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Optimal Placement and Sizing of Energy Storage Systems in Networked Microgrids

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***Abstract*—In modern power network, energy storage systems (ESSs) play a crucial role by maintaining stability, supporting fast and effective control, and storing excess power from intermittent renewable energy sources (RESs). It is essential to determine the best-suited locations and sizes of ESSs in order to implement them economically and effectively in power systems. Networked microgrids are emerging as one of the solutions for enhancing power system reliability and resiliency in modern power networks. This paper focuses on finding the best location and size for ESS within a networked microgrids. The objective function is to minimize the power loss, improve the voltage profile and reduce peak load by utilizing ESSs in the network. Here, the Genetic Algorithm has been used to identify the optimal placement and sizing of a battery in a networked microgrids. The proposed approach has been demonstrated on a benchmark test system of networked microgrids. The obtained results of battery location and sizing demonstrate the effectiveness and suitability in reducing active power loss, maintaining the voltage profile, and ensuring power balance in the system.**

***Index Terms*—Distributed Generators, Renewable Energy Sources, Energy Storage System, Networked microgrids, and Genetic algorithm.**

I. Introduction

Renewable energy generation has emerged as the predominant trend in the modern power system, with photovoltaic (PV) and wind turbine (WT) power plants becoming increasingly prevalent in countries worldwide. These plants are often integrated into microgrids (MGs), which are entities that combine clusters of distributed generation (DG) sources, including both renewable and non-renewable sources, to supply loads within a clearly defined electrical boundary. One of the key advantages of MGs is their ability to increase the penetration of renewable power into the system. They enable controlled and effective operation among multiple or single renewable or nonrenewable distributed generations. Moreover, combining and operating multiple microgrids together in a coordinated manner is defined as a networked microgrids, which supports microgrids as islanded or grid-connected modes of operation. This is a promising alternative for enhancing the resilience and reliability of power networks and offering the necessary electrical infrastructure to make use of the economical and environmentally favorable electricity produced by distributed energy resources (DERs) [1].

The networked microgrids concept can also provide enhanced flexibility and reliability, as it allows for the seamless integration and management of various energy sources and loads. This can be achieved by using intelligent algorithms and advanced communication protocols that enable real-time monitoring and control of the operational parameters of MGs. Moreover, networked microgrids can support a range of applications, from small-scale residential systems to large-scale industrial and commercial systems, which makes them highly versatile and scalable. The combination of renewable energy sources, microgrids, and networked microgrids offers a promising alternative for enhancing the resilience, reliability, and sustainability of power systems [2].

The market for energy storage has significantly expanded since distributed energy resources were integrated into the power grid. Renewable energy sources, like the sun and wind, are plentiful in nature and are clean energy sources. However, due to political and economic barriers, the cost of converting this energy to electricity is expensive. Energy storage systems are used to make up for the imbalance in power generation caused by the intermittent character of renewable energy sources. As a result, the expense of the entire system rises.

Battery energy storage system (BESS) is one of the best energy storage systems with respect to service life, operating temperature, discharge depth, self-discharge, and as well as economical. Overall, BESS offers a range of technical and economic advantages that make them a promising solution for energy storage. As renewable energy sources continue to become more prevalent, the importance of energy storage systems, including BESS, will only continue to grow [3].

Several studies state the benefits of energy storage systems and the optimal placement and sizing of the battery storage system. By carefully examining the PV and BESS's size and placement, the system can be optimized to minimize power loss. Using a genetic algorithm (GA), location and size are optimized. The findings of the optimized size and placement can result in less power loss [3]. A multi-objective

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approach of real power loss, voltage deviation, branch current capacity, and cost factor index to identify the best placement and sizing of BESS [4]. An approach of virtual multi-slack power flow analysis is based on the power sensitivity matrix to find the optimal placement and sizing of the battery [5]. Optimal charging and discharging schedules of BESS for a residential PV system in a cost-effective manner are detailed in [6]. Scheduling and finding ideal sizing and placement with different considerations like with hybrid PV-Wind or with only PV, or with PV, WT, and biomass plants using different approaches like power sensitivity analysis, load frequency control, probabilistic frequency stability analysis with system uncertainties using techniques like GA, particle swarm optimization (PSO) analytical approaches.

