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Optimal Planning of Energy Storage System in a PV Integrated Semi-Urban Microgrid Pilot

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Abstract - Recent transformations in the electrical distribution network include formation of microgrids and large deployment of Renewable Energy Sources (RESs), particularly Solar Photo Voltaic (SPV) and wind plants. Due to intermittency of the power outputs of these sources, maintaining continuity and reliability of supply becomes more challenging, which can be addressed through deployment of storage systems. The Battery Energy Storage System (BESS) is the most popular choice at present in the distribution systems and microgrids. It is important to decide optimal placement and sizing of BESS in order to reduce the power losses and large voltage deviation in the system, while maintaining the continuity of supply and power quality. This work presents the optimal planning of the BESS in a residential area microgrid pilot inside IITK campus, mimicking typical semi- urban distribution in India, as part of joint Indo-US project 'UI-ASSIST'. It has been formulated as an optimization problem having objective function to minimize the total network real power loss and voltage deviation at each node, subject to various physical and operating constraints. DigSilent is used to simulate different operating conditions and perform load flows. An analytic approach is used to minimize the objective function. The results are further validated on the simulation model of microgrid pilot under various operating conditions using Real Time Digital Simulator (RTDS).

***Keywords*:** Microgrid, BESS planning, Optimal sizing and siting, Loss minimization, Voltage profile improvement

1. Introduction

The present-day electric power system is witnessing fast changes, specifically the distribution networks, which are getting transformed from radial & passive systems to active network due to growing deployment of RESs. Amongst various types of RESs, the SPV based sources are growing at faster rate. While these sources promote development of clean energy, they pose operating challenges due to their intermittent outputs, dependent on the time of the day and weather conditions. To make the growth of RESs sustainable, deployment of energy storage system is required, the Battery Energy Storage System (BESS) being the most popular at distribution level. Microgrids, containing RESs, BESS and loads, are also being planned at remote, community and strategic locations to ensure security of supply. In order to gain maximum benefit from the RESs, it needs to optimize the placement and sizing of the BESS in the distribution networks and microgrids. This has been formulated as an optimization problem by several researchers in the literature, considering the objectives to minimize power losses, voltage deviation, reactive power loss, improving reliability of the system, etc. In [1], the SPV source and BESS optimal placement and sizing are done using an analytical method with the voltage regulation as an objective. However, it has not included the effect of load level changes. In [2], optimal placement and sizing of Distributed Energy Resources (DERs) are formulated using particle swarm optimization, considering DER economics, power exchange, and load not supplied charges in both connected and islanded mode of operation. However, it did not include power loss or any technical loss into objective function. In [3], BESS optimal placement is performed using voltage to load sensitivity but did not perform battery sizing. In [4], BESS location is optimized using genetic algorithm, using power loss minimization as an objective function with high PV penetration without considering battery sizing. In [5], BESS placement problem is solved using loss sensitivity-based algorithm and BESS sizing using particle swarm optimization method considering only loss minimization. In [6], Cross-Entropy optimization method is used to optimally place the BESS and has considered optimization of only voltage stability index. In [7], an algorithm was proposed based on linearized multiperiod optimal power flow method for optimal sizing and placement of BESS, with focus on only economics of BESS. In [8], voltage rise problem, due to high PV penetration in radial system is addresses and bee-colony optimization is proposed to find optimal location and sizing of BESS without minimizing the power loss or any other objective. Ref. [9] has discussed optimal battery placement in PV based distribution grid using binary firefly algorithm for minimizing voltage deviation at PV distributed generator buses. [10] has proposed two step method for optimal placement and sizing of battery energy system using genetic algorithm.

The main objective of this work has been to find the optimal size and location of BESS in a practical low voltage AC semi-urban microgrid pilot, inside IITK campus, having distributed SPV installations on residences in two of its lanes. It is part of the field demonstration under joint Indo-US project 'UI-ASSIST', which has committed to demonstrate five pilots each by Indian and US consortia under urban, semi-urban and rural settings. While SPV sources in the semi-urban pilot are planned on rooftop of majority of the houses, the BESS is planned at centralized but multiple feasible locations. A multi-objective function optimization problem is formulated to minimize overall system power loss and voltage deviation at each node. DigSilent is used to run for evaluation under different operating scenarios. The results obtained are also validated on the real time simulation model implemented on RTDS.

