simulink is used for simulation and bi-directional DC-DC converter is used to connect the battery and supercapacitor to the DC bus as shown in Figure 1. Bi-directional converters are controlled by the energy management system based on the generation, load, SOC of the storage devices.

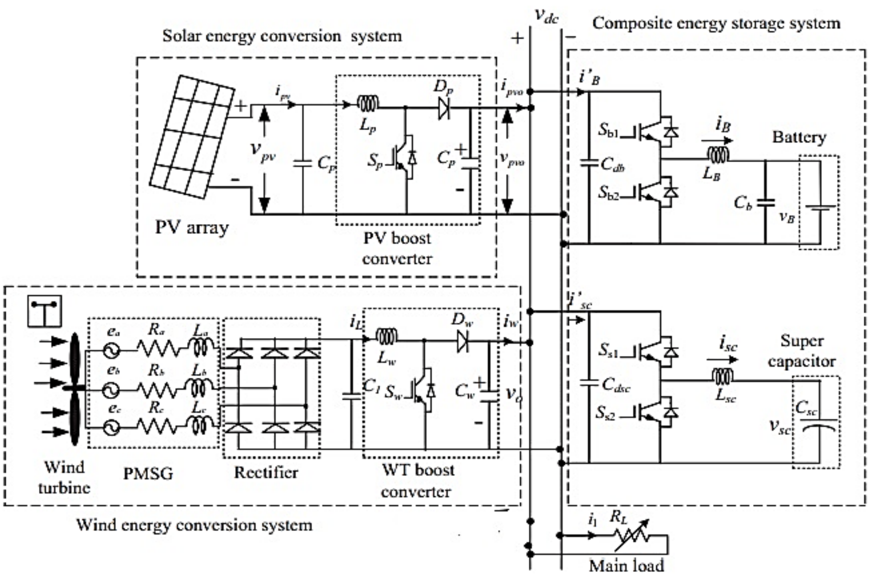

Figure 1. DC Microgrid configuration [1]

2.1. Wind energy system model

Wind energy conversion system proposed is adjustable speed wind energy conversion system. Wind turbine coupled with permanent magnet synchronous generator is proposed [19].

The output power of wind energy conversion system is written as:

$$P_{mec} = \frac{1\rho A v^3 C_p(\lambda,\beta)}{2} \quad (1)$$

$$T_{mec} = \frac{P_{mech}}{\omega_r} \quad (2)$$

Where P_{mec}, T_{mec} are the turbine generated mechanical power and mechanical torque. Parameters of the wind turbine model utilized is given in Table 1. Figure 2 shows the wind power output of the turbine for various wind speed. It shows the maximum power achieved at base wind speed 12 m/s.It also depicts the achievable power levels at different speeds. Speed and power curve is depicted in PU.

Table 1. System parameters

Subsystems	Parameter specification
PV cell	V_p=17.1 V, I_P=7.1 A, power=120 W
Wind system	Rotor radius=1 m, tip speed=8.1, air density=1.3 kg/m^3
Battery	14 Ah,24 V(li-ion)
Supercapacitor (SC)	32 V,29 F
DC-DC converter SC	L=0.35 H, C-300 µF, f=16 KHz, V_0=50 V
DC-DC converter battery	L=0.02 mH, C=300 µF, V_0=50 V.

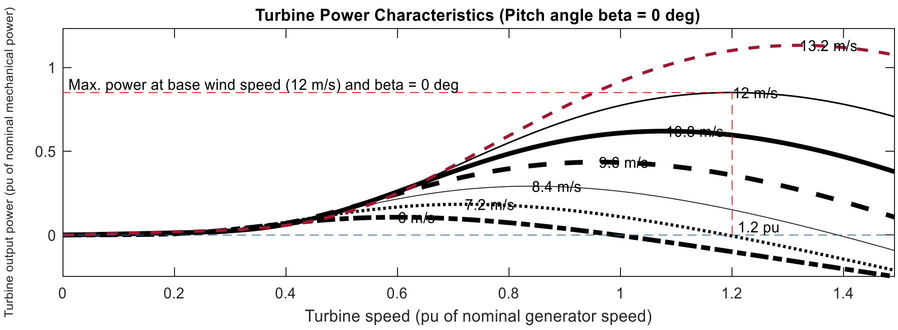

Figure 2. Turbine output for various wind speeds

2.2. PV system model

Ideal single diode model of the PV system is utilized for the proposed Microgrid system. The reverse power flow is avoided by using the by-pass diode. An equivalent model of the PV cell is considered for the proposed system. The model Waaree MS 120 model is utilized. Parameters of the model proposed in Table 1.

2.3. Battery and supercapacitor model

Lithium -ion battery model is used for the proposed system from the MATLAB/Simulink library [20], it is a common model which represents different characteristics of various types of battery. Charging and discharging character tics are shown in Figure 3 and its parameters are given in Table 1and it also shown in Figure 3 that battery can discharge 6.5 A for around 2 hours,13 A for 1 hour,32.5 A for less than half an hour. The supercapacitor model utilized is Electric double layer generic model available in MATLAB/Simulink library [21]. Charge characteristics of the super capacitor model is shown in Figure 4. Figure 4 shows supercapacitor charging time for different current rating and its voltage levels. Super capacitors can charge and discharge fast. Life span of the supercapacitor is 50,000 cycles.

