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Research Article

An Algorithm for Power Sharing in a Standalone DC Microgrid Cluster with Centralized Storage

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Abstract:

Stand-alone microgrids utilizing renewable energy sources are the most efficient energy alternative for electrifying rural areas when expanding the utility system is not economically feasible. One of the primary challenges in these systems is maintaining a constant power supply to the load under varying power generation and demand conditions. To overcome from this problem multiple neighbouring microgrids can be connected to form a cluster. This interconnection allows for the exchange of power when there is either an overproduction or a shortfall in power generation. This paper introduces a power sharing algorithm for a standalone DC microgrid cluster. The proposed algorithm utilizes centralized storage to manage excess power. The power sharing process is based on power generation and consumption profiles with the centralized storage acting as a buffer to store surplus power in one microgrid and redistribute it to the other in times of deficit. MATLAB SIMULINK is used to simulate the system's performance. The findings show that the proposed algorithm improves reliability of standalone DC microgrid cluster by reducing energy wastage, eliminating deficits and promoting the efficient use of renewable energy resources.

1. Introduction

The exhaustion of fossil fuels, a steadily increasing need for energy, the imperative to safeguard the planet from carbon emissions and issues associated with extending the grid to provide electricity to isolated villages because of financial and technical limitations have led to the extensive adoption of renewable energy sources for distributed generation. Microgrids are groups of distributed energy sources and associated loads that function as a single, controllable unit with relation to the power grid [1],[2],[3]. Based on the bus configuration, microgrids are grouped into three types: an AC microgrid, a DC microgrid and hybrid AC-DC Microgrid. Among these three types of microgrids , the DC microgrid is gaining attention because most renewable DERs produce DC and the use of DC loads such as home appliances, EV chargers, computers have increased. Less number of power conversion stages in DC microgrid increases the efficiency. Compared to an AC microgrid, a DC microgrid is significantly easier to manage and operate[4],[5]. DC microgrids can operate in islanded mode and grid-connected mode. In grid-connected mode, the grid is interfaced with the DC network using a bidirectional voltage source converter to supply additional power or take in excess power. In islanded mode, the DC microgrid functions independently [6],[7]. The isolated communities which cannot be reached by the conventional grid, due to technical challenges or financial constraints can be powered using microgrids.

Standalone DC microgrids rely on energy storage due to their reliance on intermittent power sources. Critical loads are a major concern in standalone microgrids. To support critical loads a dual battery system is proposed in [8].

The interconnected microgrid systems have recently attracted significant interest. This shift is attributed to their capacity to adjust their electrical limits by interconnecting multiple microgrids, referred to as a microgrid cluster [9].

Effective energy management in microgrid clusters is necessary for improving flexibility, reliability, and economic advantages. Many power exchange methods are proposed in the literature.

Somanath Reddy et al. [10] proposed a unique hierarchical power control technique using cloud architecture. Plug and play services and microgrid clusters are also made possible by the control technique.

A centralized energy management strategy for an independent DC microgrid has been suggested by Ramesh Gugulothu et al. [11]. The centralized controller, while offering enhanced controllability and observability, faces challenges such as communication failures, reduced reliability, and limitations in scalability and adaptability [12]. T. L. Nguyen et al. [13] suggested a flexible and self-sustaining control method that eliminates the need for a communication system for interconnected DC microgrids. The suggested control method considers both the external DC bus signal and SoC level of the battery to prevent both the external DC bus from collapsing and the battery from being overcharged or deeply discharged.

Wahid A et al. [14] suggested a method that manages demand in the microgrid during power outages efficiently.

The load management procedure assigns priority levels to loads. Critical loads of each microgrid are considered with highest priority.However in this approach storage systems are not used, which reduces the relability of the system. An AI-driven predictive control algorithm has been developed by Afshin Hasani et al. [15]. In their approach historical data is used to anticipate power generation and load requirements. This method constantly adjusts power sharing to minimize power losses and optimize energy efficiency. R. Rashidi et al. [16] proposed an energy management strategy for a microgrid at the tertiary control level, employing an adaptive optimal control model aimed at minimizing operational costs for short-term planning, all while ensuring compliance with the network's operational constraints.Rabia Khan et al. [17] implemented an optimization technique to the group of homes for power sharing, which reduced overall system losses by 12%. Zheng Dong et al. [18] proposed a distributed cooperative control for a DC microgrid cluster with several voltage levels connected using a multi-port interconnected converter. A multi-active-bridge converter functions as an intermediary for power transfer between microgrids. This method facilitate the distribution of energy storage resources among these microgrids within a limited communication network.

