2023 First International Conference on Cyber Physical Systems, Power Electronics and Electric Vehicles (ICPEEV) | 979-8-3503-2356-6/23/$31.00 ©2023 IEEE | DOI: 10.1109/ICPEEV58650.2023.10391942

Design of Centralized Controller for Efficient Power sharing and Voltage Regulation in DC Microgrid

Pradeep Kumar Andra
Department of Electrical Engineering
National Institute of Technology, Warangal
Warangal, India
apee21319@student.nitw.ac.in

Ram Krishan
Department of Electrical Engineering
National Institute of Technology, Warangal
Warangal, India
rkrishan@nitw.ac.in

***Abstract*— Direct Current (DC) Microgrid systems have gained popularity due to their advantages over Alternating Current (AC) Microgrid systems, including fewer power conversion control stages and the increasing use of distributed energy resources (DERs) and loads. Voltage regulation and active power sharing are crucial for stable and optimal operation in DC Microgrids since they lack frequency and reactive power. Neglecting proper power sharing and voltage regulation can lead to increased power losses and even blackouts. This paper presents a novel centralized controller without droop control, aiming to achieve precise DC bus voltage regulation and efficient power sharing within a fully isolated DC Microgrid equipped with Photovoltaic-Battery Energy Storage Systems (PV-BESSs) and loads. The proposed non-droop-based centralized control strategy modifies the typical primary controller inner current and outer voltage control loops, while a centralized secondary controller generates power/current reference signals for various distributed generators (DGs) and DC converters to facilitate load sharing. This approach offers the advantage of eliminating conventional droop control and secondary controller. The Simulation results substantiate the efficacy and effectiveness of the proposed centralized control strategy in regulating the DC bus voltage and managing dynamic power variations within the Direct Current (DC) Microgrid.**

Keywords—centralized control, direct current, power sharing, microgrid, voltage regulation, distributed energy resources (DERs)

I. Introduction

Microgrids (MGs) have emerged as vital enablers in effectively integrating renewable energy sources into the power system., distributed energy resources (PV, BESSs, EVs), and improving grid resilience [1]. MGs can help to reduce energy losses, manage power supply, and demand, and enhance the utilization of zero-emission energy sources. Microgrids (MGs) can be classified into two categories based on their electrical characteristics: DC (Direct Current) or AC (Alternating Current). While AC systems have traditionally been more widely used, the advancements in power electronics technology and the increasing adoption of DC loads and distributed renewable energy resources (DERs) have led to the emergence of DC microgrid (DCMG) systems.

This research is supported by the Science and Engineering Research Board (SERB) DST India under grant number SRG/2021/000810.

DCMGs present various advantages over AC microgrids [2]. They effectively mitigate challenges related to synchronization, management of reactive power and losses occurring in both transmission and distribution due to power flow in two directions. Moreover, DCMGs address concerns regarding power system inertia and power quality. The increasing prevalence of DC outputs from renewable energy sources (RESs) and emerging loads indicates a potential dominance of DC distribution systems and DCMGs [3] in future grid transformations. In furthermore, ongoing research has been in power electronic technology suggests a gradual shift towards a DC conceptual framework.

In Distributed Control Microgrids the effective coordination and control of power flow are crucial, and power-electronics converters play a vital role in achieving this. These converters are responsible for facilitating ease in the management of power flow and simplified control, especially when it comes to power-sharing among Microgrids (MGs). In DCMGs that utilize Photovoltaic-Battery Energy Storage Systems (PV-BESS), DC-DC (Boost, Bi-directional) converters are commonly employed [4]. Multiple distributed generators (PV-BESSs) can be interconnected through bidirectional or boost DC-DC converter topologies to form a shared DC bus to meet the load. However, it is crucial for an MG to operate independently from the external grid, known as islanded mode [5].