This paper proposes an approach to find the optimal size and placement of the battery in networked microgrids having different considerations, constraints, configurations, and along with variations of load, and generations. The objective function is to minimize the power loss, improve the voltage profile and reduce power loss and peak load by utilizing batteries at different locations in the network using GA. No approach is on a Networked microgrid. This proposed approach has been demonstrated on a benchmark test system of networked microgrids and the obtained results have been analyzed in reducing active power loss, maintaining the voltage profile, and ensuring power balance in the system.

II. Networked Microgrids

A. Microgrids

Microgrid is an independent controller for distributed generation units to serve the load in a small region. Based on the type of load demand microgrids are classified as DC, AC, and hybrid AC-DC. In terms of ownership, an MG may be the property of a utility, a neighbourhood, or a private individual. These MGs may run on a number of schedules, depending on their energy planning and economic features. Under all operating conditions, load and generation balance must be maintained to keep the frequency and voltage of MGs within the operational limits. In a grid-connected mode, the grid, which acts as the slack bus for the MG, controls this balance. To maintain the load and generation balance, dispatchable DG must be present in systems islanded mode. In this paper, all individual MGs are taken into account to be of the AC type and equipped with synchronous generators (SG) based dispatchable DG to sustain the entire load of the MG throughout the autonomous operation in the system. Each MG has the same voltage level, hence no tie-converter is needed for the tie-line.

B. Networked Microgrids and its Configurations

Networked microgrids are a collection of microgrids that are interconnected to each other to improve the overall resiliency, reliability, and efficiency of the power system. The networking of multiple self-governed microgrids allows them to work together in a coordinated manner, thereby achieving optimal energy management, operation, and control. This helps make our electricity more reliable, affordable, and better for the environment.

1) Single Common Point Utility Interconnection: Only one connection to the utility grid for all MGs. Four MGs make up this networked MG system, which may be linked together with five point of common coupling (PCC) tie-cables. MG1 has a direct connection to the utility grid. If MG1 is not operational, MG2 and MG3 can obtain power either from the utility grid or directly through MG1. Power for MG4 comes from MG2 and/or MG3. The number is networked MG connections may be numerous. Each PCC only has two operational states: ”ON” and ”OFF. ” Hence, the total number of networked MG configurations is dependent on the PCC state, which is described as follows:

$$TN = 2^{N_{PCC}} \tag{1}$$

where N_{PCC} is the number of PCCs and TN is the total number of possible configurations In this, a total of 32 interconnections are possible among the four MGs.

2) Multiple Common Point Utility Interconnection: Through different common points of interconnection, MGs can be connected to distribution feeders at different nodes. Through two separate feeders, microgrids can link to the utility grid in this configuration.

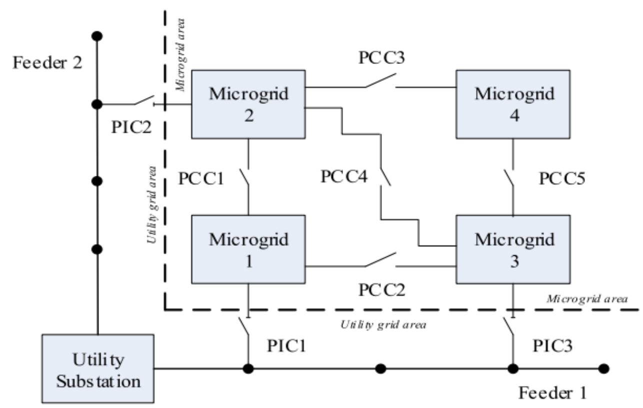

Fig. 1. Block diagram of networked microgrid benchmark test system [2].