2. Semi-Urban Distribution System

Optimal BESS placement and sizing is performed for the typical semi-urban microgrid system utilizing distribution network in two of the residential lanes having single storey houses inside IITK campus, forming a ring and fed from a common 11kV/415V substation. While main 415 V 3-ph 50 Hz AC feed to the various Feeder Pillars (FPs), as shown in Fig. 1, is through 3.5 core 240 mm2 ACSR conductor cable from substation, 1-phase 240 V AC 50 Hz, distribution from a FP to individual houses is through and 2 core 16 mm2 ACSR conductor cable. Typical 4 kW peak of time varying impedance load is assumed for each house. The microgrid distribution system comprises of two Sub Networks (SN) named as SN-1 & SN-2 connected to substation of 11 kV. A double pole isolator is provided at the FP_{1c} to continue the power supply in case of loss of supply in either subnetwork. The isolator remains open in normal operating conditions and load at FP_{1c} are included in SN-1, as shown in Fig. 1. Rooftop solar PV panels are planned to be installed at 25 residential houses, each with 5 kW peak power generation. BESS of total 100 kW capacity with 2 hours back up (200kWh capacity) is planned to be installed for this distribution system. Total BESS capacity can be installed at one place or can be divided and installed at multiple feasible locations to support local residential loads in case of power outage or peak demand. The surplus power from SPV and BESS is planned to be fed into the main grid. The incoming feeds to the microgrid are provided with smart meters to carry out base case load profiling.

3. Problem Formulation

3.1. Mathematical Formulation

The optimal sizing and siting of the BESS is obtained by solving the following optimization problem that minimizes the normalized value of the total real power loss and voltage deviation.

$$Min.f = w_{loss} * \frac{TPL}{TPL_{max}} + \sum_{i=1}^{n} \left(w_{dv} \left| \frac{V_i}{V_{max}} - 1 \right| \right) \tag{1}$$

Subject to:

$$V_{min} \leq V_i \leq V_{max} \tag{2}$$

$$0 \leq P_{pv} \leq P_{pvmax} \tag{3}$$

$$P_{chg} \leq P_{batt} \leq P_{battmax} \tag{4}$$

Were, TPL = Total real power loss of system, V_i = voltage at node i. w_{loss} = weight for total power loss, w_{dV} = weight for voltage deviation, TPL_{max} = maximum value of total power loss, and V_{max} = maximum allowed voltage, P_{pv}, P_{pvmax} = power generated by PV and rated power of PV panel, P_{chg} is the charging power, P_{batt} is actual battery power and $P_{battmax}$ is the maximum power supplied by battery.