Additionally, to maintain stable operation during islanded mode, advanced control strategies are employed in DCMGs. These strategies involve the utilization of advanced algorithms and communication systems to enable efficient coordination between distributed generators and loads. By dynamically adjusting the power flow and voltage levels within the DC bus, these control strategies ensure optimal utilization of available resources and improve overall system performance. Moreover, the incorporation of energy storage systems, such as batteries, further enhances the capability of DC MGs to balance supply and demand, mitigate intermittency issues, and provide reliable power to critical loads. The integration of intelligent energy management systems and advanced control techniques paves the way for the effective implementation of autonomous and resilient DC microgrids in various applications.

The primary control goal in a DC microgrid is to achieve load sharing, ensuring a balanced distribution of power among the connected loads. However, conventional approaches such as traditional I-V droop control [6]-[8] relies on fixed coefficients for load sharing but may leads to performance issue such as inadequate transient performance, voltage deviations, and imprecise power sharing in power systems and a lack of consideration for load dynamics. Non-droop control adapts to load dynamics, potentially improving performance and precise power allocation. To mitigate, this paper proposes a novel centralized control strategy with a proposed configured DC microgrid. The key highlights of this strategy are as follows:

- Employing a non-droop-based control technique that incorporates an improved outer voltage loop and inner current loop as the primary control mechanism for Power sharing. This design simplifies the primary control complexity and reduces the reliance on Communication.
- The centralized controller [9]-[12] makes informed decisions by monitoring the solar PV system, BESSs, and load generation, enabling the dispatch of accurate power or current reference signals to various DGs and DC converters.

The remaining paper is organized as follows: the structure and configuration of the DCMG is presented in Section II. Section III details the control strategy and design of the centralized controller for coordination of power and voltage regulation. Section IV illustrates the simulation results produced by the designed models and suggested control methodology. The work's conclusion has been provided in the Section V.

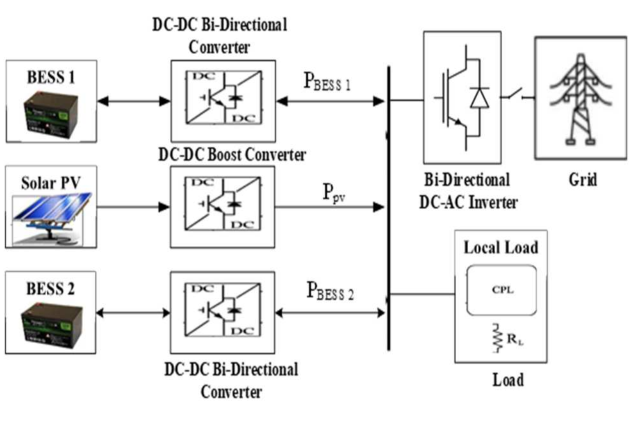


Fig. 1. Proposed DC microgrid configuration

II. DC MICROGRID CONFIGURATION

The configuration of the proposed DC microgrid, as depicts in Fig. 1, consists of key components: a solar PV system and two BESSs – 1) lithium-ion battery, 2) lead-acid battery. These components are interconnected to provide power to a common DC load connected to a DC bus operating at a rated voltage of 380V. The solar PV system is designed with four parallel strings, each comprising 10 PV modules connected in series. To enhance the efficiency of power harvesting from the solar system, the implementation of a DC-DC (boost) converter with MPPT control is employed. The MPPT controller utilizes the perturb and observe (P&O) method to monitor the solar PV system's output and generate a reference voltage signal.

The intermittent nature of solar PV generation can be effectively addressed by including a BESS that runs in a DC microgrid. While existing household-level BESSs have limits in terms of cost and longevity, incorporating BESSs at the microgrid level as communal storage offers an economically viable option. Advances in battery chemistry and cost reduction are predicted to dramatically affect the future form of microgrids. In this setup two BESSs are integrated and connected to the DC bus via a bidirectional DC-DC converter, enabling both charging and discharging operations.

The usage of two different types of batteries, a lithium-ion and a lead-acid battery, provides redundancy and improves the overall reliability of the microgrid. In case one battery type fails or degrades, the other battery can still produce power, ensuring continuous operation of the microgrid. However, one battery can serve the same purpose.