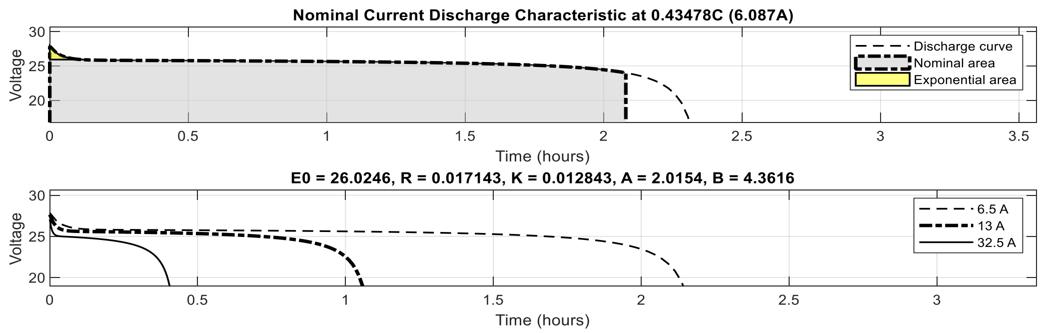

Figure 3. Battery discharge characteristics

2.4. Bi-directional converter and controller

Energy storage devices battery and super capacitor are connected parallel to the DC bus via bi-directional converters. Battery and supercapacitor converter switches are controlled by the switching pulses generated by the energy management strategy. In [22]–[26], the power availability bi-directional converters of battery and supercapacitor either will act in buck mode/charging or boost mode/discharging. If the power generation from PV and wind is more than the load power, converters will act in buck mode. If power generation is less than the load power converters will act in boost mode.

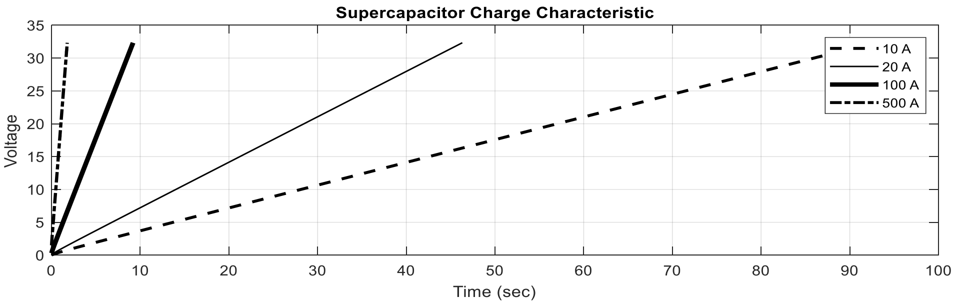

Figure 4. Supercapacitor charge characteristics

3. CONTROL STRATEGY FOR ENERGY MANAGEMENT

The conventional control strategy used for energy management of hybrid energy storage system is shown in Figure 5. The fundamental idea in this conventional strategy [26] is transient is divided it into slow transient and fast transient. Slow transient is allocated to battery storage system and fast transients are allocated to supercapacitor system. To achieve this actual DC grid voltage is compared with the reference DC voltage and then it is given to the current controller. The controller gives the total load current requirement that needs to be supplied by battery and supercapacitor. Using Low pass filter total load current requirement is split into average power requirement and transient power requirement. And average power requirement is given as the input to the battery current control loop and transient power requirement is given as the input to the super capacitor current control loop.

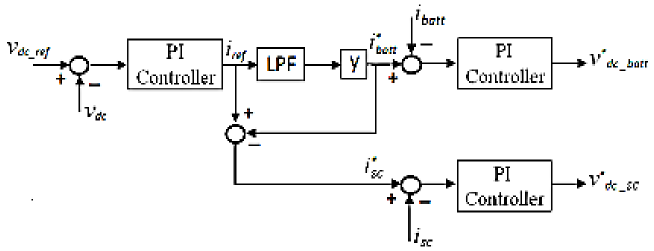

Figure 5. Conventional control strategy [26]

3.1. Proposed DC microgrid control strategy

DC microgrid control strategy proposed is shown in Figure 6. It is a two-loop cascaded controller. Main goal of the control strategy proposed is to reduce the stresses placed on the battery due to charging and discharging and also increase the life span of the battery and to achieve comparatively fast DC link voltage regulation than the conventional control strategy. It is considered here that state of charge of the storage devices is within the limits.

In the algorithm proposed actual DC voltage is compared with the reference voltage and the error signal is given to PI controller, which generates total current required by the load from the energy storage devices. And this forms the outer control loop which controls the DC link voltage. Total current requirement of the load is split into average current requirement and the transient current requirement using the filter controller.

$$I_{br} = F(I_{total}) \tag{3}$$

Where I_{total} is the total current requirement, I_{br} is average current requirement, I_{ba} is available battery current. Average current requirement is taken as reference current for the battery and compared with the available battery current and error signal (I_{berr}) as given in (4), and is given to the PI controller.

$$I_{berr} = I_{br} - I_{ba} \tag{4}$$

And output of PI controller is duty ratio and is given to the rate limiter to control limits of the charge /discharge and is given to pulse width generator to generate switching pulses for the bidirectional controller of the battery. High frequency component of current I_{hf} is obtained by subtracting average current component from the total current requirement as given in (5). The high frequency current requirement is added to $(I_{br} - I_{ba})\frac{V_b}{V_{sc}}$ term to compensate the slow response of the battery and this current is taken as the reference current input for the supercapacitor.

$$I_{hf} = I_{total} - I_{br} \tag{5}$$

Supercapacitor reference current is compared with the actual super capacitor current and it is passed through the PI controller to get the duty cycle. Duty cycle generated is given to pulse width modulation generator to generate the switching pulses for bidirectional converter of the supercapacitor. And supercapacitor reference current is in given in the (6).

$$I_{SCref} = I_{hf} + (I_{br} - I_{ba})\frac{V_b}{V_{sc}} \tag{6}$$

Where V_b is battery current and V_{sc} is the super capacitor voltage.