C. Benefits of networked MGs

1) Reliability improvement: Networked MGs can provide higher reliability and power quality to customers by integrating multiple sources of generation, such as solar, wind, and battery storage, and coordinating their operations.

2) Black-start support: Networked MGs can support the restoration of power in the event of a blackout by providing power to critical loads and gradually bringing up the grid to normal operating conditions.

3) Best utilization of DERs: Networked MGs can enable the efficient integration and utilization of distributed energy resources (DERs) by managing their production and consumption in coordination with the grid.

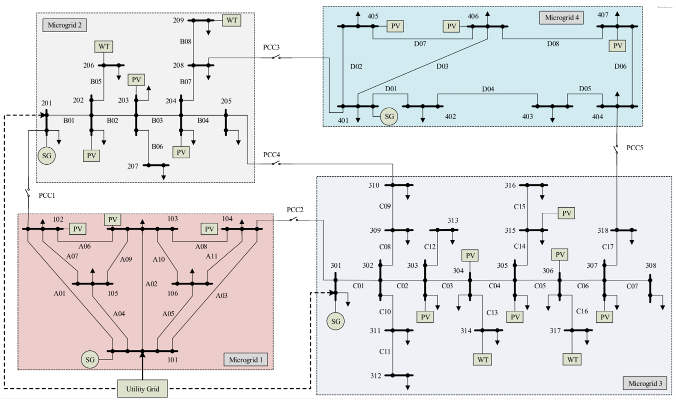

Fig. 2. The 40 bus networked microgrid benchmark test system [2].

4) The overall cost of supply reduction: Networked MGs can reduce the overall cost of supply by optimizing the use of renewable energy resources, reducing transmission and distribution losses, and avoiding or deferring the need for expensive grid infrastructure upgrades.

D. Challenges of networked MGs

1) Stability issues: Networked MGs may face stability issues due to the intermittent and variable nature of renewable energy sources, which can cause voltage and frequency fluctuations in the grid.

2) Privacy concern: Privacy concerns: Private and community MGs may have privacy concerns, as their operational data and energy consumption patterns can be accessed by the network operator and other stakeholders.

3) Cyber security: Networked MGs may be vulnerable to cyber-attacks, which can disrupt their operations and cause damage to the grid.

4) Protection coordination: Networked MGs may face challenges in maintaining proper protection coordination under various operating conditions, which can lead to equipment damage or even blackouts.

III. Need of Battery

To improve the power quality and to shift the peak load, the energy storage system (ESS) has been implemented as a key component of the power system. Fast charging/discharging and the capacity to store excess energy are the two most crucial features of an ESS that enable better power system stability. The ESS's ability to smooth out power output through the use of its fast charging and discharging features is its primary addition to the stability of the power system. DG power output varies quickly and dramatically, particularly for those using wind and solar energy. An ESS can minimise fluctuations in the power generation of DGs, ensuring flexibility within the power system. It does this by swiftly charging if the generated power suddenly rises and discharging if it declines. The technology for ESSs has been established to improve the stability and efficiency of power systems in response to the rising penetration of DGs into microgrids.

Li-ion battery storage is thought to be the most effective and reliable BESS type currently on the market. Li-ion batteries are a great option for many energy storage applications because of their high energy density, extended cycle life, and minimal maintenance needs.

In order to keep the grid resilient and stable in the face of unforeseen load and generation conditions, BESS is essential. More control over energy use and cost is possible because to its spinning reserve management and end-user energy management features. BESS can be used in a variety of ways to integrate renewable energy sources into the grid. For example, BESS can enhance grid stability and dependability by bringing renewable energy installations into compliance with grid code standards. Additionally, it can help the grid with P and Q support, spinning reserve, energy arbitrage, voltage and frequency management and support, and peak shaving. BESS can also be used in microgrids, where it can offer islanding operation, enabling the microgrid to function separately from the main grid in times of power shortages or other calamities. By doing so, the continuity of the energy supply is ensured and key loads are kept running. Ineffective BESS technicians could impede performance or possibly increase power losses in the system. Better operational and planning strategies must be used in order to function at peak levels.