The successful creation of multi-microgrids still requires further attention in a few areas, despite the recent surge in popularity of this microgrid operation model. Among these is the requirement for more sophisticated control techniques, the use of cutting-edge algorithms to maximize coordination across multiple microgrids, protecting and maintaining data privacy among the different agents in the multi microgrid, and creating techniques to measure both the potential for individual resilience and the sharing of resilience in cooperative operation [19]-[21].

In existing literature, power sharing approaches assume that one microgrid will have excess power when there is a need in the other microgrid. This assumption does not consider real-world scenarios where power imbalances could occur. In particular, there may be cases where one microgrid possesses surplus power, while the other microgrid does not need it at that moment. Conversely, when there is a need in one microgrid, the other may not have sufficient surplus power to meet the demand.

This study introduces a novel approach to energy management in a DC microgrid cluster, which consists of two interconnected microgrids. Each microgrid has a solar photovoltaic (PV) array, primary and backup battery systems, local controllers, and resistive loads. The loads are categorized as critical and non-critical to ensure effective prioritization of energy distribution. A centralized energy storage unit is used to enable power exchange between the microgrids.

The system model ,arrangement and working mechanisms are detailed in Section 2. Section 3 presents the results, while Section 4 summarizes the findings and explores future possibilities.

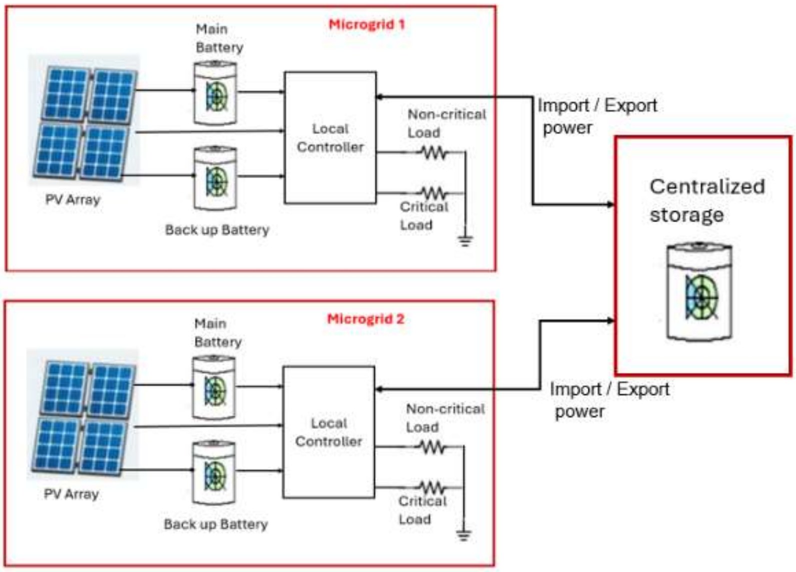

Figure 1. Proposed system model

2. System Model

Figure 1 shows a DC microgrid cluster with centralized storage.

2.1. System Arrangement

Each microgrid has photovoltaic (PV) array to harness solar energy. Photovoltaic systems transform solar energy into electrical energy, which is subsequently utilized to power loads and recharge batteries.The main battery in each microgrid is responsible for supplying power to both critical and non-critical loads. Backup battery is used to power only the critical loads. It provides additional reliability and ensures uninterrupted power supply to essential loads during contingencies. Every microgrid has a local controller that is in charge of monitoring how the photovoltaic array, battery systems, and electrical loads are operating. The local controller ensures efficient power distribution and maintains the balance between generation and consumption.A centralized battery is shared between the two microgrids in the cluster. It is used for storing excess power generated by the microgrids and supplying power when there is a deficit. Main battery, backup battery and centralized battery operates within defined State of Charge (SoC) limits to prevent overcharging and over discharging.