BESS 1 is a lithium-ion battery with a capacity of 50Ah, chosen for its advantages such as fast charging, greater longevity, greater energy density, and more efficient compared to lead-acid batteries. Therefore, the microgrid prioritizes use of a lithium-ion battery as the predominant storage system. Combining a BESS with solar power is popular approach in distributed energy resources (DERs), allowing excess solar energy to be stored and utilized when needed. The BESS can dispatch stored power during peak load periods and supply energy to the grid when solar generation is low.

III. CENTRALIZED CONTROL STRATEGY FOR PROPOSED SYSTEM

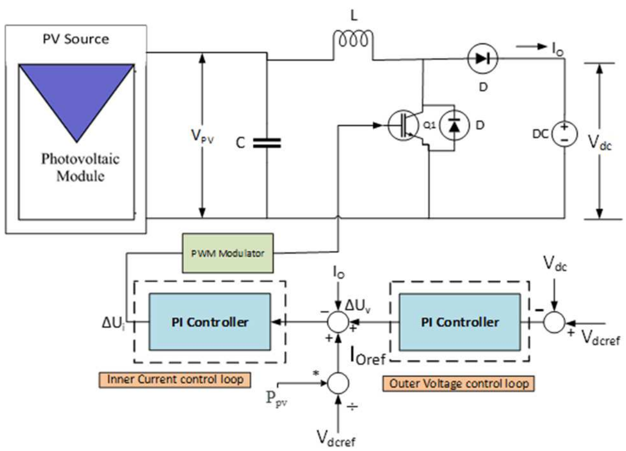
The proposed centralized control framework for DC microgrid Consists of two controllers A) primary controller depicts in Fig. 2. B) supervisory controller control techniques are critical for providing effective co-ordination and maximum efficiency of the given arrangement.

A. Primary Controller:

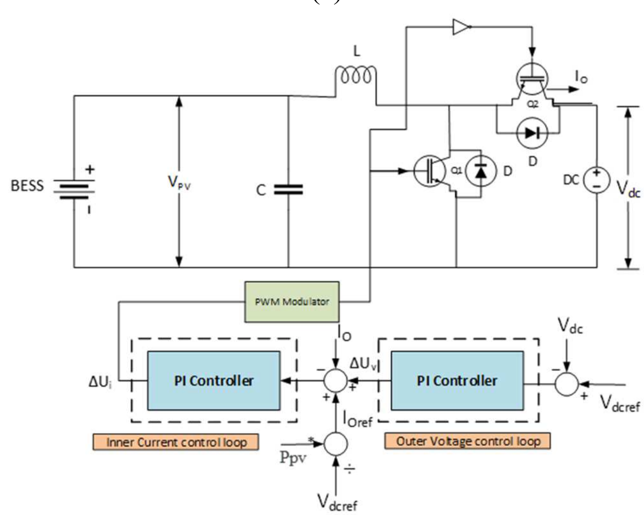
The commonly utilized primary control method is the double PI-based control, which encompasses an inner loop responsible for current control and an outer loop for voltage control. In conventional droop control, the current reference for the inner loop is derived by utilizing the DC bus voltage reference and the measured voltage within the voltage loop., which might result in voltage variations. An extra PI control is often used as secondary controller to mitigate this and return the voltage to its nominal value.

In the proposed method, the current reference is transferred from the centralized supervisory controller to the corresponding distributed generators (DGs), decoupling it from the outer voltage loop. As a result, voltage deviations are eliminated, and there is no need for an additional PI control in secondary controller, like traditional control.

A PV-BESSs-based DC microgrid configuration is the sole one for which the primary control strategy was developed. When operating in MPPT mode, the solar PV system optimizes voltage and current to get most power possible from the panel.