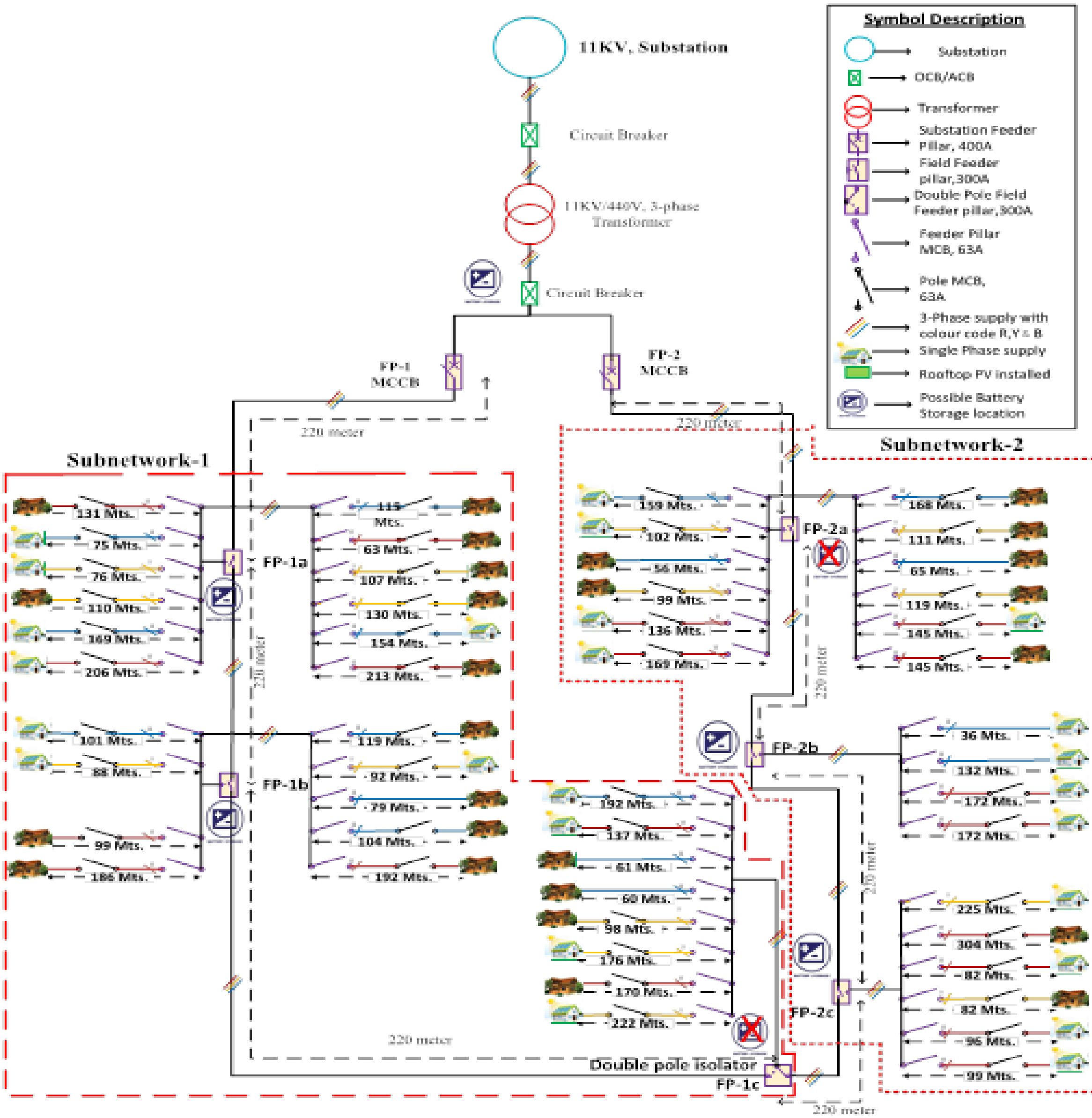

Fig. 1: Semi-urban AC microgrid distribution system at IIT Kanpur campus

To solve the above problem, an analytical method is used. Weights are selected in such a way that it is not dominated by single objective. Electrical constraints such as upper and lower voltage limits, power flow limits, etc., were also considered through the load flow analysis of the distribution system. The method involves three steps. The first step is used for generation of all possible scenarios including constraints, the second step involves execution of power flow algorithm for each test case, and finally to calculate the objective function *f* given in (1).

3.2. Scenario Generation for Test system

In the semi-urban microgrid pilot considered, different possible BESSs locations such as near FP, residential houses or at substation are identified and also shown in Fig. 1. Both physical and technical constraints are considered while generating the different possibilities of BESS placement. Required land area for BESS installation, clearance for safety, and proximity to FP are considered as physical constraints, whereas minimum distance to Point Of Connection (POC) from BESS, and POC availability are considered as a technical constraints while shortlisting the test cases. The minimum distance between POC and BESS is selected to reduce the voltage drop caused by the impedance of the connecting cable. After considering the above technical and physical constraints, overall 5 locations are identified where BESS can be installed and other locations are cross-marked, as shown in Fig. 1. All possible and worst case operating scenarios, as given below, are assumed to select the optimal location and sizing of battery.

1) Battery combination with PV generation.
2) Battery combination with PV generation and fault in one of the cable connecting FP (FP_1 or FP_2) and substation.
3) Battery combination with no PV generation either due to bad weather or night condition.
4) Battery combination with no PV generation either due to bad weather or night condition with fault.

Four operating conditions, 25 possible battery locations, and 7 different size ratios of BESS capacity add up to the generation of many possible scenarios to be considered to determine the optimal BESS placement and sizing. Initially the above mentioned test cases are simulated for the equal battery sizing i.e., 100% battery capacity is divided into two and four parts and placed at different locations. Power flow algorithm is executed to get total power losses and voltages at each node for each of the operating conditions. Accordingly, the results from power flow are used to find the value of objective function (1). After identifying the possible optimal placements, the problem is narrowed down to find the optimum battery size. For this, the test scenarios are generated for unequal distribution of BESS capacity and executed only for optimum locations. To choose the battery chemistry various types of Li-ion batteries were compared based on various parameters such as energy density, safety margins, and power density. Accordingly, Li Ferrous Phosphate (LiFePO4) chemistry was chosen for BESS.

