Journal of Engineering Science and Technology
Vol. 15, No. 2 (2020) 778 - 791
© School of Engineering, Taylor's University

DETERMINATION OF OPTIMAL SIZING MODEL FOR BATTERY ENERGY STORAGE SYSTEM IN GRID CONNECTED MICROGRID

PRAKRUTI SHAH[1], BHINAL MEHTA[2]

[1]Department of Electrical Engineering, Navrachana University, Vadodara, India
[2]Department of Electrical Engineering, Pandit Deendayal Petroleum University, Gandhinagar, India
*Corresponding Author: bhinal.mehta@gmail.com.

Abstract

In recent decades, Battery Energy Storage Systems (BESS) has played a significant role in the microgrid. Optimally sized installed BESS offers a cost-effective microgrid operation. This paper proposes the optimal BESS sizing model, which reduces the overall operating cost of the microgrid. The oversized BESS requires more investment cost and it increases the overall cost of microgrid while the undersized BESS may not provide flexibility, reliability and economic benefit in the microgrid. The results showcase the cost-effectiveness of optimally sized BESS in the microgrid. Dynamic Programming (DP) approach is used to formulate the optimal sizing problem. Numerical simulation has been done by MATLAB to express the effectiveness of the proposed optimal sizing model**.**

Keywords: Battery storage system (BESS), Distributed energy resources (DER), Microgrid, Main grid, Renewable generation.

1. Introduction

The major obstacle of the microgrid is its high investment cost. Initially, microgrid was introduced to operate and control the local distributed energy resources (DERs) and local renewable resources, which offers the reliability and economic benefit to consumers [1]. The precise assessment of the economic benefit of the microgrid is a tough job due to the involvement of uncertain data in assessment. Thus, planning of an accurate model of the microgrid is required to ensure the economic feasibility and justify the investment cost. Battery energy storage sources (BESS) plays a major role in the operation of the microgrid. The response of BESS is fast with control flexibility, which provides economic benefit and security to the microgrid. The major problem in a microgrid is the intermittent nature of renewable resources; BESS can manage the quick power variation of renewable resources. BESS provides economic benefits in microgrid by charging at the time of low electricity price and discharging at high electricity price. The optimal sized and precisely modelled BESS prevent it is over and underutilization [2, 3].

The optimal sizing of BESS is required as undersized of BESS will not offer economic benefit and flexibility of generation in the microgrid. The oversized BESS will increase investment cost in microgrid [4]. Khodaei [5] the model of BESS is based on a predefined profile of charging and discharging. Mitra [6] proposed the approach to find the optimal size of back up storage in the form of fuel or electricity taking into consideration with reliability constraint. Lee and Chen [7] proposed the optimal sizing of contract capacities and BESS for industrial consumer based on time of use rates. Wang et al. [8] and Venu et al. [9] described the optimal sizing BESS in coordination with renewable sources like solar and wind. Le and Nguyen [10] proposed the BESS optimal sizing in microgrid containing wind farm is proposed by an analytical approach with maximum profit. The renewable sources generally produce volatile output power and huge generation intermittency is there in the microgrid. Various methods are analysed to mitigate it by Gouveia et al. [11]. To fully utilize the resources two or more microgrid is connected when main grid connectivity is lost, which is known as microgrid cluster. The concept of a cluster of microgrid and provisional microgrid is also discussed by Boroojeni et al. [12] and Khodaei [13].

Provisional microgrid facilitates the integration of the renewable source, but for the economical and reliable operation, it requires additional control mechanism and investments. The microgrid operation cost can be reduced by optimally using the local DER units, renewable unit, controllable loads and Battery energy storage resources [14]. For the frequency regulation and power quality aspects the best suitable BESS are in which, have a quality of fast response, and high-power density. The battery storage technologies, which have long discharge time and high energy density are more suitable for peak saving and long-term use [15]. The operating cost decreases and the investment cost is linearly increased, by increasing the size of BESS. Optimal sizing of battery energy storage in a grid-connected microgrid with the objective of minimizing overall operating costs discussed by Bahramirad and Daneshi [16], Bahramirad et al. [17]. Yuan and Sun [18] discussed the hybrid energy storage system design consists of a supercapacitor and BESS. Figure 1 represents the outline of BESS optimal sizing regarding operation cost, planning cost and investment cost [19]. As the size of BESS increases the cost of investment linearly increases while operating cost decreases.