(a)



(b)

Fig. 2. Proposed primary control loop of a) PV b) BESS

While allowing power to flow in both directions, the battery energy storage system's bidirectional controller enables the BESS to store excess solar energy and deliver it back to the microgrid when necessary. To maintain bus voltage regulation, the external voltage controller computes the disparity between the desired bus voltage and the measured bus voltage. The secondary supervisory controller supplies both the voltage compensation element and the current loop reference.

$$v_{dcer} = v_{dcref} - v_{dc}$$

$$\Delta U_V = K_p v_{dcer} + K_i \int v_{dcer} dt \quad (1)$$

$$i_{0er} = \Delta U_V + (i_{oref} - i_o)$$

$$\Delta U_I = K_p i_{oer} + K_i \int i_{oer} dt \quad (2)$$

Where v_{dcref}, v_{dc} are Reference and actual DC bus voltage. i_{oref} and i_o are Reference and actual output current. ΔU_V and ΔU_I are the control parameters of both voltage and current. K_p and K_i refer to the time constants for proportional and integral control, respectively.

As a result, this method avoids the droop equation components. In this manner, the inner current loop can easily control the converter inductor current to keep the voltage regulation within limits.

B. Supervisory Controller:

The proposed supervisory controller is in responsible for controlling the solar PV system's power supply in respect to grid voltage. To do this, the primary controller for the solar PV distributed generator (DG) divides the solar PV system's peak power by the grid voltage, producing a current signal that acts as a reference for the inner current loop. The centralized supervisory controller also keeps track of the power imbalance between the peak power capacity of the solar PV system and the total amount of load power. The power reference signal for the inner current loop of the primary controller, which regulates the battery energy storage systems (BESSs), is highly dependent on this mismatch signal. At the beginning of the DCMG, the solar PV system was configured to operate in MPPT mode using the perturb and observe method [13]-[15]. Whenever the solar PV system generates more power than needed by the load, the additional energy is utilized to charge the BESSs. As a result, this energy can be dispatched during peak load times.

This ensures that the excess energy generated by the PV system can be stored and later dispatched during peak load periods. In terms of discharging, BESS 1 takes precedence in meeting the load demand When the power requirement surpasses the solar PV system's highest achievable power output. In scenarios where the combined solar PV system maximum output power and BESS 1 falls short of meeting the total load demand, BESS 2 is engaged to bridge the remaining power gap. This dynamic response helps maintain stable bus voltage. In extreme cases where the BESSs cannot function and the load demand surpasses the maximum power generated by the solar PV system, implementing load shedding becomes imperative to ensure the secure operation of the DC microgrid.

In our DC microgrid, robust communication among nodes and DERs is pivotal for seamless coordination. A communication network enables real-time data exchange with supervisory controller receiving information on solar PV power output, battery charge status and load demand.

This bidirectional communication allows the centralized supervisory controller to make informed decisions in response to fluctuations in power generation and load requirements. For instance, when excess energy is generated by the solar PV system, the supervisory controller communicates with the battery energy storage systems (BESSs) to initiate charging, ensuring optimal energy utilization. In turn, when load demands exceed the combined capacity of the PV system and BESSs, the supervisory controller can trigger load shedding measures to maintain grid stability.

The proposed system maximizes the utilization of solar energy through the implementation of effective MPPT operation, enhances the longevity of battery storage by optimizing the operation of BESSs based on their capabilities, and simplifies the design of local controllers with the adoption of a centralized architecture.

TABLE I. SYSTEM PARAMERS

Components		**Parameters**	**Values**
Solar PV panel		Maximum power	6.2kW
Batteries	Lead Acid	Capacity	50 Ah
	Lithium-ion	Nominal Voltage	48V
DC Bus Voltage		Voltage	380V
DC Load		Resistive load	12kW