IV. Methodology

Using evolutionary optimization algorithms like a genetic algorithm (GA), the issue can be solved in the best possible way. In artificial intelligence and computation, the genetic algorithm is a heuristic search technique that is typically used to discover the best answers to non-linear problems.

Genetic algorithms are commonly used for optimization problems, such as maximizing or minimizing a function. They can be used for problems with multiple objectives or constraints and can search through large solution spaces efficiently.

In general, the GA formulation has a lot of different factors. In GA, the population's size, selection, crossover parameters, objective function, probability, and mutation, each require a specific setting depending on the intended solution to the optimization issue. The accuracy of the GA output and the amount of time needed for computation or processing both depend on the selection of these factors, which must be done carefully.

The objectives are mathematically stated as

$$\min\ f(x) = f_1 + f_2 + f_3 \tag{2}$$

$$f_1 = losses = \frac{(P_G - P_L)}{Loss\, factor} \tag{3}$$

$$f_2 = 1 - V_{\min} \tag{4}$$

$$f_3 = 1 - V_{avg} \tag{5}$$

The fitness function is the minimization of the objective function. Here, losses should decrease. The minimum voltage and average voltage should increase.

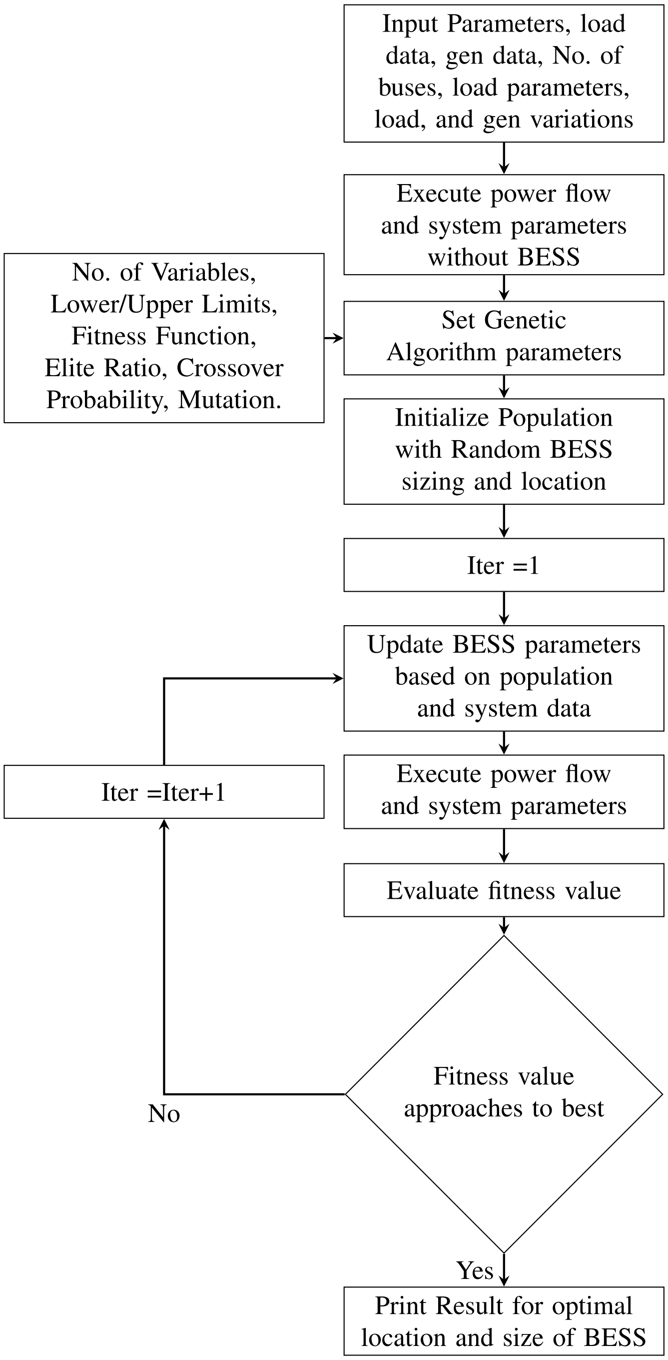

Fig. 3. Flowchart of the developed approach.