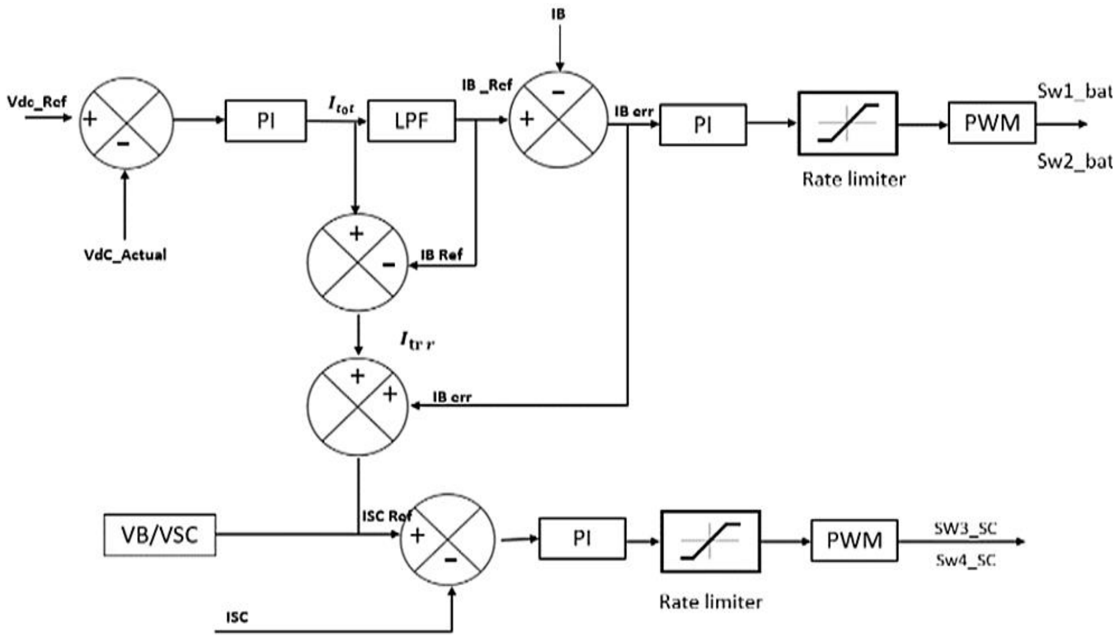

Figure 6. Proposed DC microgrid control strategy

4. RESULTS AND ANALYSIS

The proposed system depicted in Figure 7. In this proposed system PV and wind energy sources are considered as the main energy sources. PV system of 1 KW capacity is integrated to the DC bus via MPPT implemented boost converter. PMSG based wind turbine of capacity 1.5 KW is utilized and generated AC power is converted to DC using AC to DC converter. DC output is fed to boost converter to boost voltage to 50 V. Battery and supercapacitor is connected to DC bus via bidirectional converters in parallel. And the proposed system is verified for load change, generation change and under fault condition and the results obtained are compared with conventional system.

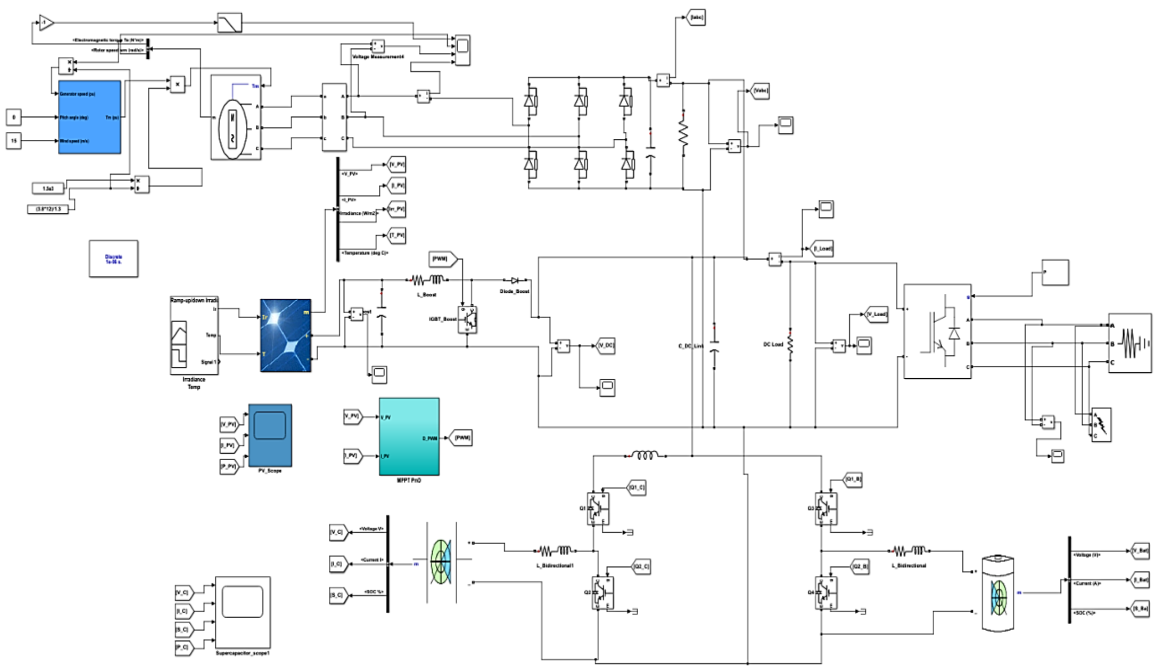

Figure 7. Simulation of the proposed DC microgrid

4.1. Case: 1 generation variation

To analyze the generation, change the wind power is maintained constant at 1500 W and solar irradiation is varied from 1000 W/m^2 to 600 W/m^2. The load is maintained at 1500 W. When the solar irradiation. is varied at 0.2 sec from 1000W/m^2 to 500 W/m^2. The sudden reduction in generation leads to transients at 0.2 sec, from the Figure 8, it is observed that supercapacitor manages the power requirement as depicted and it shows the power curve of various energy sources and energy storage devices. From the Figure 9, it is also observed that DC-link voltage is kept constant irrespective of the generation variation.