Mahesh et al. [20] the optimal size of BESS to mitigate the output power variations in wind, solar and hybrid renewable system including climate change condition is discussed. Liu et al. [21] discussed the optimal sizing of BESS planning model in distribution system considering reliability enhancement. Jing et al. [22] explained how the particle swarm optimization is used to obtain optimal sizing of BESS for the small island microgrid. Micro pumped storage is suggested as a BESS. The optimal size of BESS by cost-based criteria in a microgrid is explained, to reduce the cost of dispatch a new technique bat algorithm is proposed for grid-connected microgrid [23]. The role of BESS in the standalone microgrid to reduce the overall cost and enhance reliability is explained. The BESS investment cost, operating cost and charging/ discharging schedule related to BESS lifetime is discussed by Alsaidan et al. [24].

The main objective of this paper is to propose the optimal sizing of BESS in grid-connected microgrid considering the economic aspects along with the flexibility of generation in microgrid and reliability. The proposed paper is prepared as follows: Section 2 explains the problem description of the sizing of BESS with its optimal sizing, by fulfilment of objective reduction of microgrid operating cost. Section 3 is about problem formulation and the storage system modelling, while Section 4 proposed the numerical simulation with a test data system to validate the proposed model in Microgrid. Section 5 discusses the results and Section 6 conclude the paper.

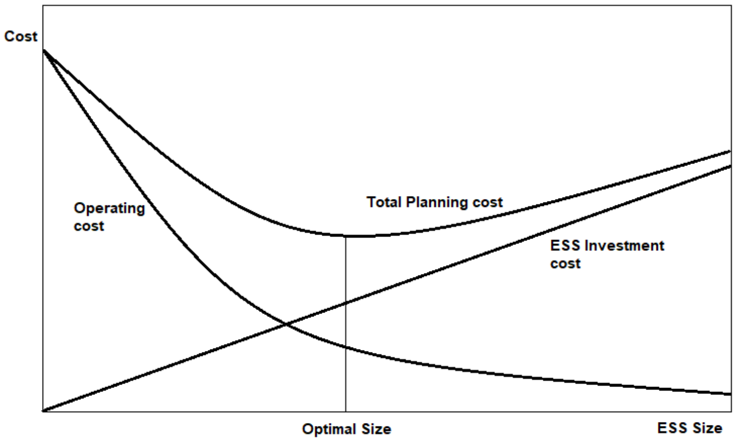

Fig. 1. Optimal sizing of BESS (cost vs. BESS size) [19].

2. Problem Outline

Size of BESS - The cost of BESS depends on its size, means the energy rating and power rating. If the BESS is oversized it will increase the investment cost while the undersized BESS will not provide desired flexibility and benefits. As per Fig. 1 total cost of the microgrid is lowest when the size of the BESS is optimal.

The main objective of the paper is to minimize the operating cost of a microgrid by using optimally sized BESS. The total operating cost of microgrid comprises the generation cost of DER units and the cost of power purchased from the main grid. The projected objective in the paper decides the size of BESS, which will provide economical and reliable benefit to the microgrid, for long term planning it is a decision tool to provide information. A novel simulation method based on dynamic programming to calculate the optimal size of BESS and microgrid operating cost is proposed.

3. Problem Formulations

To minimize the microgrid total operating cost and BESS investment cost for annually is proposed in Eq. (1). The optimal sizing of BESS for one year is proposed. The BESS investment cost presented by Eq. (2) includes the investment cost of energy rating and investment cost of power rating.

The predictable and unpredictable operating and maintenance costs are included in investment cost for power rating. The cost is equally distributed throughout the year; due to this the operating cost of BESS would be zero.

The operating cost is shown in Eq. (3) includes fuel cost of DERs power generation inside the microgrid, unit start-up and shut down cost, the cost of the power transfer through the main grid (imported or exported) in the microgrid.

$$MinBIC + MOC(1) \qquad (1)$$

$$BIC = BICP_B P_B^R + BIC\ E_B\ E_B^{max} \qquad (2)$$

$$MOC = \sum_{t=1}^{NT} \sum_{h=1}^{NH} \sum_{i=1}^{ND} [F_i(P_{out\ ith}) DGU_{ith} + SUC_{ith} + SUD_{ith}] + \sum_{t=1}^{NT} \sum_{h=1}^{NH} \rho_{th} P_{M,th} \qquad (3)$$

3.1. Microgrid constraints

The constraint for microgrid includes power transfer limit from the main grid to the microgrid, which is depicted in Eq. (4), the limit for load curtailment is expressed in Eq. (5), and equality constraint of power balance is shown in Eq. (6).