TABLE II. CONTROL PARAMETERS

Control Parameters	**Values**
f_{sw_PV}	10 kHz
f_{sw_BESS}	20 kHz
$K_{P\_V\_PV\_MPPT}$	8
$K_{I\_V\_PV\_MPPT}$	50
$K_{P\_I\_PV\_MPPT}$	11
$K_{I\_I\_PV\_MPPT}$	625
$K_{P\_V\_BESS\_1}$	0.6
$K_{I\_V\_BESS\_1}$	3
$K_{P\_I\_BESS\_2}$	0.04
$K_{I\_I\_BESS\_2}$	33

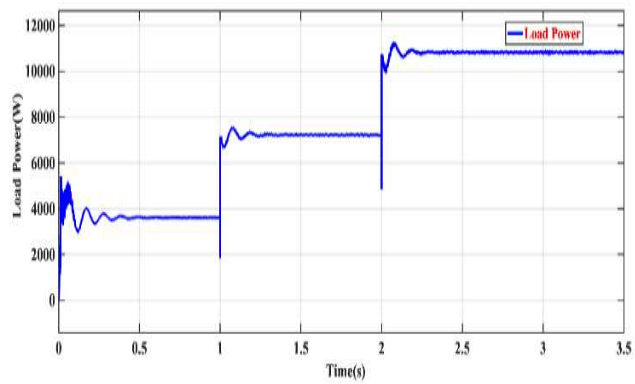
IV. Simulation Results

Simulation of DC microgrid and proposed centralized controller carried out in MATLAB/Simulink for analyzing power sharing and voltage regulation. Above Table I and Table II represents the system and control parameters respectively. There have been several different scenarios used to test the performance of the controller. For instance, when a DC microgrid is operating normally with fluctuating load demand, as well as with analyzing the effectiveness of a proposed controller while changing the solar irradiation of a solar PV system.

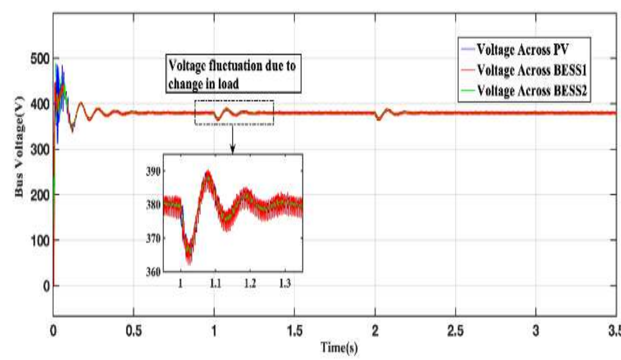
A. Case 1: Variation of Load Demand.

In this scenario, the controller's performance is being examined and evaluated by applying load changes in steps at frequent intervals of time. The solar irradiance and temperature of a solar PV system are kept constant throughout operation at 1000 W/m^2 and 25^0C respectively. Fig. 3(b) illustrates the fluctuation in bus voltage and Fig. 3(c) illustrates the power between PV power and BESS 1 and BESS 2with variation of load demand.

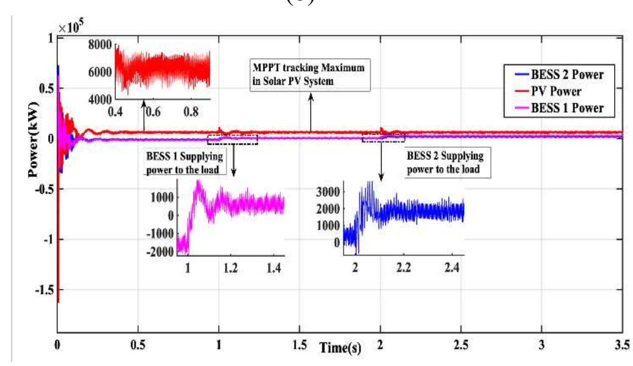
Emerging a DC microgrid with a 3.6 kW load demand from t=0 to t=1s.The solar PV system is tracking a maximum power point of 6.2kW as configured by the perturb and observe strategy. With the PV system generating more power than the load requires, the excess energy is accumulated in the BESSs. In other words, the BESSs begin charging. At t=1 s to t=2s the load power being increased from 3.6 kW to 7.2kW.the PV is maintained 6.2 kW from MPPT mode. However, there is power mismatch between the PV power and load demand.