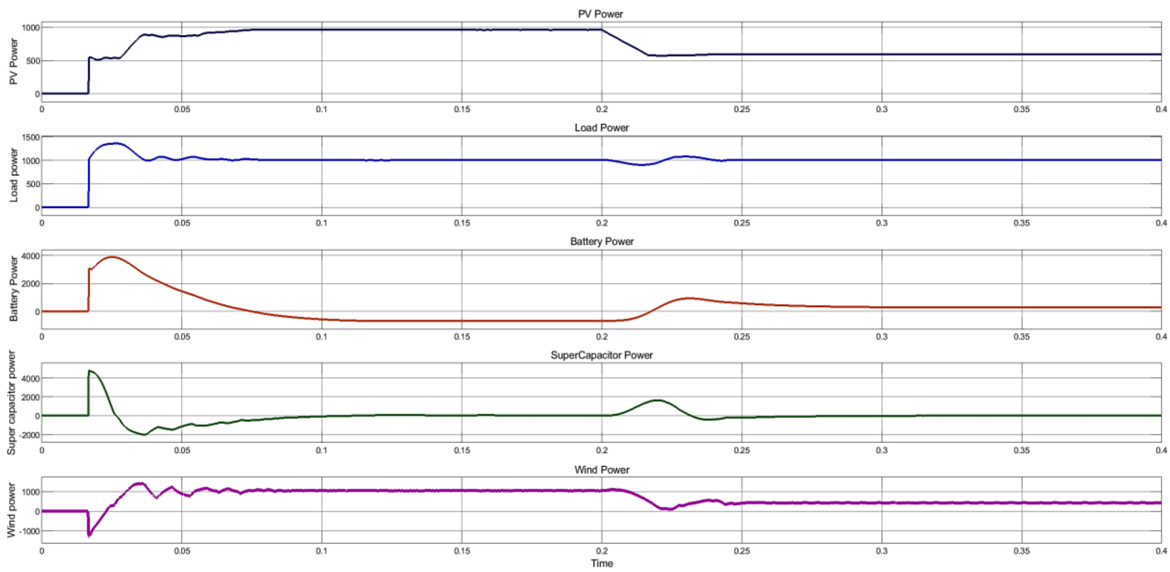

Figure 8. Power response of the grid for generation variation

4.2. Case: 2 load variation

To analyze the varying load power condition, the wind generation is kept constant at 1500 W, PV power is kept constant till 0.2 sec, after 0.2 sec PV irradiation is reduced from 1000 W to 500 W. And load is varied from 1000 W to 2000 W at 0.25 sec up to 0.2 sec the power generation is more than the load and extra power is absorbed by battery. AT 0.25 sec sudden load change from 1000W to 2000W and it is managed by supercapacitor immediately discharging at 0.25 sec as depicted in Figure 10 and from the Figure 11. it is also absorbed that DC link voltage is maintained constant irrespective of load variation.