Table 1: Power flow and objective function value for case-1, 2, 3 and 4

Sl. No.	Placement Scenario	Case-1		Case-2		Case-3		Case-4	
		TPL (kW)	Obj. fun.	TPL (kW)	Obj. fun.	TPL (kW)	Obj. fun.	TPL (kW)	Obj. fun.
1	B at FP_{1a}	4.80	0.2700	9.09	0.4188	5.95	0.4088	17.45	0.6508
2	B at FP_{1b}	5.85	0.3090	9.28	0.3805	6.29	0.4173	14.21	0.5394
3	B at FP_{2c}	8.46	0.4673	10.90	0.4366	7.53	0.4630	11.43	0.4113
4	B at FP_{2b}	6.91	0.3863	11.56	0.4532	6.64	0.4255	10.95	0.3785
5	0.5B at FP_{1b} & FP_{2c}	5.13	0.2782	8.96	0.3511	5.41	0.3603	12.42	0.4839
6	0.5B at FP_{1b} & FP_{2b}	4.76	0.2568	8.88	0.3391	5.25	0.3561	11.65	0.4562
7	0.5B at FP_{1a} & FP_{1b}	4.71	0.2634	8.68	0.3907	5.42	0.3714	15.88	0.6062
8	0.5B at FP_{1a} & FP_{2b}	4.67	0.2573	8.53	0.3461	4.99	0.3428	12.67	0.4983
9	0.5B at FP_{1a} & FP_{2c}	5.04	0.2787	8.62	0.3591	5.15	0.3464	13.47	0.5256
10	0.5B at FP_{2c} & FP_{2b}	6.75	0.379	10.01	0.3848	6.32	0.3979	11.09	0.4132
11	0.25B at FP_{1a}, FP_{1b}, FP_{2c}, FP_{1b}	4.59	0.2522	8.58	0.3429	4.87	0.6793	12.35	0.4877
12	B at Substation	4.55	0.2801	9.88	0.5046	6.09	0.4313	22.59	0.8168

4. Results & Discussion

Individual test cases are simulated on the DigSilent for various battery capacity combination and locations to find the optimal placement and sizing of BESS. Typical summer day time solar profile is considered for this study. Value of weight factors for power loss and voltage deviation are assumed as w_{loss} = 0.4 and w_{dV} = 0.6. In this paper the 100%

BESS capacity i.e., 100 kW, 200 kWh is represented as B. Therefore, 0.5B, 0.6, 0.7B, etc. refers to 50 kW, 100 kWh, 60 kW, 120 kWh and 70 kW, 140 kWh, respectively

4.1. Optimal Placement

1) Case 1: In this case, PV is generating power and there is no fault in system. The power is supplied from substation to load via FP_1 and FP_2. For this normal operating condition, various scenarios of BESS placement are simulated using DigSilent and results are presented in Table 1. From the results, it is observed that scenario 11 is the most optimal placement due to the minimum value of the objective function. The optimal battery sizing and placement are found by dividing the total capacity of BESS in equal parts and installed at various locations in the distribution network. The locations identified are FP_{1a}, FP_{1b}, FP_{2c}, and FP_{2b} each of 25 kW (50 kWh). The solution is not economically viable due to higher capital cost of installation. Further, safety is also the major concern in residential areas. Therefore, the aim is to identify either one or two optimal locations. 2.1. Header, Footer, Page Numbering
2) Case 2: In this case, solar PV is generating power and there is a fault in a cable connecting substation and FP_{2a}. As a result, the loads connected to the FP_{2a} are not energized. A double pole isolator connected at FP_{1c} is activated to energized the network via FP1a. Similar test cases are executed using the load flow algorithm and determine the objective function value for each case as shown in Table 1. It is observed in Table 1 that the placement scenario 6 is having minimum objective function value. Hence FP_{2b}, FP_{1b}, with 50 kW (100 kWh) each during fault, is the optimal placement for this case.
3) Case 3: For this case, it is assumed that the PV is not generating power. This may be due to bad weather, unclear sky condition, or night time. The microgrid is connected with the utility and is in healthy state. As a result, both FP_{1a} and FP_{2a} are supplying power to their respective areas. Similar test scenarios are simulated in DigSilent to estimate the value of objective function f and is shown in Table 1. From this table, the minimum objective function value is observed for placement scenario 8 where 50 kW (100 kWh) BESS is assumed to be connected at both FP_{1a} and FP_{2b}.