Where P_G is Active power generation
P_L is Active load

1) Constraint: Limits are necessary to keep stability and the system needs to follow the limitations

- Voltage in the bus

$$V_{\min} < V_{bus_i} < V_{\max} \tag{6}$$

$$0.95\,(p.u.) < V_{bus_i} < 1.05\,(p.u.) \tag{7}$$

- Battery Placement
  Except slack bus every other bus is a consideration for battery placement.

$$2 < BatteryLocation < 40 \tag{8}$$

- BESS Capacity
  Based on the total load battery size is considered between 20-30 percent of load.

$$P^{\min} < P_{i,y}^{BESS} < P^{\max} \tag{9}$$

  $P^{\min}$ and $P^{\max}$ are the minimum and maximum threshold values of the power generated from the BESS.

$$6MWh < P_{i,y}^{BESS} < 10MWh \tag{10}$$

- Charge / Discharge rate of BESS
  Charge and discharge BESS must not exceed the maximum discharge or charge limit.

$$0 < P_{bc_{i,y,t}} < P_{bc_{\max}} \tag{11}$$

$$0 < P_{bd_{i,y,t}} < P_{bd_{\max}} \tag{12}$$

  $P_{bc_{i,y,t}}$ and $P_{bd_{i,y,t}}$ is the charge and discharge rate of BESS in one hour (t) at bus i for battery location y.
  Where i is Bus number, y is battery location

V. Simulation Setup

A. Test System

In this study, simulations were carried out using the GA optimization toolbox using MATLAB. A 40-bus networked benchmark system is taken as the test system whose details are available in [2].

TABLE I
System Details

Components	MG1	MG2	MG3	MG4	Total
Buses	6	9	18	7	40
Lines	11	8	17	8	44
WT Systems	0	2	2	0	4
PV Systems	3	3	6	3	15
SGs	3	3	3	2	11
Slack bus	101	201	301	401	4
MG Type	Meshed	radial	radial	Meshed	-

PCCs=5

The benchmark test system is a complex electrical network that connects numerous microgrids using underground wires. The system contains five common coupling points, which serve as the points of connection between microgrids and the larger grid. A three-digit number uniquely identifies each bus in the system. The parameters of the four MGs in the system have been carefully chosen in accordance with IEEE Standard 1547-2018. The architecture of the MGs is based on already-existing benchmark test systems of various sizes but with adjustments made to meet the needs of the network and the microgrids.

As the slack bus, the first bus of each MG (101, 201, 301, and 401) is equipped with a conventional synchronous generator (SG), which provides load balancing and reactive power support to maintain the microgrid's steady operation in an islanded mode (i.e., when it is not connected to the main grid). The slack bus of MG1 (101) acts as the system's slack bus when in grid-connected mode. V/f (voltage to frequency) regulation of the system and load balancing is performed through this bus, which helps to ensure that the loads and generators are properly balanced and the voltage and frequency of the system are within acceptable limits.

VI. Results and Discussion

In this study, there are two approaches are followed, one is a conventional approach, which checks the power loss and voltage at every bus at every hour with all the possible battery placement conditions Here a lot of data is collected and compared. But this process involves a lot of data and needs to check so many conditions and comparisons. And the other approach is with a Genetic algorithm optimization toolbox with different constraints and conditions. The optimal placement of the battery and optimal sizing of the battery is obtained as they are the better solution for achieving the objective of improving the minimum voltage, and average voltage, reducing the max losses and overall losses, and improving the power balance in the system. Tables II, Table III indicates the results of the convention method with 6 and 9 MWh capacity batteries at all positions and collected the data and among all the data best results were taken. The time taken to get the result is high. Table IV and Table V indicate the results of the GA with 10 and 9 MWh capacity batteries, based on the objective function the best result of optimal location is obtained and along with that no of batteries to be taken is also obtained. It is evident that with the battery, power loss is getting reduced and voltage profile getting increased..