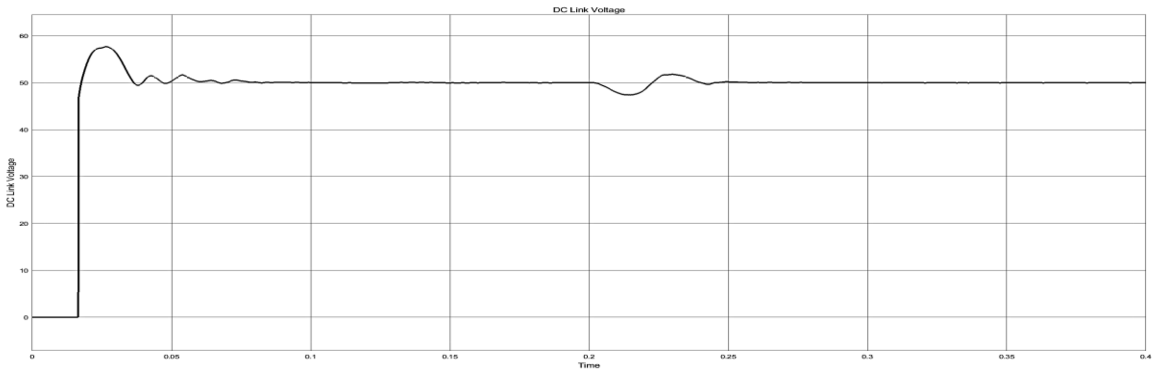

Figure 9. DC link voltage response for generation variation

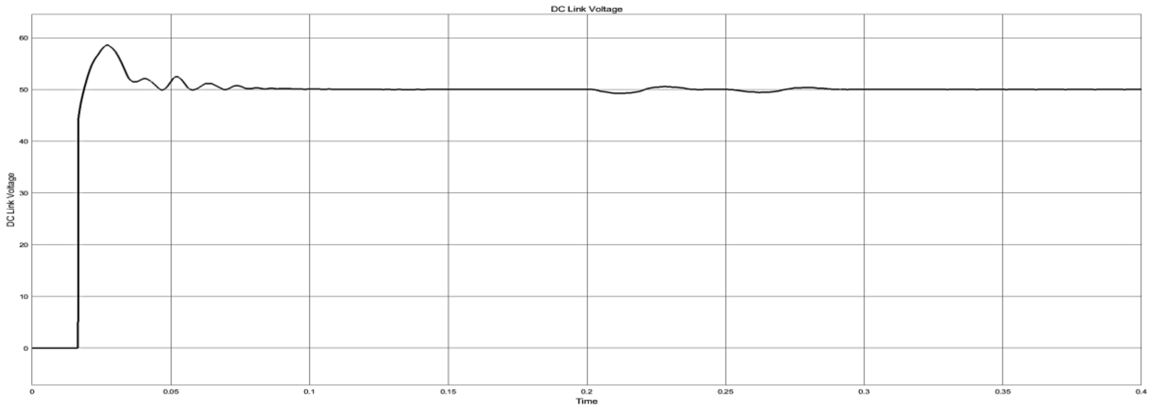

Figure 10. Power response for load variation in the system

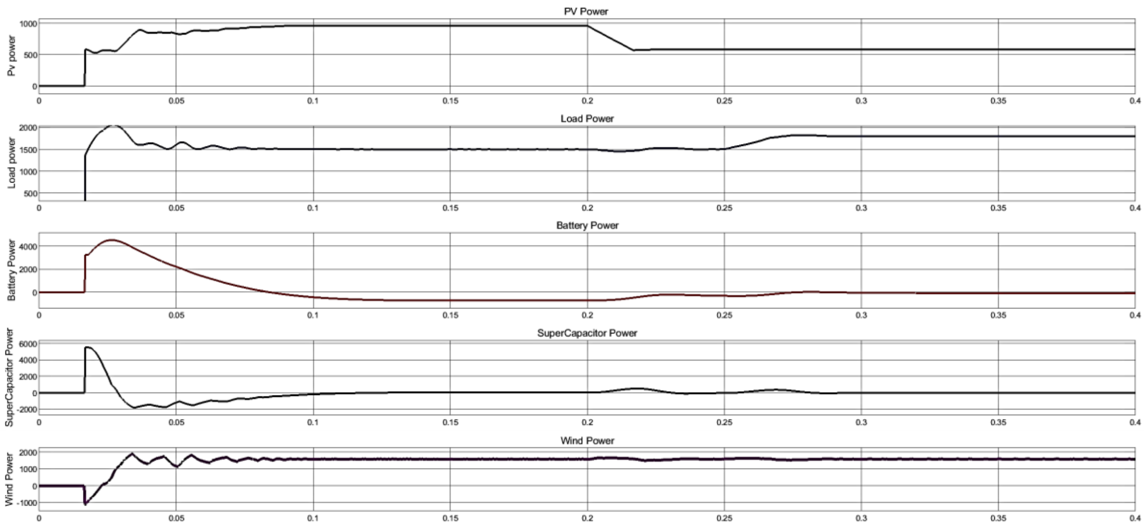

Figure 11. DC link voltage response for load variation

4.3. Comparison with conventional control strategy

The response of the conventional control strategy for generation variation is compared with the proposed control strategy at 0.2 sec. At 0.2 sec PV generation is varied from 1000 W to 600 W. Comparing the DC link voltage of conventional and proposed system for generation variation, it is observed that DC link voltage curve of conventional method is having more over shoot voltage (58 V) than the proposed method. From Figure 12 it is observed that overshoot and distortion is more in the case of conventional method and settling time is 0.15 sec, but in case of the proposed system overshoot is less and DC voltage becomes steady within 0.07 sec. The proposed method effectively fulfills the transient requirements and DC link voltage is maintained with minimal distortions as shown in the Figure 13.

Similarly for load variation from 1000 W to 2000 W, 0.2 sec, response of the conventional control strategy and proposed control algorithm is analyzed. As observed from the Figure 14, Initial overshoot, distortions, and time taken to settle to constant DC voltage is more in case of conventional control strategy. Time taken to settle to steady DC value is 0.15 sec where as in the proposed strategy the time taken is 0.08 sec. And overshoot voltage in case of conventional method is 63 V which is more than 56 V overshoot of proposed system. From Figure 15 it is observed that fast dc link voltage regulation is achieved in proposed system irrespective of load variation.

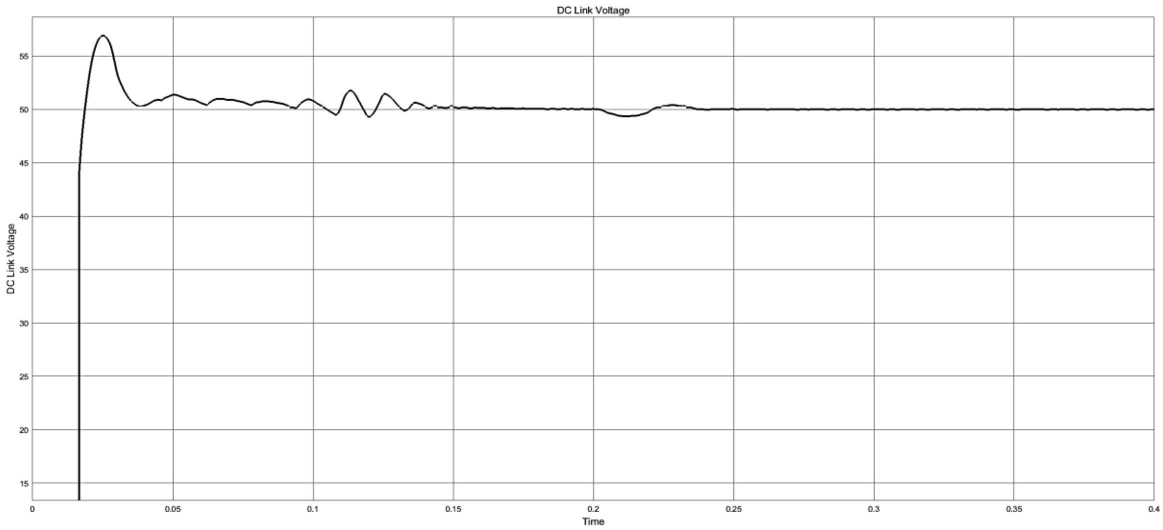

Figure 12. DC link voltage response for case 1 (conventional)