(a)



(b)



(c)

Fig. 3. Case 1: simulation results of the system under variation of load demand a) Load Power, b) Bus Voltage, c) PV power, BESS 1 and BESS 2 Power

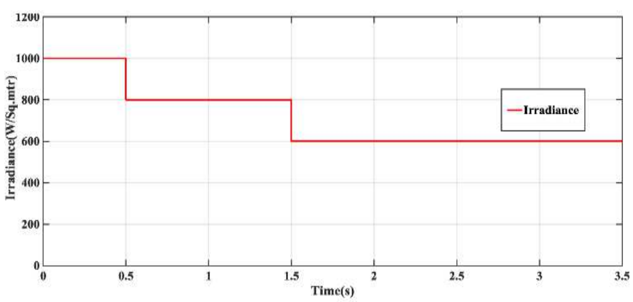
Hence BESS1 begins discharging the power to meet the load demand. As a result, BESS1 begins discharging to compensate the power mismatch and BESS 2 remains idle. From t=2 to t=3s, the load increases further from 7.2Kw to 10.8Kw while the PV power Kept at 6.2kW in MPPT mode. The BESS 1 discharging with maximum power or capacity. Still there is power imbalance. Hence, BESS 2 activated by the control signal send from the secondary controller.

Despite this, the load power experiences faster fluctuations than the MPPT tracking rate. As a result, BESS 1 and 2 discharge to accommodate the increased demand, causing the PV output power to progressively approach its maximum value. Under these conditions, DC bus exhibits voltage ripple caused by a maximum fluctuation in bus voltage reaches approximately 3%.

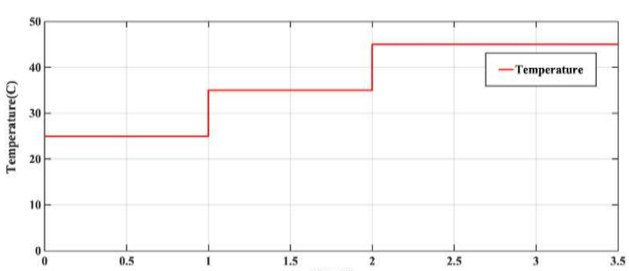
A. *Case 2: Variation of the Weather Parameters with Constant Load.*

In this scenario, the suggested centralized controller's performance is justified by maintaining the DC Microgrid load demand at 8kW while modifying weather-related factors. As depicted Fig. 4(a), 4(b) both solar irradiance and cell temperature exhibit changes characterized by step-up and subsequent step-down fluctuations. PV generation falls with decreasing solar irradiation and rising cell temperature, in Fig. 4 it can be observed that the variations follow distinct patterns. This dissimilarity arises due to the direct relationship between PV power and irradiance, while the alteration in cell temperature leads to a nonlinear change in output power.

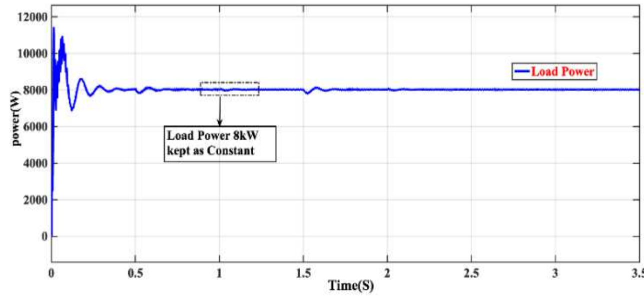
Fig. 4(e) illustrates the fluctuation between PV power and BESS powers with constant load power. The DC microgrid starts an 8kW of load constant throughout the operation, Solar irradiance and temperature maintained as 1000 W/m^2 and 25^0C *respectively*. At t=0.5s solar