Fig. 4 and Fig. 5 give the load and generation profiles of 24 hours duration, and Fig. 6 have the comparison for the load and generation. It indicated how the load is shifting from the low-generation region to the high-generation region. so that with the battery the load curve is trying to match with the generation.

TABLE II
Results For conventional approach With 6 MWh

No. of Batteries	0	1	2	3
$V_{\min}$(p.u.)	0.9799	0.9805	0.9807	0.9808
Power loss(p.u.)	0.1558	0.137	0.1369	0.1368
Location	-	39	23,39	38,23,39

TABLE III
Results For conventional approach With 9 MWh

No. of Batteries	0	1	2	3
$V_{\min}$(p.u.)	0.9799	0.9810	0.9811	0.9813
Power loss(p.u.)	0.1558	0.1362	0.1360	0.1359
Location	-	39	38,39	23,33,39

Fig. 6 tells us the generation, load, charging, and discharging period of the battery, and the load curve with different battery capacities. Based on the load and the generation curve, we

TABLE IV
Results For Genetic algorithm approach

No. of Batteries	0	1	2	3
$V_{\min}$(p.u.)	0.9799	0.9810	0.9811	0.9813
Power loss(p.u.)	0.1558	0.1362	0.1360	0.1361
Location	-	39	38, 39	23, 39, 38
Battery size	-	9 MW	2*4.5 MW	3*2.91 MW

TABLE V
Results For Genetic algorithm approach of 10 MWh capacity ESS

No. of Batteries	0	1	2	3
$V_{\min}$(p.u.)	0.9799	0.9814	0.9814	0.9811
Power loss(p.u.)	0.1558	0.1279	0.1279	0.1270
Location	-	39	38, 39	34, 39, 38
Battery size	-	10 MW	2*5 MW	3*3.333 MW

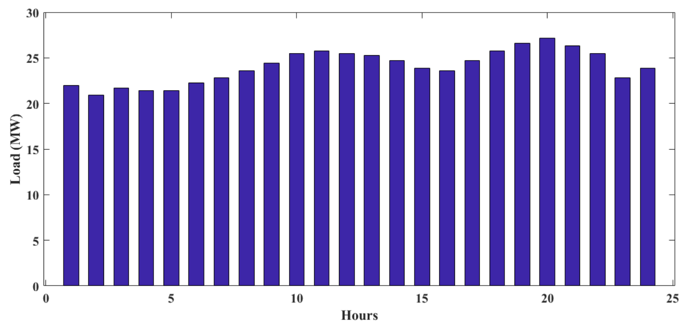

Fig. 4. Load profile of a 40-bus system for a day (24 Hrs).

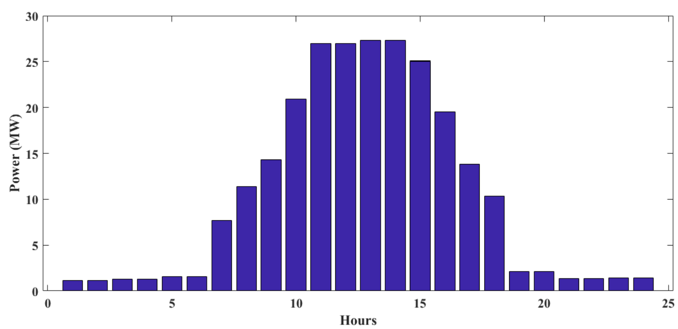

Fig. 5. Generation profile of a 40-bus system for a day (24 Hrs).

can decide the charging and discharging hours of the battery and with the battery placement, the load cliff is getting reduced and shifting the load to high RES generation hours. Placing the battery achieves the load balance so that maximum consumption from the main grid reduces and benefits economically. In Fig. 7, the total power loss value for 24 hours for zero to ten batteries to be placed in the system is shown. And among them, minimum loss occurrence is taken as the optimal number of batteries.