Table 2: Objective function for optimal sizing

Cases	Sl. No.	Placement Scenarios	FP_{1a} V (pu)	FP_{1b} V (pu)	FP_{2c} V (pu)	FP_{2b} V (pu)	FP_{2c} V (pu)	Total Power Losses	Objective function
Case-1	1	0.6 B at FP_{1b}, 0.4 B at FP_{2b}	0.981	0.983	0.997	0.996	0.99	4.70	0.4708
	2	0.7 B at FP_{1b}, 0.3 B at FP_{2b}	0.983	0.986	0.994	0.993	0.988	4.80	0.4818
	3	0.5 B at FP_{1b}, & FP_{2b}	0.979	0.979	1.001	0.999	0.991	4.76	0.4763
	4	0.4 B at FP_{1b}, 0.6 B at FP_{2b}	0.977	0.975	1.004	1.003	0.993	4.95	0.4987
	5	0.3 B at FP_{1b}, 0.7 B at FP_{2b}	0.975	0.971	1.007	1.006	0.994	5.29	0.5362
Case-2	1	0.6 B at FP_{1b}, 0.4 B at FP_{2b}	0.982	0.985	0.989	0.990	0.986	8.72	0.4918
	2	0.7 B at FP_{1b}, 0.3 B at FP_{2b}	0.982	0.985	0.985	0.984	0.98	8.69	0.4985
	3	0.5 B at FP_{1b}, & FP_{2b}	0.982	0.985	0.992	0.996	0.992	8.88	0.4925
	4	0.4 B at FP_{1b}, 0.6 B at FP_{2b}	0.982	0.985	0.996	1.001	0.997	9.15	0.5005
	5	0.3 B at FP_{1b}, 0.7 B at FP_{2b}	0.982	0.985	1.000	1.006	1.003	9.53	0.5208
Case-3	1	0.6 B at FP_{1b}, 0.4 B at FP_{2b}	0.979	0.979	1.001	0.999	0.991	5.48	0.4940
	2	0.7 B at FP_{1b}, 0.3 B at FP_{2b}	0.979	0.979	1.001	0.999	0.991	5.51	0.4966
	3	0.5 B at FP_{1b}, & FP_{2b}	0.975	0.973	0.971	0.976	0.979	5.59	0.5413
	4	0.4 B at FP_{1b}, 0.6 B at FP_{2b}	0.979	0.979	1.001	0.999	0.991	5.86	0.5264
	5	0.3 B at FP_{1b}, 0.7 B at FP_{2b}	0.979	0.979	1.001	0.999	0.991	5.77	0.5187
Case-4	1	0.6 B at FP_{1b}, 0.4 B at FP_{2b}	0.959	0.941	0.905	0.893	0.882	12.16	0.6924
	2	0.7 B at FP_{1b}, 0.3 B at FP_{2b}	0.959	0.941	0.900	0.886	0.874	12.84	0.7294
	3	0.5 B at FP_{1b}, & FP_{2b}	0.960	0.942	0.909	0.900	0.889	11.65	0.6619
	4	0.4 B at FP_{1b}, 0.6 B at FP_{2b}	0.960	0.942	0.907	0.907	0.895	11.30	0.6426
	5	0.3 B at FP_{1b}, 0.7 B at FP_{2b}	0.960	0.942	0.918	0.913	0.902	11.11	0.6227

4) Case 4: This case is the worst of all the operating conditions considered. There is no generation from solar PV and there is a fault in the distribution network connecting the substation and FP_{1a}. As a result, the double pole isolator switch is activated and therefore all loads are energized through FP_{1a}. Power flow algorithm is performed for the selected test scenarios and results are presented in Table 1. From this table, it is observed that the minimum objective function value occurs at placement scenario 4 where 100 kW (200 kWh) BESS is assumed to be installed at FP_{2b}.

From the results it can be seen that there is no clear indication of placement. BESS installation location are keeps on changing with the operating condition. It is also observed that location at FP_{2b} appear as the optimum location in most of the cases. Also, FP_{1b} and FP_{1a} are identified as the second option for battery placing. To select among FP_{1b} and FP_{1a} locations, physical constrains i.e., required footprint and safety margins are also considered. It is found that FP_{1a} is nearer to residential area as compared to FP_{1b}. Also, sufficient land area required for battery installation is available near FP_{1b} as compared to FP_{1a}. From safety view point, FP_{1a} is relatively less safe for residents than FP_{1b} due to its close proximity to houses. Therefore, FP_{1b} is selected as the other location for placement. Hence, FP_{2b} and FP_{1b} are selected as an optimal placement of BESS for this system.