2.2. Working Mechanism

2.3.Load Management And Power Flow Control

A. Normal Operation
When there is adequate sunlight, the photovoltaic arrays in both microgrids produce electricity. The generated power is first used to meet the local demands. Excess energy generated by the photovoltaic arrays is utilized to recharge both the main and backup batteries in each microgrid. Any further extra electricity is routed to the centralized battery for storage.
B. Power Sharing Between Microgrids
Each microgrid operates autonomously under normal conditions, with local controllers managing the power distribution. When a microgrid experiences a power deficit, it imports power from the centralized battery. When there is excess power in any of the microgrid it is exported to the centralized storage.
C. State of Charge (SoC) Management
The SoC limit is predefined for all the batteries to avoid overcharging and over-discharging. Local controllers monitor the SoC levels continuously and adjust the charging/discharging rates accordingly.
The flowchart of power management shown in Figure 2. Initially, the photovoltaic output power (Ppv), the load power (Pload), and the state of charge for both battery 1 and battery 2 are recorded. If Ppv exceeds Pload, the subsequent decision checks whether the state of charge of main battery is 90%. If SoC level of main battery is less than 90%, main battery is charged in MPPT mode. If SoC level of main battery is 90% or

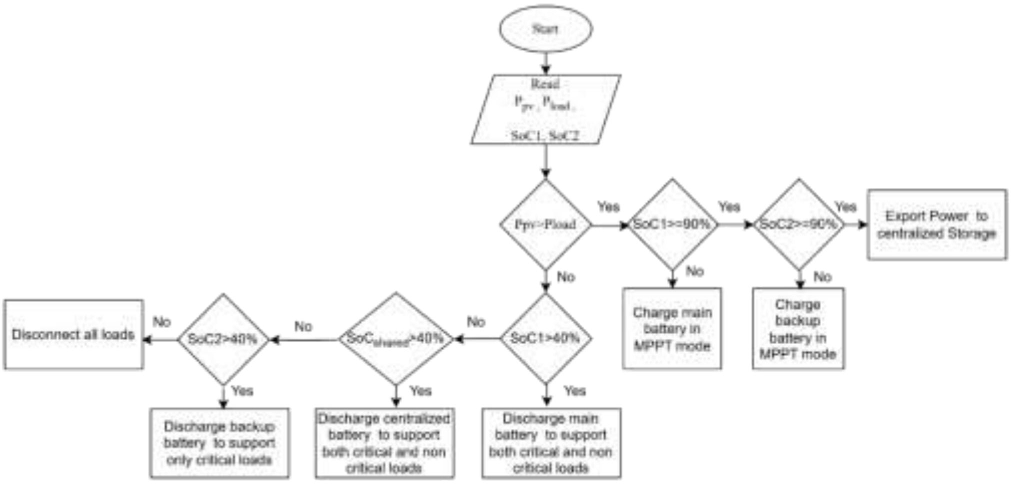

***Figure 2**. Power management flow chart*

higher, the system checks the SoC of level of backup battery. If the SoC level of backup battery is less than 90%, it is charged in MPPT mode. When SoC level of both main and backup battery is 90% or higher, then excess power is exported to the shared centralized storage system.

If Ppv<P_{load}, the system checks SoC level of main battery. When the SoC level main battery is greater than 40%, it supports both critical and noncritical loads. If the SoC level of main battery is less than 40%, then power is imported from the centralized storage to support all the loads. If there is no power in the centralized storage, then backup battery supports only the critical loads, and all noncritical loads are disconnected from the grid.

3. Results And Discussions

The power deficit mode in microgrid 1 is shown in figure3 , where the system encounters power shortages during two specific intervals: from 0 to 3 seconds and from 6 to 10 seconds. During these periods, the SoC level of both the batteries below the minimum SoC level, indicating insufficient energy storage to meet the load demand.During this period the power is imported from the centralized battery to meet the power demand in microgrid1. This approach ensures that even in the case of a power deficit the microgrid will continue to function. Between 3 to 6 seconds, microgrid 1 experiences a period where the power generated by its photovoltaic (PV) array exceeds the power required by its loads. During this period, the excess power is effectively utilized to charge the two batteries.