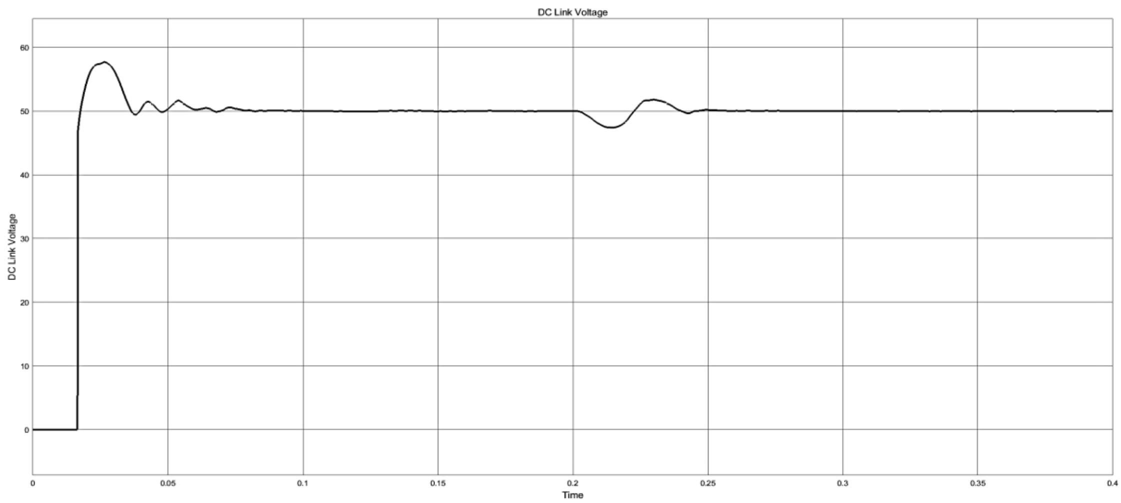

Figure 13. DC link voltage response for case 1 (proposed)

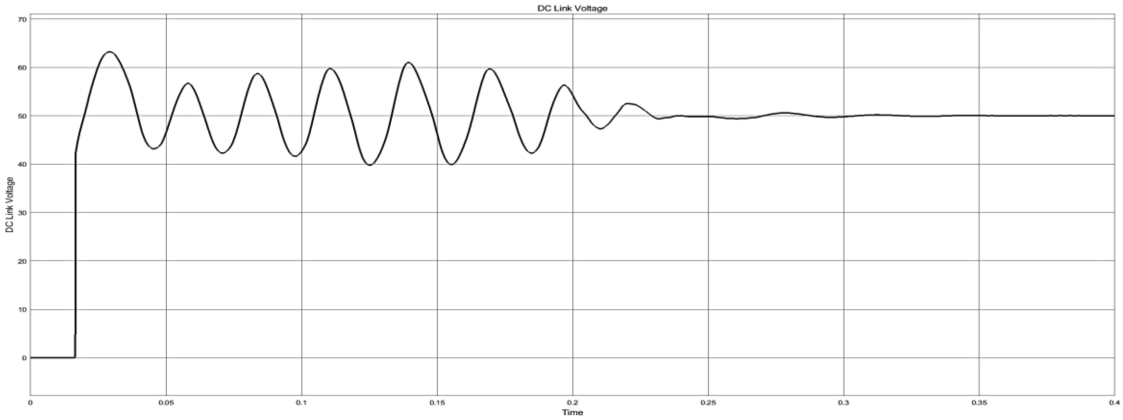

Figure 14. DC link voltage response for case 2 (conventional)

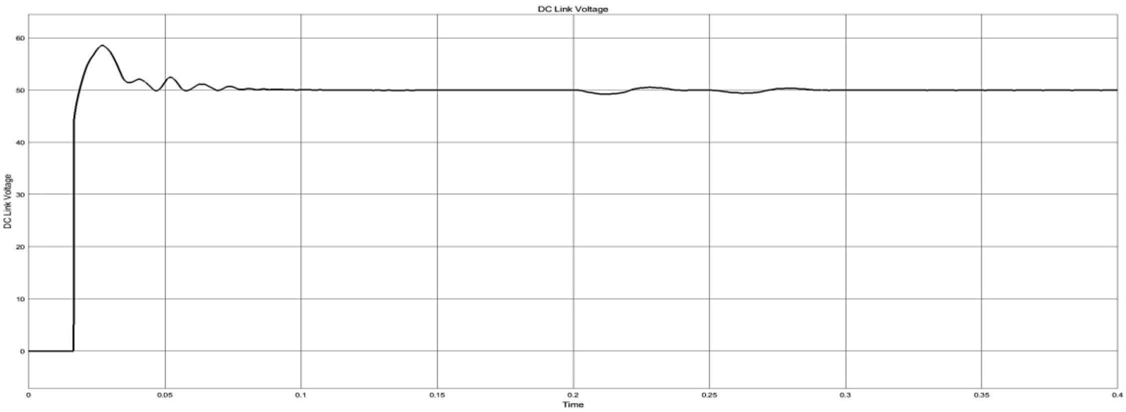

Figure 15. DC link voltage response for case 2 (proposed)

In the DC micro grid phase to ground fault is introduced along with PV power generation variation at 0.2 sec. The performance of the microgrid system is analyzed with conventional control strategy and the proposed control strategy. It is observed form the Figure 16 and Figure 17 shows the proposed system provides better DC link voltage regulation compared to conventional control strategy. Over shoot voltage is 56 V in the case of proposed system where as in case of conventional control strategy, it is 58 V and DC link voltage steady state is achieved at 0.07 sec in the proposed system and 0.15 sec in conventional system. Summary of the results of the both the methods for different cases is given in the Table 2.