4.2. Optimal Sizing

Once the optimal places for the BESS placements are decided at the two locations, possible combinations of BESS capacity (B_1 : B_2) considered for study are 1) 60 kW at FP_{1b} and 40 kW at FP_{2b}, 2) 70 kW at FP_{1b}, 30 kW at FP_{2b}, 3) 50 kW at FP_{1b}, 50 kW at FP_{2b}, 4) 40 kW at FP_{1b}, 60 kW at FP_{2b}, and 5) 30 kW at FP_{1b}, 70 kW at FP_{2b} (with kWh rating twice the kVA rating in all cases).

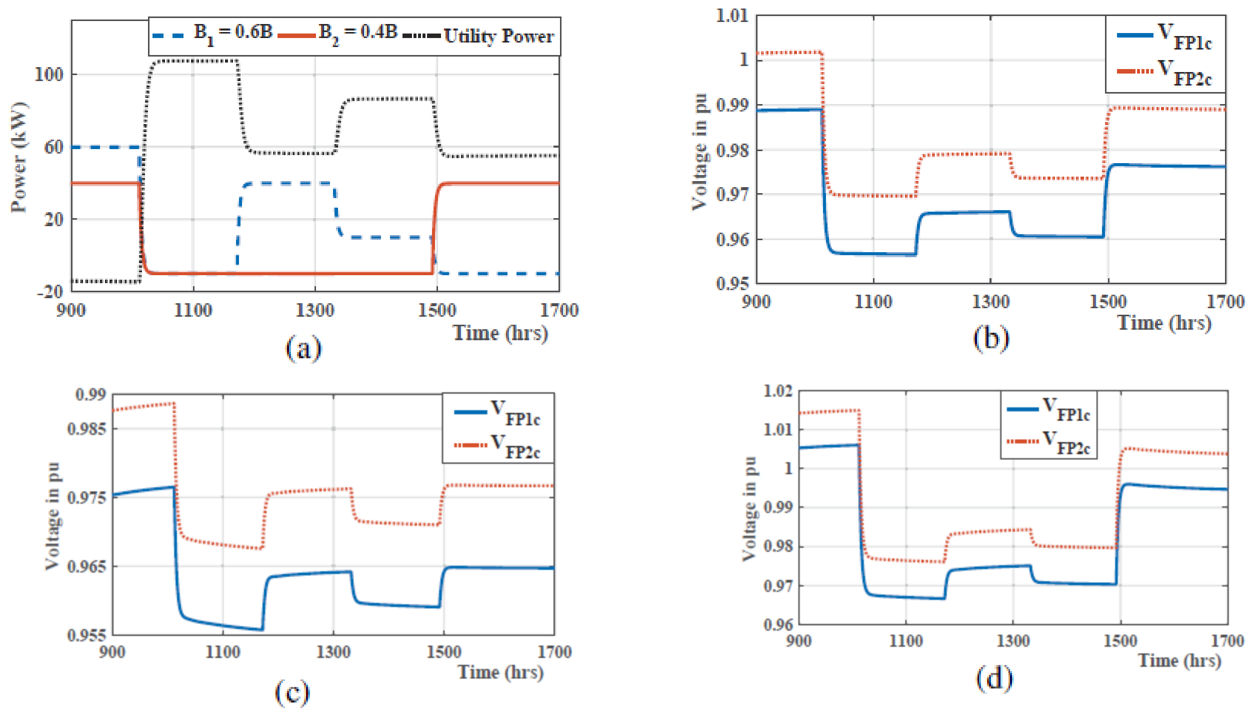

Fig. 2: (a) Time varying BESS and utility power (b) B_1 at FP_{1a}, B_2 at FP_{2a}, (c) B_1 at FP_{1a}, B_2 at FP_{1b}, (d) B_1 at FP_{1b}, B_2 at FP_{2b}.

Power flow algorithm was executed for all the test scenarios using DigSilent. Results obtained have been utilized to calculate objective function value, as shown in Table 2. It is observed also observed that B_1 60 kW (120 kWh) at FP_{1b} and B_2 of 40 kW (80 kWh) at FP_{2b} are the optimal sizes for maximum number of cases.