The power transfer from the main grid to microgrid is limited based on transmission line capacity and on the contingency state of the line. The load curtailment is dependent on microgrid hourly load and the load curtailment is always lesser than the load demand as shown in Eq. (5).

The equality constraints ensure that the total generation including DER local units, renewable sources, BESS generation (in discharging mode) and the power transfer from the main grid to microgrid should satisfy the total microgrid load. If the supply from microgrid DER unit generation and power transfer from the main grid are not sufficient to supply the demand than load shedding parameter is added in Eq. (6).

When the BESS is discharging, the power P_{Bth} is positive (acts like a generator) and when the BESS is charging, the power P_{Bth} is negative (acts like a load). When no power transfer from BESS it is idle mode P_{Bth} is zero.

Same way when the main grid power P_{Mth} transferred from the main grid to microgrid, it is positive and when exported from microgrid to main grid it is negative. When microgrid is working in islanding mode the power P_{Mth} is zero Eq. (6).

$$|P_{M,th}| \leq P_M^{max} UL_{M,th} \tag{4}$$

$$0 \leq LC_{th} \leq P_{LD,th} \tag{5}$$

$$\sum_{i=1}^{ND} P_{outith}\, DGU_{ith} + \sum_{i=1}^{NR} P_{rth} + P_{B,th} + P_{M,th} + LC_{th} P_{LD,th} \tag{6}$$

3.2. Unit constraints

The generation of a unit should be within its upper and lower limits as per inequality constraint shown in Eq. (7). The availability of the unit is based on the contingency state of the unit. When the contingency state of the unit is zero, the output of generation will be zero. This is the situation when the unit is not committed. In Eqs. (8) and (9) the limits of ramping up ramping down are given respectively. For the given generating unit Eqs. (10) and (11) define the minimum up and minimum downtime respectively.

$$P_{outi}^{min} DGU_{ith} UC_{ith} \leq P_{outith} \leq P_{outi}^{max} DGU_{ith} UC_{ith} \tag{7}$$

$$P_{outith} - P_{outit(h-1)} \leq RU_i(1 - SU_{ith}) + P_{outi}^{min} SU_{ith} \tag{8}$$

$$P_{outit(h-1)} - P_{outith} \leq DU_i(1 - SD_{ith}) + P_{outi}^{min} SD_{ith} \tag{9}$$

The generator cannot be switched off after switched on for a lesser hour of the time based on its up-time limit. The same way the unit cannot be turned on after once it is switched off for a lesser hour of time than the minimum downtime limit. Above constraints are explained based on start-up (SU) and shut down indication (SD) respectively. On the basis of unit constraint, the value of SU and SD are derived from Eqs. (12) and (13). When the unit is on, the value of SU is 1 otherwise zero, and while the unit is off the value of SD is 1 otherwise zero.

$$\sum_{x=h}^{h+TUi-1} DGU_{ith} \geq TU_i SU_{ith} \tag{10}$$

$$\sum_{x=h}^{h+TDi-1} (1 - DGU_{ith}) \tag{11}$$

$$SU_{ith} - SD_{ith} = DGU_{ith} - DGU_{it(h-1)} (12) \tag{12}$$

$$SU_{ith} + SD_{ith} \leq 1 \tag{13}$$

3.3. BESS constraints

The model of BESS is defined below by Eqs. (14) to (19). The operation modes of BESS are charging, discharging and idle mode. Equation (14) explains the maximum permissible limit of BESS rated power.

The State of Charge (SOC) of BESS is defined by Eq. (15). State of charge is defined as the addition of SOC at a previous time (hour) and the stored energy at the current time (hour). The time interval is taken of 1-hour duration for day-ahead unit commitment.

BESS rated power performance-based regulation (PBR) is negative when BESS is in charging mode and PBR is positive when BESS is in discharging mode. When BESS is charging the SOC will reduce and when BESS is discharging the SOC will boost up. The problem of overcharging of BESS will be prevented by Eq. (16).

At the starting and end of the day, the value of the state of charge is calculated by Eqs. (17) and (18). The size of BESS is restricted based on the value of investment fund given by Eq. (19). In BESS minimum charging and minimum discharging time is also an important constraint. Undercharging mode of BESS, maintain mode ON for at least minimum charging time. Same way in discharging mode of BESS, maintain mode ON for at least minimum discharging time.