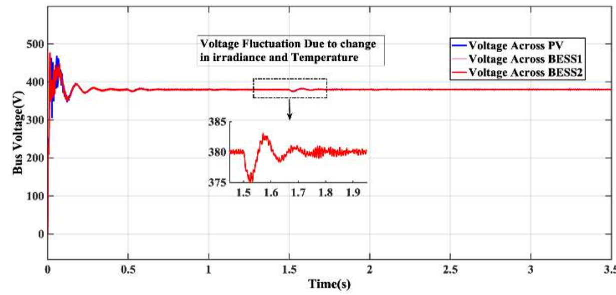
(a)



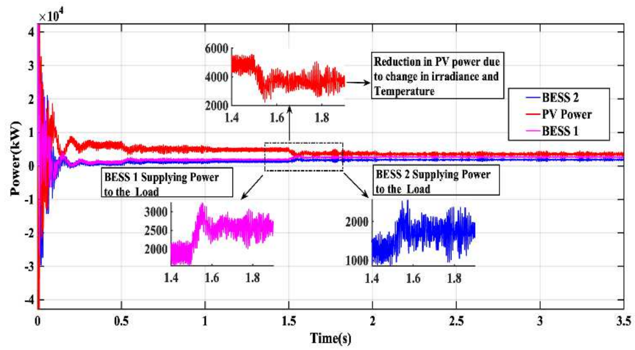
(b)



(C)



(d)



(e)

Fig. 4. Case 2: The results of simulation of the system under variation of Irradiance and Temperature a) irradiance b) temperature c) Load Power, d) Bus voltage, e) PV, BESS 1 and BESS 2 power.

Irradiance decreased from 1000W/m^2 to 800 W/m^2 . but temperature remains constant at 25^0C. Due to reduction in solar irradiance, there is reduction in solar maximum power because solar irradiance is directly related to the solar power. As a results BESS 1 will compensate the mismatch power. At t=1 s the temperature raised from 25^0C. to 35^0C, solar irradiance remains constant as 800 W/m^2. When the temperature rises, the solar power decreases nonlinearly, and the mismatched power is supplied by BESS 1 while BESS 2 remains idle throughout this time. At t=1.5 s solar irradiance decreased from 800 W/m^2 to 600 W/m^2 but, the temperature remains constant at 35^0C.

The maximum solar output decreases further, increasing the mismatch power. To compensate for this mismatch power, both BESS 1 and BESS 2 begin discharging to meet the load demand. At t=2 s, temperature raised from 35^0C to 45^0C but solar irradiance remains constant at 600 W/m^2.The maximum solar output decreases further, increasing the mismatch power.

To compensate for this mismatch power, both BESS 1 and BESS 2 begin discharging to meet the load demand. The fluctuation of bus voltage is illustrated in Fig. 4(d) all through the scenario. Under these circumstances, the DC bus highest voltage variation is limited to less than 3% voltage ripple.

V. Conclusion

In this paper, a centralized control technique for DC microgrid is suggested to achieve appropriate power sharing and bus voltage regulation. Centralized control strategy consists of a modified inner current and outer voltage loop to control the distributed local converters control, which eliminates the traditional droop control. thus, no additional middle layer for voltage restoration control is not required. To give the output power reference of each unit through several realistic simulations, the supervisory controller has been monitoring all the DGs of the DC MG. Simulation tests were used to investigate and validate the feasibility and stability of DC MG.

The proposed centralized control approach improves transient performance, mitigates voltage deviations, and ensures accurate power sharing, justifying its effectiveness for DC microgrids These tests considered various operating conditions, including load demand variations, temperature fluctuations, and irradiance changes. Remarkably, our simulation results demonstrate that the maximum voltage fluctuation remains below 3%, validating the effectiveness of the proposed centralized control approach.

Acknowledgment

The authors thank NIT Warangal for encouraging and granting permission to present this paper. This research is supported by the Science and Engineering Research Board (SERB) DST India under grant number SRG/2021/000810.