Microgrid 2's battery system remains in a stable condition with a high SoC level of 95% as shown in Figure 4 in power surplus mode. When Ppv< P_{load} during 0 to 3 seconds and 6 to 10 seconds substantial capacity of battery allows microgrid 2 to independently handle its own load without the need for external assistance. During 3 to 6 seconds the excess power in microgrid 2 is exported to centralized storage.

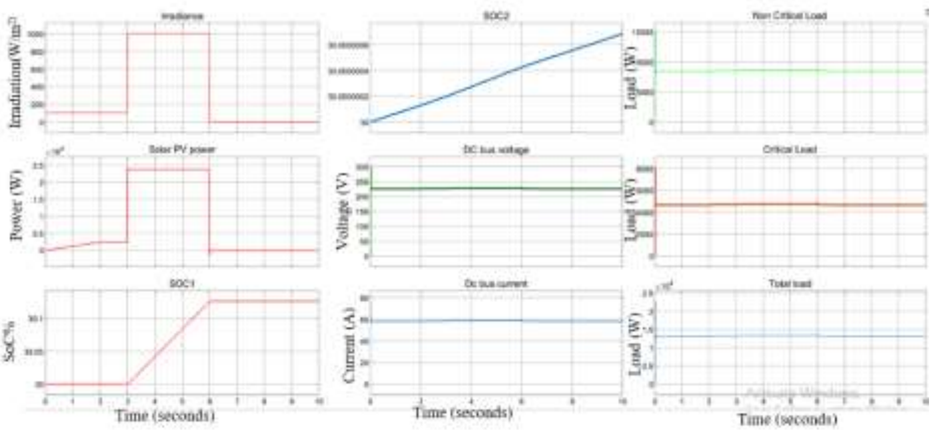

***Figure 3.** Simulation findings for microgrid 1's power shortfall with power import*

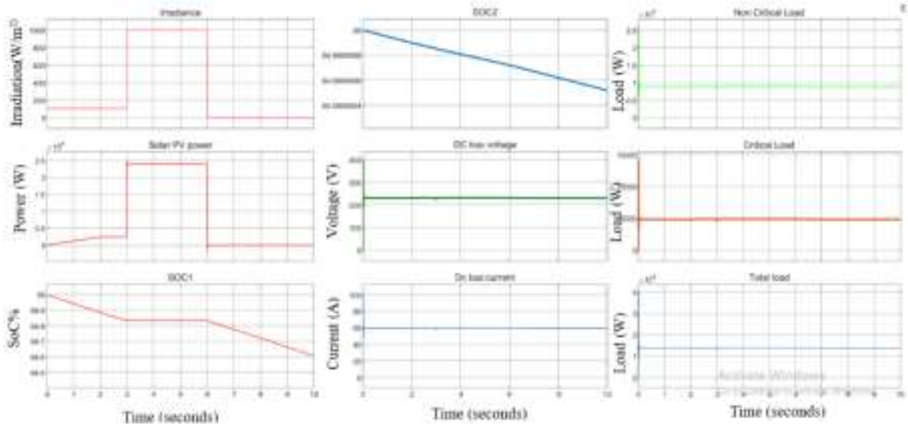

Figure 4. *Simulation results for battery discharging in microgrid2*

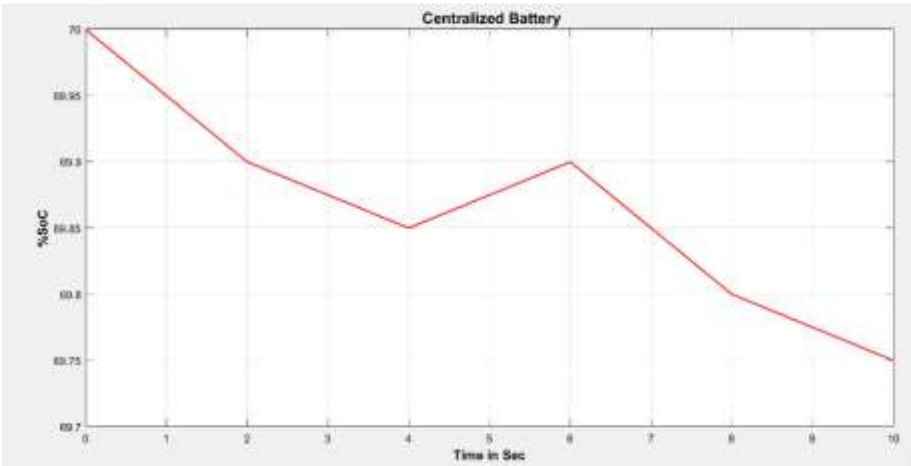

Figure 5. *Simulation results of centralized battery discharging to overcome power deficit in microgrid1*

The simulation also examines power surplus scenarios for both microgrids, as shown in Figures 6 and 7. During the interval of 3 to 6 seconds, both Microgrid 1 and Microgrid 2 encounter a surplus of power generated by photovoltaic sources in relation to their load requirements. Since the SoC level of both the batteries are greater than 90%, the excess power is exported to the centralized storage as shown in Figure 8. By efficiently balancing variations in power generation and consumption, this centralized storage technique improves the microgrid cluster's overall energy management.