The charging nature of BESS mostly has a rectangular shape, when the charging process started as the charging command is given, it charges at a constant power level. The discharging profile of BESS mostly has a trapezoidal shape. From each discharge, the available amount of energy can be optimized by the trapezoidal profile. Based on the requirement of the customer the discharge profile can be defined by the manufacturer [19].

$$-P_B^R \leq P_{B,th} \leq xP_B^R \tag{14}$$

$$C_{th} = C_{t(h-1)} - P_{B,th}\Delta t \tag{15}$$

$$0 \leq C_{th} \leq C^{max} \tag{16}$$

$$C_{t1} \leq C^{start} \tag{17}$$

$$C_{th} = C^{end} \forall h = NH \tag{18}$$

$$MCP_B P_B^R + MCE_B E_B^{max} \leq CIF_B \tag{19}$$

4. Numerical Simulations

A battery energy optimal sizing of the microgrid is analysed in the proposed method. The microgrid model consists of four dispatchable units, two non-dispatchable units (renewable energy sources), five adjustable loads and one energy storage system.

The proposed method has been implemented using MATLAB. The values and characteristics of dispatchable and non-dispatchable units, adjustable loads and energy storage system are shown in Tables 1 and 2. In addition, storage device characteristics for Battery Energy Storage System (BESS) results are as follows: ESS (battery) power capacity: 10 MW, charging/discharging power limits (MW): 0.4-2.0 and minimum charging/discharging time: 5 hours.

For the 24-hour horizon, the hourly fixed load and non-dispatchable unit generation are forecasted and given in Tables 3 and 4. The market price for a 24-hour horizon is provided in Table 5. Based on input data the following cases have been carried out. Khodei [5] taken the input data. The total cost incurred on the incorporation of BESS has led to additional cost of energy and power investment of 21 \$/kWh/year and 40 \$/kW/year respectively.

Input data is shown in Table 1. Following four cases are considered:

Case 1 - Without BESS - Base case
Case 2 - With BESS
Case 3 - Optimal sizing of BESS
Case 4 - Oversized BESS

Table 1. Units generation characteristics.

Generation type	Unit number	Cost coefficient ($/MWh)	Minimum to maximum capacity (MW)	Minimum up/downtime (h)	Ramp-up/ down rate (MW/h)
D	G1	27.7	1.0-5.0	3	2.5
D	G2	39.1	1.0-5.0	3	2.5
D	G3	61.3	0.8-3.0	1	3
D	G4	65.6	0.8-3.0	1	3
ND	G5	0	0-1.0	-	-
ND	G6	0	0-1.5	-	-

(D: Dispatchable, ND: Non-Dispatchable)

Table 2. Characteristics of adjustable loads

Type of load	Load	Power capacity limits (MW)	Energy required (MWh)	Starting-ending time (h)	Minimum uptime (h)
S	L1	0.0 - 0.4	1.6	11 - 15	1
S	L2	0.0 - 0.4	1.6	15 - 19	1
S	L3	0.02 - 0.8	2.4	16 - 18	1
S	L4	0.02 - 0.8	2.4	14 - 22	1
C	L5	1.8 - 2.0	47	1 - 24	24

(S: Shiftable, C: Curtailable)

Table 3. Fixed load of microgrid (hourly).

Time (h)	Load (MW)	Time (h)	Load (MW)
\	8.73	13	13.92
2	8.54	14	15.27
3	8.47	15	15.36
4	9.03	16	15.69
5	8.79	17	16.13
6	8.81	18	16.14
7	10.12	19	15.56
8	10.93	20	15.51
9	11.19	21	14
10	11.78	22	13.03
11	12.08	23	9.82
12	12.13	24	9.45

Table 4. Non-dispatchable unit characteristics (hourly).

Time (h)	Generation of G5	Generation of G6	Time (h)	Generation of G5	Generation of G6
1	0	0	13	0.81	0.4
2	0	0	14	1.2	0.37
3	0	0	15	1.23	0
4	0	0	16	1.28	0
5	0	0.63	17	1	0.05
6	0	0.8	18	0.78	0.04
7	0	0.62	19	0.71	0
8	0	0.71	20	0.92	0
9	0	0.68	21	0	0.57
10	0	0.35	22	0	0.6
11	0	0.62	23	0	0
12	0.75	0.36	24	0	0

Table 5. Market price (hourly).