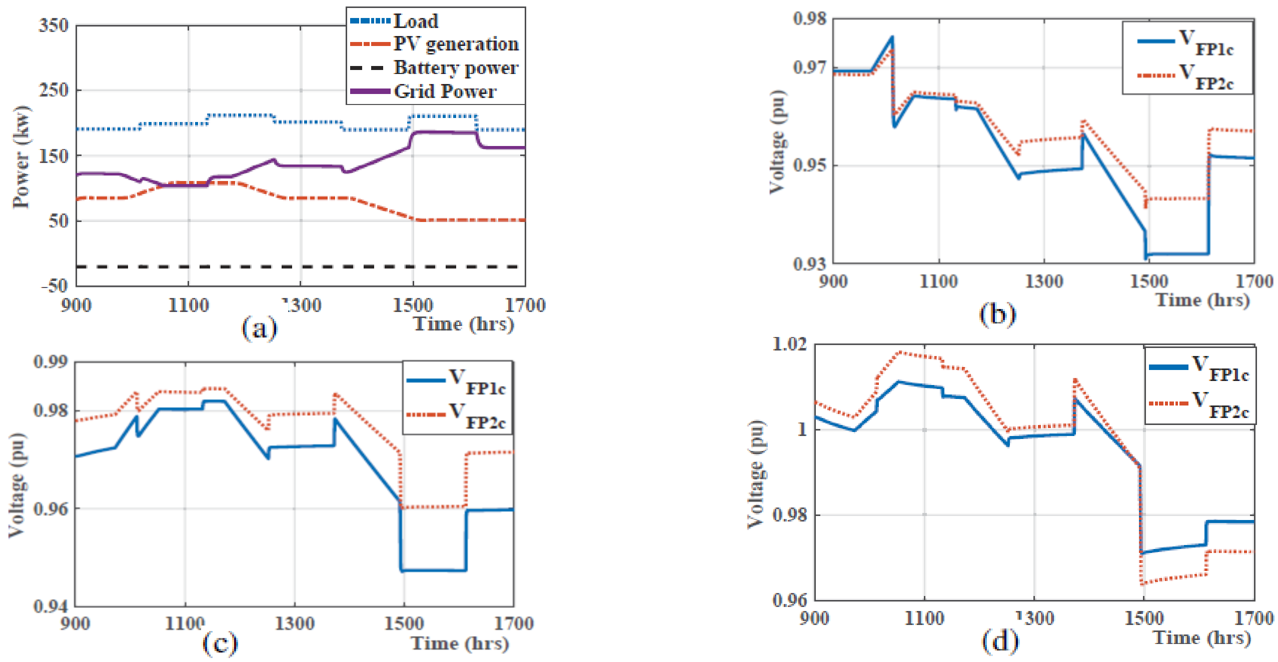

Fig. 3: (a) Time varying load, and solar irradiation, (b) B_1 at FP_{1a}, B_2 at FP_{2a}, (c) B_1 at FP_{1a}, B_2 at FP_{1b}, (d) B_1 at FP_{1b} B_2 at FP_{2b}.

4.3. Real-Time Simulation

The aforementioned placement and sizing of the BESS is based on extreme operating conditions where the load is maximum, battery is discharging and solar irradiation is maximum. To further validate the result of the optimal BESS sizing and placement, various tests are conducted on the Real Time Digital Simulator (RTDS) [11]. A 5 kW peak rooftop solar PV along with a single phase converter and its controller is implemented for each house. The cables are simulated using physical data in Bergeron model. The power system and controller components are simulated with large time step of 50 µs whereas the power electronics with small time step of 2 µs. In this study two batteries B_1 and B_2 60kW, 120 kWh and 40kW, 80KWh, respectively, are assumed and considered to be connected at different locations.

1) Variation in BESS: In this test setup the effect of battery charging (represented as -ve power) and discharging on the voltage at node FP_{1c} and FP_{2c} is observed. It is noted that when the BESSs B_1 and B_2 are connected at locations FP_{1a} and FP_{2a}, respectively, the voltage at node FP_{2c} is reached below 0.96 pu when the battery is charging, as shown in Fig. 2b. The overall voltage profile is relatively better for optimal location irrespective of BESS is charging or dis charging.
2) Load Variation: In this study the BESS at different locations are assumed to be absorbing constant power whereas load and solar irradiation are varying with time. The surplus or deficit power is taken care by the grid, as shown in Fig 3a. The minimum deviation in voltages are observed at node FP_{1c} and FP_{2c} when BESSs are placed at their idetified optimal location, as shown in Fig. 3d. Other general observations, which are drawn from Fig. 2 and 3 are as follows:

- If both th BESSs are placed in SN-1, then the voltage profile of the that network improves, as shown in Fig. 2c and 3c.
- Generation is more in SN-2 whereas SN-1 has more load, as shown in Fig. 1 which results in improved voltage profile of SN-2, as shown in Fig. 2(b to d) and 3(b & d).
- In general BESS is provided for each subnetwork to ensure independent backup supply in case of grid failure. The two networks can be connected via double pole isolator switch for load-generation balance.
- The resultant BESS sizing is turn out such that higher kVA rating is connected in SN-1 with higher load. The ratio of BESS ratings B_1 approximately can be equivalent to the ratio of load at SN-1 and SN-2.

5. Conclusion

In this paper an optimal placement and sizing of BESS for a practical semi-urban microgrid pilot inside IIT Kanpur campus has been presented using multiple objective functions to minimize the total power loss and voltage deviation at node. Apart from technical constraints, implementation constraints such as accessibility of Point Of Connection (POC), proximity from BESS, and the availability of sufficient land area were also considered. The resultant location and BESS are validated using the simulation model of the microgrid system implemented on RTDS. Voltage profile were observed under various operating conditions such as BESS charging-discharging, time varying load, and solar irradiation. It is observed that the system voltage profile improves for the suggested BESS placement and sizing. The optimal BESS placement can provide a backup to subnetwork independently. Also, the ratios of two BESS power ratings are approximately equal to the load in its respective network and is independent of the PV-penetration level. In high-renewable penetrated distribution networks, the inverters can also support voltage regulation which is not considered in present work and is being taken up as future work.

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References

[1] 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," in *2015 IEEE Power Energy Society General Meeting*, 2015.

[2] F. Tooryan, E. R. Collins, A. Ahmadi, and S. S. Rangarajan, "Distributed generators optimal sizing and placement in a microgrid using pso," in *2017 IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA)*, 2017, pp. 614–619.

[3] S. Shafiq, B. Khan, and A. T. Al-Awami, "Optimal battery placement in distribution network using voltage sensitivity approach," in *2019 IEEE Power and Energy Conference at Illinois (PECI)*, 2019, pp. 1–4.

[4] A. Alzahrani, H. Alharthi, and M. Khalid, "Optimal battery energy storage placement in highly pv - penetrated distribution networks," in *2020 IEEE Power Energy Society Innovative Smart Grid Technologies Conference (ISGT)*, 2020, pp. 1–5.

[5] S. B. Karanki and D. Xu, "Optimal capacity and placement of battery energy storage systems for integrating renewable energy sources in distribution system," in *2016 National Power Systems Conference (NPSC)*, 2016, pp. 1–6.

[6] Y. Zhu, C. Liu, R. Dai, G. Liu, and Y. Xu, "Optimal battery energy storage placement for transient voltage stability enhancement," in *2019 IEEE Power Energy Society General Meeting (PESGM)*, 2019, pp. 1–5.

[7] P. Fortenbacher, M. Zellner, and G. Andersson, "Optimal sizing and placement of distributed storage in low voltage networks," in *2016 Power Systems Computation Conference (PSCC)*, 2016, pp. 1–7.

[8] T. Chaiyatham and I. Ngamroo, "Bee colony optimization of battery capacity and placement for mitigation of voltage rise by p v in radial distribution network," in *2012 10th International Power Energy Conference (IPEC)*, 2012, pp. 13–18.

[9] W. L. Ai, H. Shareef, A. A. Ibrahim, and A. Mohamed, "Optimal battery placement in photovoltaic based distributed generation using binary firefly algorithm for voltage rise mitigation," in *2014 IEEE International Conference on Power and Energy (PECon)*, 2014, pp. 155–158.

[10] S. Salee and P. Wirasanti, "Optimal siting and sizing of battery energy storage systems for grid-supporting in electrical distribution network," in *2018 International ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunications Engineering (ECTI-NCON)*, 2018, pp. 100–105.

[11] P. McLaren, R. Kuffel, R. P. Wierckx, J. Giesbrecht, and L. Arendt, "A real time digital simulator for testing relays," *IEEE Trans. Power Del.*, vol. 1, no. 1, pp. 207–213, Jan 1992.