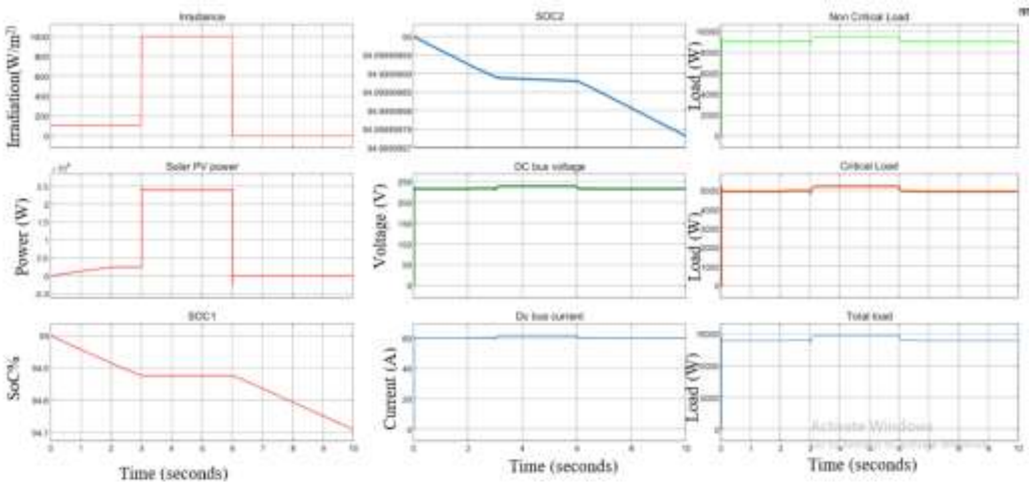

Figure 6. *Simulation results for surplus power in microgrid1*

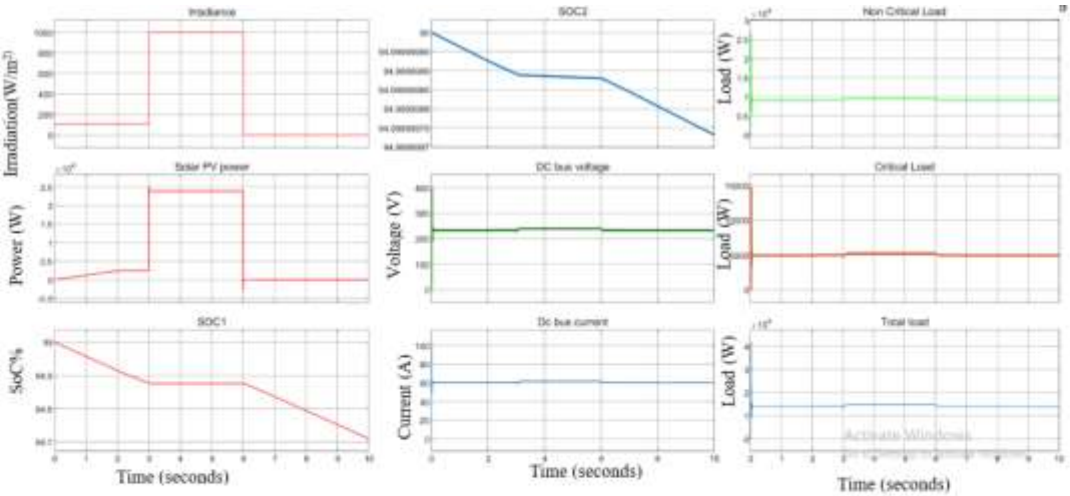

Figure 7. *Simulation results for surplus power in microgrid2*

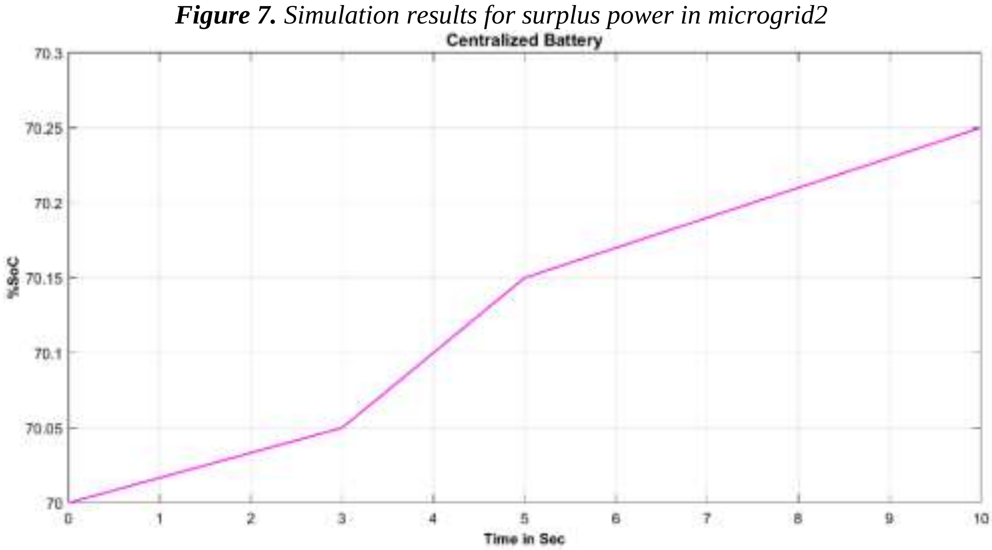

Figure 8. *Simulation results of centralized battery charging due to surplus power in microgrid1 and microgrid*

In this study the performance of the microgrid cluster with centralized storage system is compared with a microgrid cluster without centralized storage in order to assess the effectiveness of the suggested power-sharing algorithm.

Table 1.*Comparison of performance of microgrids*

Metrics	**Without Centralized Storage**	**With Centralized Storage**
Energy Wasted	50.23 kWh	30.12 kWh
Backup battery Usage	15.35 kWh	5.67 kWh
Load Supports	8.5 hours	12 hours
Efficiency	80.5%	91.2%

The analysis of energy-sharing strategies, as illustrated in Table 1, shows the improvements in both energy efficiency and reliability when centralized storage is employed compared to a microgrid cluster without it. The energy wasted decreases from 50.23 kWh to 30.12 kWh when centralized storage is used in the microgrid cluster. Backup batteries are used less frequently when centralized storage is available to supply deficits. The system continues to function for extended periods, decreasing power outages and enhancing stability. Improved power utilization in microgrid cluster with centralized storage results in improved system efficiency.

4. Conclusion And Future Scope

This work explores the effectiveness of centralized energy storage in improving power sharing and reliability of a standalone microgrid cluster. The performance of the proposed system is analyzed by considering a microgrid cluster with and without centralized storage. The results show that adding centralized storage reduces waste of energy and improves the efficiency of the system.

In this study only PV source is considered, future research could explore the integration of other renewable energy sources. The advancement and application of more advanced control algorithms through machine learning or artificial intelligence may enhance the optimization of energy distribution and storage management. Such algorithms could predict load demands and renewable energy generation more accurately, leading to even more efficient energy management.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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