Time (h)	Market price ($/MWh)	Time (h)	Market price ($/MWh)
1	15.03	13	65.79
2	10.97	14	66.57
3	13.51	15	65.44
4	15.36	16	79.79
5	18.51	17	115.45
6	21.8	18	110.28
7	17.3	19	96.05
8	22.83	20	90.53
9	21.84	21	77.38
10	27.09	22	70.95
11	37.06	23	59.42
12	68.95	24	56.68

4.1. Case 1

In this case, BESS is not included. The cumulative cost of the microgrid is $4,238,951. The amount incurred on generation is $3,071,183 and the cost of power imported from the main grid is $1,177,909. At the times of surplus power generated in the microgrid, the power is sold back to the main grid, which generates the benefits worth $10,141. Generator 1 has been considered as the base unit for the24-hour horizon of operation. When the demand for electricity and market price both goes high and unit 1 generation is not sufficient then other units are also committed to the microgrid. Power is drawn back from the main grid when market prices go low. At higher prices, all the thermal units are put into operation and the surplus power produces is supplied to the main grid. All conventional units inside the microgrid are turned on to satisfy the load during the period of higher market prices and excessive generated power is sold back to the main grid.

4.2. Case 2

In this case, case 1 has been supplemented with 10 MWh BESS with a power capacity of 2 MW in the microgrid. The BESS charging and discharging period of 5 hours is considered. The cost incurred on generation and importing power is \$3,158,818 and \$ 1,043,321 respectively. The cost of power export to microgrid is \$303,287. By adding the BESS, the investment cost of BESS has been added, which is \$290,000.

The total cost of microgrid amounts to \$4,188,852. With respect to the base case, the total price is reduced by 1.18% in Case 2. Due to charged BESS, the export power to the main grid during high prize hours is increased. BESS has been charged during low market prize hours and discharged during high market prize hours. It increases the economic benefit to the microgrid. The discharge power of BESS is also used to satisfy the access load in the microgrid.

4.3. Case 3

This case suggests the optimal size of BESS for the microgrid. Using this proposal, the optimal size of BESS rated power of 3.4 MW at a capacity of 20.4 MWh is achieved through the numerical solution in the microgrid. The generation cost is \$3,166,903, the power import from main grid cost is \$1,061,387, the investment cost for BESS is \$564,400 and the cost of export power to the main grid is \$620,837.

The total operating cost incurred on the microgrid is \$4,171,853. The total cost reduction achieved is 1.58% compared to the base case. The export power to the main grid indicated the negative sign as it has been considered as a benefit for the microgrid.

4.4. Case 4

In this case the oversized 40 MWh BESS is added to the microgrid. Adding an oversized BESS, the total cost of generation is \$2,856,937 and power imports amount is \$1,569,362. The profit to the microgrid on account of selling power to the grid is \$1,178,926. Apart from this, the investment made to the BESS amounts to \$1,040,000. Thus, the total cost amount is \$4,287,373. With respect to the base case, the total price is increased by 1.18% in Case 4.

5. Result Analysis and Cost Comparison

Table 6 is a summary table of system costs and shows the comparison for all four cases i.e., Cases 1 to 4. To investigate further the impact of BESS size in the microgrid, the problem is solved for the different sizes of BESS. The tabulated cost in Figs. 2 to 4 represents the total cost of microgrid operation cost as a function of capacity and power of BESS.

The capacity of BESS is in the range of 1 to 10 times the rated power and the BESS rated power is in the variation of 1 to 5 MW, with a 1 MW step variation.

Table 6. Summary table of system costs.

Case	Case 1	Case 2	Case 3	Case 4
	No BESS	**BESS (2×5 = 10 MWh)**	**Optimum size BESS (3.4×6 = 20.4 MWh)**	**Oversized BESS (5×8 = 40 MWh)**
Cost of generation ($)	3,071,183	3,158,818	3,166,903	2,856,937
Import power ($)	1,177,909	1,043,321	1,061,387	1,569,362
Export power ($)	-10,141	-303,287	-620,837	-1,178,926
BESS investment cost ($)	0	290,000	564,400	1,040,000
Total cost of microgrid ($)	4,238,951	4,188,852	4,171,853	4,287,373
% Variation in total cost compare to case 1	-	1.18% reduction	1.58% reduction	1.14% increase
% Variation in total cost compare to case 1 [17]	-	0.34% reduction	0.72% reduction	-

Figure 2 shows the investment cost of BESS is linearly increased with the size of BESS. The X-axis depicts the number of hours, in which, the capacity of BESS reaches up to its maximum value.