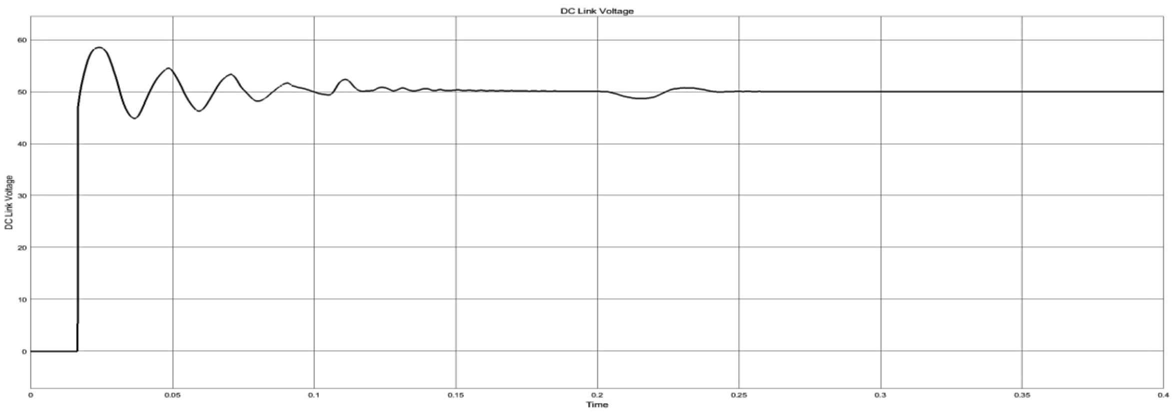

Figure 16. DC link voltage response for phase to ground fault with conventional system

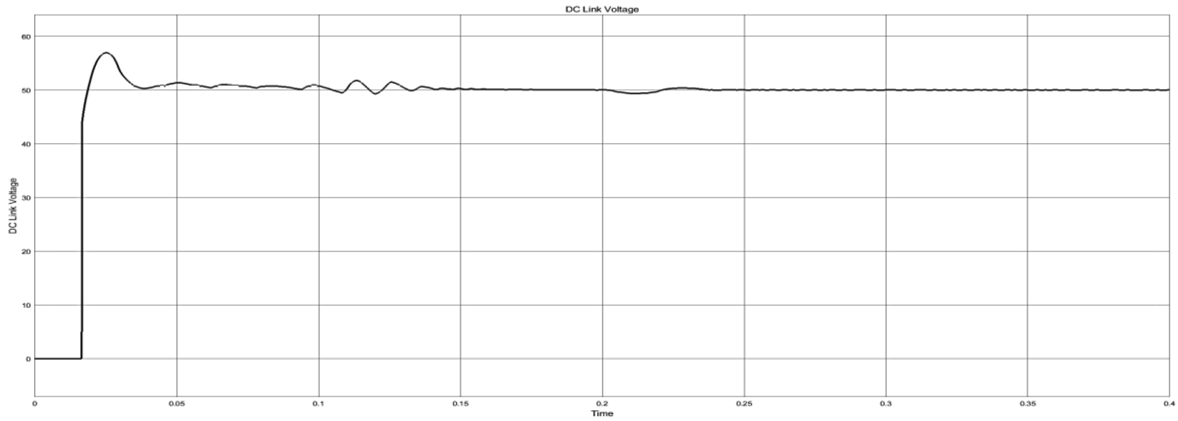

Figure 17. DC link voltage response for phase to ground fault with proposed system

Table 2. Comparative analysis of results

Different cases	Conventional control		Proposed Control	
	Overshoot Voltage	Settling time	Overshoot voltage	Settling time
Generation Variation	58V	0.15Sec	56V	0.08sec
Load Variation	63V	0.15sec	56V	0.07sec
Under fault	57V	0.15 sec	56V	0.07sec

5. CONCLUSION

The proposed Microgrid energy management control strategy with hybrid energy storage system is analyzed for generation variation, load variation and under fault conditions. It is observed from the analysis of the DC microgrid, the proposed control strategy maintains the energy balance effectively between the load and source and also maintains the DC link voltage constant irrespective of these variation in generation and load condition. It is also observed that transient as well as average power requirements are satisfied effectively using super capacitor and battery energy storage systems. Comparative analysis of the system with the conventional control strategy shows that proposed system performs better in all cases and provides faster DC link voltage regulation.

REFERENCES

[1] D. M. R. Korada, M. K. Mishra and R. S. Yallamilli, "Dynamic energy management in DC microgrid using composite energy storage system," *2020 IEEE International Conference on Power Electronics, Smart Grid and Renewable Energy (PESGRE2020)*, 2020, pp. 1–6, doi: 10.1109/PESGRE45664.2020.9070693.

[2] Y. S. Perdana, S. M. Muyeen, A. Al-Durra, H. K. Morales-Paredes, and M. G. Simões, "Direct connection of super capacitor-battery hybrid storage system to the grid-tied photovoltaic system," *IEEE Transactions on Sustainable Energy*, vol. 10, no. 3, pp. 1370–1379, 2019. doi: 10.1109/TSTE.2018.2868073.

[3] H. F. Habib, A.A.S. Mohamed, M. El Hariri, and O. A. Mohammed "Utilizing super capacitors for resiliency enhancements and adaptive microgrid protection against communication failures," *Electric Power Systems Research*, vol. 145, pp. 223–233. 2017, doi: 10.1016/j.epsr.2016.12.027.

[4] M. H. Nehrir *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, pp. 392–403, Oct 2011, doi: 10.1109/TSTE.2011.2157540.

[5] S. Neelagiri, P. Usha, "Modeling and analysis of dynamic energy management of DC microgrid using HESS," *5th International Conference on Electronics, Communication and Aerospace Technology (ICECA)*, 2021, pp. 23–29, doi: 10.1109/ICECA52323.2021.9676105.

[6] 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 2020, doi: 10.1109/TSTE.2019.2917513.

[7] A. Timbus, M. Liserre, R. Teodorescu, P. Rodriguez, and F. Blaabjerg, "Evaluation of current controllers for distributed power generation systems," *IEEE Transactions on Power Electronics*, vol. 24, no. 3, pp. 654–664, 2009. doi: 10.1109/tpel.2009.2012527.

[8] 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. S. Neelagiri, P. Usha, "Review of energy storage devices used in microgrid," in *the three-day virtual international conference on Recent Trends in Electrical, Electronics, Telecommunications, Instrumentation Engg. Medical Electronics Engg. Physics*, December 7, 2020.

[9] R. K. Sharma, and S. Mishra, "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, no. 1, pp. 526–538, 2018, doi: 10.1109/TIA.2017.2756032.