Fig. 8 indicates the objective value for the placement of one battery at each bus of a 40-bus system. The bus with minimum objective function value should be the location for

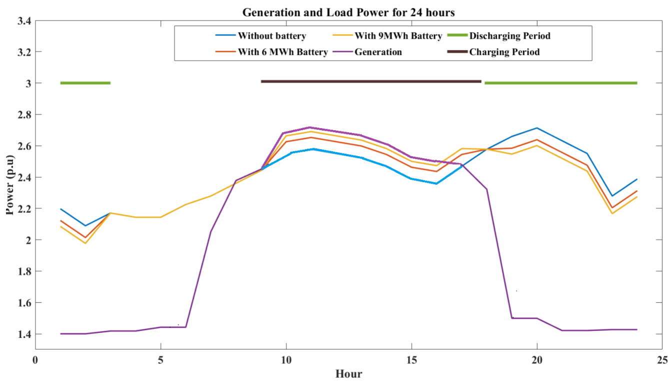

Fig. 6. Load and Generation profile of a 40-bus system for a day (24 Hrs).

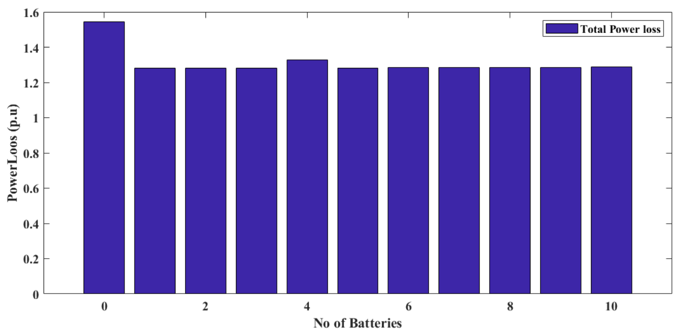

Fig. 7. Maximum losses for different placements.

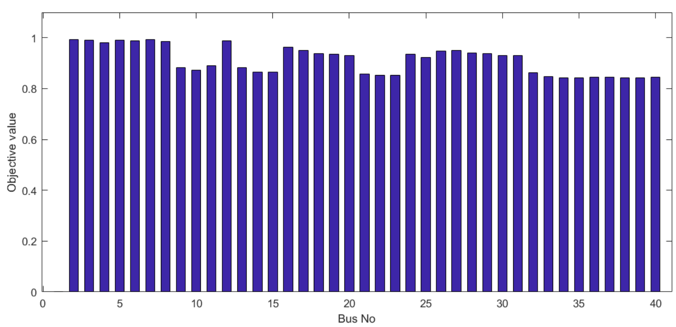

Fig. 8. Objective function for each bus of 1 Battery placement).

the placement of the battery.

BESS in the networked MGs leads to an increase in reliability and resiliency of the system by balancing the renewable energy power, reducing the power loss, and increasing voltage stability. It makes the system to be less independent on the main grid. Able to supply critical loads for a longer period in emergency conditions. Economical in reducing the peak load tariff. Provides a more reliable and economical power supply to consumers.

VII. Conclusion and Future work

The optimal placement and the optimal sizing of the battery are very important issues for the stability of the power system. With better placement and sizing, losses got reduced, the voltage profile got improved, and power balance is achieved. The installation cost of the ESS is directly related to the installation sizing, so optimal sizing and an optimal number of batteries lead to economical benefits. This paper is only for 24 hrs. Future work extends to annual data and other configurations of networked MGs as well. Implementing other algorithms and comparing them can give the best result of optimal sizing and placement which helps in economical aspects as well as better energy management planning.

References

[1] M. N. Alam, S. Chakrabarti, and A. Ghosh, “Networked Microgrids: State-of-the-art and future perspectives,” IEEE Transaction on Industrial Informatics, vol. 15, No. 3, November 2019.