In Fig. 3, the total microgrid operation cost includes the generation cost and main grid power transfer cost is reduced with the size of BESS. As the size of BESS is increased the investment cost is increased and operating cost is reduced due to increase of power export with the main grid during high peak hours and increase the power import during the off-peak hours. In the large size BESS (5 MW) the investment cost variation is much higher than a reduction in operating cost, so the overall cost of the microgrid is increased.

In Fig. 4, the total amount incurred on a microgrid, which takes, the investment cost of BESS and operating cost into consideration, as a function of the size of BESS is shown.

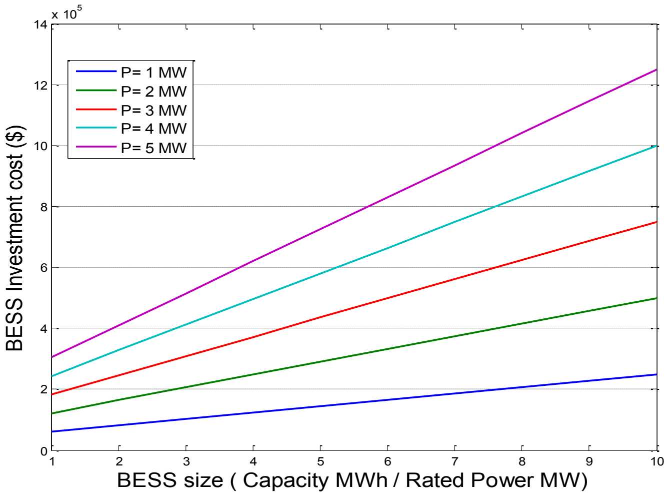

Fig. 2. Dependency of BESS investment cost on BESS size.

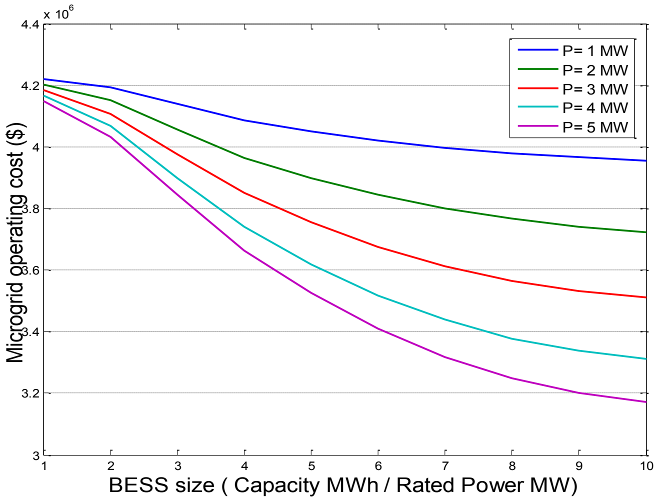

Fig. 3. Variation of microgrid operating cost with BESS.

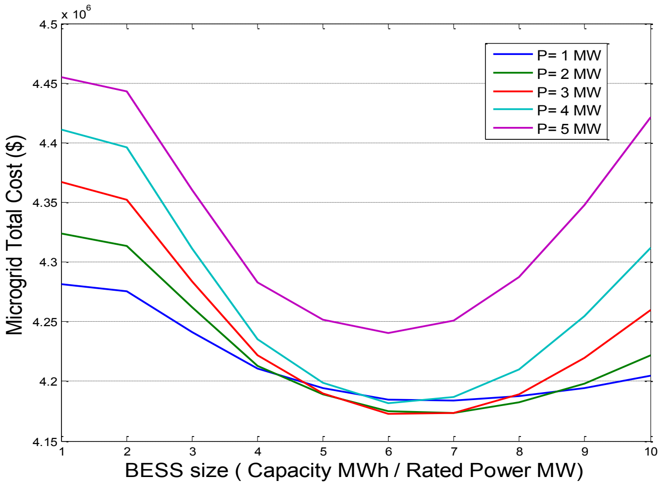

Fig. 4. Variation of microgrid cumulative cost with BESS.

The microgrid total cost is reduced by increasing the size of BESS; however, the larger size of BESS implies an increased cost of the microgrid. In the proposed model optimally sized BESS is installed, which reduce the total cost of the microgrid. According to Table 3, the total cost of a microgrid for optimal size of BESS is less compared to the total cost of a microgrid for undersized BESS (Case 1) as well as the total cost of a microgrid for oversized BESS (Case 4). The total cost of the microgrid is lowest when the installed BESS is optimally sized. The BESS offers power at low cost to local load in microgrid and reduces the power import from the main grid during high prize hours, which provide huge economic benefits to the microgrid. By charging at low prize hours and discharging at high prize hours, BESS reduce the total operating cost, reduce the load shedding, reduce the peak loading and increase the reliability of microgrid.