[10] K. Bruninx, Y. Dvorkin, E. Delarue, H. Pandžić, W. D'haeseleer, and D. S. Kirschen, "Coupling pumped hydro energy storage with unit commitment," in *IEEE Transactions on Sustainable Energy*, vol. 7, no. 2, pp. 786-796, April 2016, doi: 10.1109/TSTE.2015.2498555.

[11] A. M. Yasin and M. F. Alsayed, "Fuzzy logic power management for a PV/Wind microgrid with backup and storage systems," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 11, no. 4, pp. 2876–2888, 2021, doi: 10.11591/ijece.v11.i4.pp2876-2888.

[12] B. Ahmadi and R. Çağlar, "Determining the Pareto front of distributed generator and static VAR compensator units placement in distribution networks," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 12, no. 4, pp. 3440–3453, 2022, doi: 10.11591/ijece.v12i4.pp3440-3453.

[13] H. S. M. Al -Wazni, and S. S. A. Al-Kubragyi, "A hybrid algorithm for voltage stability enhancement of distribution systems," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 12, no. 1, pp. 50–61, 2022, doi: 10.11591/ijece.v12.i1.pp50-61.

[14] S. Hajiaghasi, A. Salemnia, and M. Hamzeh, "Hybrid energy storage system control analogous to power quality enhancement operation of interlinking converters," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 11, no. 2, pp. 909–918, 2021, doi: 10.11591/ijai.v10.i1.pp191-199.

[15] A. Basma and O. Benyounes, "A simulation energy management system of a multi-source renewable energy based on multi agent system," *IAES International Journal of Artificial Intelligence (IJ-AI)*, vol. 10, no. 1, pp. 191–199, 2021, doi: 10.11591/ijai.v10.i1.pp191-199.

[16] A. Saleh, A. Awad, and W. Ghanem, "Modeling, control, and simulation of a new topology of flywheel energy storage systems in microgrid," *IEEE Access*, vol. 7, pp. 160363–160376, 2019, doi: 10.1109/ACCESS.2019.2951029.

[17] S. Kollimalla, M. K. Mishra, and N. L. Narasamma, "Design and analysis of novel control strategy for battery and supercapacitor storage system, IEEE Transactions on Sustainable Energy, Vol. 5, no. 4, pp.1137–1144, Oct 2014, doi: 10.1109/TSTE.2014.2336896.

[18] M. J. Mnati *et al.*, "Review different types of MPPT techniques for photovoltaic systems," *International Conference on Sustainable Energy and Environment Sensing (SEES 2018)*, June 2018.

[19] N. Hashim, Z. Salam, D. Johari, and N. F. N. Ismail, "DC-DC boost converter design for fast and accurate MPPT algorithms in stand-alone photovoltaic system," *International Journal of Power Electronics and Drive System (IJPEDS)*, vol. 9, no. 3, pp. 1038–1050, September 2018, doi: 10.11591/ijpeds.v9.i3.pp1038-1050.

[20] MathWorks, "Battery-Generic battery model", Available: https://www.mathworks.com/help/physmod/sps/powersys/ref/battery.html

[21] MathWorks, "Supercapacitor-Implement generic supercapacitor model", Available: https://www.mathworks.com/help/physmod/sps/powersys/ref/supercapacitor.html

[22] A. Özdemir and Z. Erdem, "Double-loop PI controller design of the DC-DC boost converter with a proposed approach for calculation of the controller parameters," *Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering,* vol. 232, no. 2, 2017, doi: 10.1177/0959651817740006.

[23] A. Lahyani, P. Venet, A. Guermazi, and A. Troudi "Battery/super capacitors combination in uninterruptible power supply (ups)," *IEEE Transactions on Power Electronics*, vol. 28, no. 4, pp. 1509–1522, April 2013, doi: 10.1109/TPEL.2012.2210736.

[24] Madhura S, Deepthi G, Chihnitha B, and Disha D, "IoT based monitoring and control system using sensors," *Journal ofIoT in Social, Mobile, Analytics, and Cloud*, vol. 3, no. 2, pp. 111-120, doi: 10.36548/jismac.2021.2.004.

[25] J. Hawke, P. Enjeti, L. Palma, and H. Sarma, "A modular fuel cell with hybrid energy storage," *2011 IEEE Energy Conversion Congress and Exposition*, 2011, doi: 10.1109/ECCE.2011.6064169.

[26] M. Akbari, M. A. Golkar and S. M. M. Tafreshi, "Voltage control of a hybrid ac/dc microgrid in grid-connected operation mode," ISGT2011-India, 2011, pp. 358-362, doi: 10.1109/ISET-India.2011.6145341.

BIOGRAPHIES OF AUTHORS

Suganthi Neelagiri received the bachelor's degree in Electrical and Electronics Engineering from Bharathiyar University in 2001, the master's degree in Electrical Power and Energy System from Uttara Pradesh Technical University in 2013, and currently pursuing philosophy of doctorate degree in Electrical Engineering from Visvesvaraya University respectively. She is currently working as an Assistant Professor at the Department of Electrical and Electronics Engineering, Dayananda Sagar College of Engineering. Her research areas include microgrid, renewable energy systems, energy storage systems. She can be contacted at email: suganthi_neelagiri@yahoo.com.

Pasumarthi Usha received the bachelor's degree in Electrical and Electronics from J.N.T.U, College of Engineering Kakinada in 1990, the master's degree in Power System with emphasis in High Voltage from J.N.T.U, College of Engineering Kakinada in 1992, and the Ph.D. in HVDC Power Transmission from Visvesvaraya Technical University in 2013, respectively. She is currently working as a Professor and Head of the Department at the Department of Electrical and Electronics Engineering, Dayananda Sagar College of Engineering. Her research areas HVDC power systems, microgrid, and power electronics. She can be contacted at email: pu1968@yahoo.co.in.