[2] M. N. Alam, S. Chakrabarti, and X. Liang, “A Benchmark Test System for Networked Microgrids,” IEEE Transaction on Industrial Informatics, vol. 16, No. 10, October 2020.

[3] M. Dewantara, L. M. Putranto, R. Irnawan, and Sarjiya, “Minimization of Power Losses through Optimal Placement and Sizing from Solar Power and Battery Energy Storage System in Distribution System,” 2020 3rd International Seminar on Research of Information Technology and Intelligent Systems (ISRITI) December 2020.

[4] S. R. Gampa, and D. Das, “Optimum placement and sizing of DGs considering average hourly variations of load,” Electrical Power and Energy Systems Elsevier, vol. 66, 25–40, March 2015.

[5] D. Kim, K. Yoon, S. H. Lee, and J.-W. Park, “Optimal Placement and Sizing of an Energy Storage System Using a Power Sensitivity Analysis in a Practical Stand-Alone Microgrid,” Electronics 2021, 10, 1598.

[6] A. Kapoor, and A. Sharma, “Optimal Charge/Discharge Scheduling of Battery Storage Interconnected With Residential PV System,” IEEE Systems Journal, vol. 14, NO. 3, 3825 - 3835, September 2020.

[7] M. A. S. Masoum, S. M. M. Badejani, and M. Kalantar, “Optimal Placement of Hybrid PV-Wind Systems Using Genetic Algorithm,” 2010 Innovative Smart Grid Technologies(ISGT), 19-21 January 2010, Gaithersburg, MD, USA.

[8] Sukhlal Sisodiya, G. B. Kumbhar, and M. N. Alam, “A Home Energy Management Incorporating Energy Storage Systems with Utility under Demand Response using PSO,” 2018 IEEMA Engineer Infinite Conference, 13-14 March 2018, New Delhi, India.

[9] S. K. Aditya, D. Das, “Battery energy storage for load frequency control of an interconnected power system,” Electric Power Systems Research, Vol. 58, Issue 3, 179–185, 20 July 2001.

[10]] Hassan Alsharif, and Mahdi Jalili, Kazi N. Hasan, “Power system frequency stability using optimal sizing and placement of Battery Energy Storage System under uncertainty,” Journal of Energy Storage, vol. 50, June 2022, 104610.

[11] Thongchart Kerdphol, and Yaser Qudaih, Yasunori Mitani, “Optimum battery energy storage system using PSO considering dynamic demand response,” Electrical Power and Energy Systems, vol. 83, 58–66, December 2016.

[12] Maneesh Kumar, Kalpana Shanmugam, Kaustove Pradeep, and Matteo Filippone, “Grid integration and application of Battery Energy Storage Systems,” 2022 IEEE International Conference on Electronics, Computing and Communication Technologies (CONECCT), 08-10 July 2022, Bangalore, India.

[13] H. Nazaripouya, Y. Wang, P. Chu, H. R. Pota, and R. Gadh, “Optimal Sizing and Placement of Battery Energy Storage in Distribution System Based on Solar Size for Voltage Regulation,” 2015 IEEE Power and Energy Society General Meeting, 26-30 July 2015, Denver, CO, USA.

[14] Saw, Bikash Kumar, Balmukund Kumar, and Aashish Kumar Bohre, ”Optimal Allocation of Renewable DGs with Optimal Reconfiguration Using Adaptive PSO in Distribution Network,” 2021 2nd Electric Power and Renewable Energy Conference (EPREC-2021).

[15] caisheng wang, and M. Hashem Nehrir, “Analytical Approaches for Optimal Placement of Distributed Generation Sources in Power Systems,” IEEE Transactions on Power Systems vol. 19, NO. 4 November 2004.

[16] Saw, Bikash Kumar, Balmukund Kumar, and Aashish Kumar Bohre, ”Intelligent Approach for Distributed Generation Planning and Distribution Network Reconfiguration Using Metaheuristic Technique,” Intelligent Data Analytics for Power and Energy Systems, pp. 29-44. Singapore: Springer Nature Singapore, 2022.