6. Conclusions

An accurate scheduling model with battery energy storage system optimal sizing for the grid-connected microgrid is proposed. The BESS investment cost, operating cost, which is the summation of generation cost and power transfer cost of the main grid has been considered. The undersized BESS will not provide reliability and oversized BESS will not provide the economic benefits. The results demonstrate that with the undersized BESS the cost reduction is 1.18% and with the oversized BESS the cost increment is 1.14%, while with optimal size BESS the cost reduction is 1.58%, which is lowest among all cases. The results indicate that under both the cases where BESS is undersized and oversized the total amount incurred on the microgrid is high, which does not provide economic benefits. There is one point where microgrid is operated at minimal cost and this optimal size of BESS should be installed in the microgrid.

Nomenclatures

BIC	Investment cost of BESS
C_{th}	BESS SOC, at hour *h* at day *t*
DGU_{ith}	Unit commitment state, *I* at hour *h* at day t
Fi	Cost of generation
H	Index for hour
I	Index for conventional DER unit
k	Depth of discharge
LC_{th}	Curtailment of load, at hour *h* at day *t*
MCE_B	Investment cost of BESS for energy rating
MCP_B	Investment cost of BESS for power rating
MOC	Operating cost of microgrid
ND	Generation units (conventional)
NH	Mount of hours
NR	Renewable generation units (unconventional)
NT	Amount of days
P	Market price
$P_{B,\ th}$	Generated power by BESS, at hour *h* at day *t*
P_M^{max}	Maximum power transfer limit from main grid to microgrid
$P_{M,\ th}$	Microgrid power transfer with main grid, at hour *h* at day *t*
$P_{outi,th}$	Output power of generation unit *I*, at hour *h* at day *t*
P_{outi}^{max}	Maximum power generation of unit, at hour *h* at day *t*
P_{outi}^{min}	Minimum power generation of unit *I*, at hour *h* at day *t*
P_B^R	BESS rated power
$P_{LD,\ th}$	Load demand in microgrid, at hour *h* at day *t*
RD	Rate ramp-down
RD_i	Limit for ramp-down rate for unit *i*
RU	Rate ramp-up
RU_i	Limit for ramp-up rate for unit *i*
r	Index for renewable unit
SD_{ith}	Indicator for starting down the unit, at *I* at hour h at day t
SU_{ith}	Indicator for starting up the unit, at *I* at hour *h* at day *t*
$UC_{\ M,th}$	Unit *I* contingency state, at hour *h* at day *t*

$UL_{M,th}$	Contingency state of line connected from main grid to microgrid, at hour *h* at day *t*
TD_i	Minimum downtime for unit *I*
TU_i	Minimum uptime for unit *I*
t	Index for day
Greek Symbols	
λ_{th}	Value of load lost, at hour *h* at day *t*
Abbreviations	
BESS	Battery Energy Storage System
DER	Distributed Energy Resources
DP	Dynamic programming

References

1. Shahidehpour, M. (2010). Role of smart microgrid in a perfect power system. *Proceedings of the IEEE Power Energy Soc*iety *General Meeting*. Providence, Rhode Island, United States of America.
2. Joseph, A.; and Shahidehpour, M. (2006). Battery storage systems in electric power systems. *Proceedings of the IEEE Power Engineering Soc*iety *General Meeting.* Montreal, Quebec, Canada.
3. Marwali, M.K.C.; Haili, M.; Shahidehpour, S.M.; and Abdul-Rahman, K.H. (1998). Short term generation scheduling in photovoltaic-utility grid with battery storage. *IEEE Transactions on Power Systems*, 13(3), 1057-1062.
4. Bahramirad, S.; and Daneshi, H. (2012). Optimal sizing of smart grid SMS™ storage management system in a microgrid. *Proceedings of the IEEE PES Innovative Smart Grid Technologies (ISGT).* Tianjin, China, 1-7.
5. Khodaei, A. (2014). Microgrid optimal scheduling with multi-period islanding constraints. *IEEE Transactions on Power Systems*, 29(3), 1383-1392.
6. Mitra, J. (2010). Reliability-based sizing of backup storage. *IEEE Transactions on Power Systems*, 25(2), 1198-1199.
7. Lee, T.-Y.; and Chen, N. (1995). Determination of optimal contract capacities and optimal sizes of battery energy storage systems for time-of-use rates industrial customers. *IEEE Transactions on Energy Conversion*, 10(3), 562-568.
8. Wang, X.Y.; Vilathgamuwa, D.M.; and Choi, S.S. (2008). Determination of battery storage capacity in energy buffer for wind farm. *IEEE Transactions on Energy Conversion*, 23(3), 868-878.
9. Venu, C.; Riffonneau, Y.; Bacha, S.; and Baghzouz, Y. (2009). Battery storage system sizing in distribution feeders with distributed photovoltaic systems. *Proceedings of the IEEE Bucharest PowerTech.* Bucharest, Romania, 1-5.
10. Le, H.T.; and Nguyen, T.Q. (2008). Sizing energy storage systems for wind power firming: An analytical approach and a cost-benefit analysis. *Proceedings of the IEEE Power and Energy Society General Meeting – Conversion and Delivery of Electrical Energy in 21st Century*. Pittsburgh, Pennsylvania, USA, 1-8.