References

[1] I. Patrao, E. Figueres, G. Garcerá, and R. González-medina, “Microgrid architectures for low voltage distributed generation,” *Renew. Sustain. Energy Rev.* vol. 43, pp. 415–424, 2015.

[2] E. Planas, J. Andreu, J. I. Gárate, I. M. De Alegría, and E. Ibarra, “AC and DC technology in microgrids: A review,” *Renew. Sustain. Energy ev.*, vol. 43, pp. 726–749, 2015.

[3] N. Ertugrul and D. Abbott, "DC is the Future [Point of View]," in *Proceedings of the IEEE*, vol. 108, no. 5, pp. 615-624, May 2020.

[4] L. Xu *et al.*, "A Review of DC Shipboard Microgrids—Part I: Power Architectures, Energy Storage, and Power Converters," *in IEEE Transactions on Power Electronics*, vol. 37, no. 5, pp. 5155-5172, May 2022.

[5] O. Palizban, and K. Kauhaniemi, “Hierarchical control structure in microgrids with distributed generation: Island and grid-connected mode,” *Renewable and Sustainable Energy Reviews,* vol. 44, pp. 797-813, 2015.

[6] J. Ni, B. Zhao, A. Goudarzi, Y. Li and J. Xiang, "A Dispatchable Droop Control Method for PV Systems in DC Microgrids," in *IEEE Access*, vol. 11, pp. 7588-7598, 2023.

[7] C. A. Hammouda, R. Bradai, R. Boukenoui, A. Kherbachi and A. Bendib, "Modeling and Design of Primary Control’s Inner Loops for Droop-Controlled Three-Phase Inverters within a Microgrid System," *2023 International Conference on Advances in Electronics, Control and Communication Systems (ICAECCS)*, BLIDA, Algeria, 2023, pp. 1-6.

[8] M. V. Kumar and M. Kudadala, "A Novel Fuzzy Logic Controller Topology for Grid Connected PV System by DC Voltage Droop Controller," *2023 International Conference on Recent Trends in Electronics and Communication (ICRTEC)*, Mysore, India, 2023, pp. 1-5.

[9] A. G. Tsakalidis and N. D. Hatziargyriou, "Centralized Control for Optimizing Microgrids Operation," in *IEEE Transactions on Energy Conversion,* vol. 23, no. 1, pp. 241-248, March 2008.

[10] F. Guo, C. Deng, C. Wen, X. Zheng, Z. Lian and W. Jiang, "Partially Decentralized Secondary Current Sharing and Voltage Restoration Controller Design for DC Microgrids With Event-Triggered Sampling," in *IEEE Transactions on Smart Grid*, vol. 14, no. 3, pp. 1777-1789, May 2023.

[11] M. Mehdi, C. -H. Kim and M. Saad, "Robust Centralized Control for DC Islanded Microgrid Considering Communication Network Delay," in *IEEE Access*, vol. 8, pp.77765-77778,2020.

[12] N. L. Díaz, A. C. Luna, J. C. Vasquez and J. M. Guerrero, "Centralized Control Architecture for Coordination of Distributed Renewable Generation and Energy Storage in Islanded AC Microgrids," in *IEEE Transactions on Power Electronics*, vol. 32, no. 7, pp. 5202-5213, July 2017.

[13] M. Killi and S. Samanta, "Modified Perturb and Observe MPPT Algorithm for Drift Avoidance in Photovoltaic Systems," in *IEEE Transactions on Industrial Electronics*, vol. 62, no. 9, pp. 5549-5559, Sept. 2015.

[14] R Krishan, AVerma, S Mishra, “Loadability analysis of DC distribution systems”, International Journal of Electrical Power & Energy Systems, Volume 103, Pages 176-184,2018.

[15] S. K. Kollimalla and M. K. Mishra, "A Novel Adaptive P&O MPPT Algorithm Considering Sudden Changes in the Irradiance," in *IEEE Transactions on Energy Conversion*, vol. 29, no. 3, pp. 602-610, Sept. 2014.