11. Gouveia, C.; Moreira, J.; Moreira, C.L.; and Pecas Lopes, J.A. (2013). Coordinating storage and demand response for microgrid emergency operation. *IEEE Transactions on Smart Grid*, 4(4), 1898-1908.
12. Boroojeni, K.; Amini, M.H.; Nejadpak, A.; Dragicevic, T.; Iyengar, S.S.; and Blaabjerg, F. (2017). A novel cloud-based platform for implementation of oblivious power routing for clusters of microgrids. *IEEE Access*, 5, 607-619.
13. Khodaei, A.(2015). Provisional microgrids. *IEEE Transactions on Smart Grid*, 6(3), 1107-1115.
14. Sortomme, E.; and El-Sharkawi, M.A. (2009). Optimal power flow for a system of microgrids with controllable loads and battery storage. *Proceedings of the IEEE/PES Power Systems Conference and Exposition.* Seattle, Washington, United States of America, 1-5.
15. Fu, Q.; Hamidi, A.; Nasiri, A.; Bhavaraju, V.; Krstic, S.B.; and Theisen, P. (2013). The role of energy storage in a microgrid concept: Examining the opportunities and promise of microgrids. *IEEE Electrification Magazine*, 1(2), 21-29.
16. Bahramirad, S.; and Daneshi, H. (2012). Optimal sizing of smart grid storage management system in a microgrid. *Proceedings of the IEEE PES Innovative Smart Grid Technologies (ISGT).* Washington, D.C., United States of America, 1-7.
17. Bahramirad, S.; Reder, W.; and Khodaei, A. (2012). Reliability-constrained optimal sizing of energy storage system in a microgrid. *IEEE Transactions on Smart Grid*, 3(4), 2056-2062.
18. Sun, C.; and Yuan, Y. (2013). Sizing of hybrid energy storage system in independent microgrid based on BP neural network. *Proceedings of the 2nd IET Renewable Power Generation Conference (RPG).* Beijing, China, 1-4.
19. Nourai, A. (2007). Installation of the first distributed energy storage system (DESS) at American Electric Power (AEP). *Sandia Report, SAND2007-3580.*
20. Mahesh, A.; Sandhu, K.S.; and Rao, J.V. (2017). Optimal sizing of battery energy storage system for smoothing power fluctuations of a PV/wind hybrid system. *International Journal of Emerging Electric Power Systems*, 18(1), 1-13.
21. Liu, W.; Niu, S.; and Xu, H. (2017). Optimal planning of battery energy storage considering reliability benefit and operation strategy in active distribution system. *Journal of Modern Power System and Clean Energy,* 5(2), 177-186.
22. Jing, Z.; Zhu, J.; and Hu, R. (2018). Sizing optimization for island microgrid with pumped storage system considering demand response. *Journal of Modern Power System and Clean Energy,* 6(4), 791-801.
23. Bahmani-Firouzi, B.; and Azizipanah-Abarghooee, R. (2014). Optimal sizing of battery energy storage for micro-grid operation management using a new improved bat algorithm. *International Journal of Electric Power and Energy Systems*, 56, 42-54.
24. Alsaidan, I.; Khodaei, A.; and Gao, W. (2016). Determination of optimal size and depth of discharge for battery energy storage in standalone microgrids. *Proceedings of the North American Power Symposium (NAPS).* Denver, Colorado, United States of America, 1-6.