Optimal placement of battery energy storage system considering penetration of distributed generations

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ABSTRACT

This paper proposes the optimal problem of location and power of the battery-energy-storage-system (BESS) on the distribution system (DS) considering different penetration levels of distributed generations (DGs). The objective is to minimize electricity cost of the DS in a typical day considering the power limit of DG fed to the DS. Growth optimizer (GO) is first applied to search the BESS's location and power for each interval of the day. The considered problem and GO method are evaluated on the 18-node DS with two penetrations levels of photovoltaic system and wind turbine. The results demonstrate that the optimal BESS placement significantly reduces electricity cost. Furthermore, the optimal BESS location and power also help to reduce the cut capacity of DGs as their power greater than the load demand. The compared results between GO and particle swarm optimization (PSO) method have shown that GO reaches the better performance than PSO in term the optimal solution and the statistical results. Thus, GO is an effective approach for the BESS placement problem.

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1. INTRODUCTION

The distribution system (DS) carries electricity from the intermediate transformer to customers. Due to operation at low-voltage level, the DS often has high power loss and voltage drop. In recent years, the connection of distributed generation (DG) resources using renewable energy like photovoltaic system (PVS) and wind turbine (WT) has contributed to overcome the above limitations of the DS. However, because of the uncertainty of the primary energy sources like sun and wind, the mismatch among load demand, DG output power and grid power is at increased risk that causes to waste energy [1]. In this case, battery-energy-storage-system (BESS) is one of effective solution to tackle the challenge of the negative impacts of renewable energy on the DS [2] and dispatch ability of the DS [3].

In addition to the technical benefits of placement of BESS on the DS like reduction of power loss [4], line loading [5] and voltage drift [6], the economic benefits are also great when BESS is installed and operated efficiently. Several benefits have been considered when optimizing the installation and operation of BESS such as generation costs [7], annual costs [8], daily operating costs [9], operation cost including capital, fuel consumption, cycle and maintenance costs [10] and energy arbitrage profits [11]. Furthermore, to encourage users to use electricity during off-peak hours, most governments is currently applying different electricity rates for different periods. Then, optimizing the installation and operation of BESS is one of the effective solutions for the peak shaving solution. Therefore, considering the electricity cost minimum problems by optimal BESS placement needs to be also encouraged.

In recent years, the optimal location and power of BESS is mainly found by the metaheuristic algorithms because they are easy to apply for different objectives and handle the problems' constraints. In [4], coyote optimization algorithm is applied successfully for the optimal BESS placement for decreasing power loss in the DS. In research [12], salp swarm algorithm is presented for optimal BESS placement to reduce transmission loss, voltage deviation and peak power costs. In research [13], gorilla-troop-optimizer algorithm is applied to optimal BESS placement for minimizing power loss and voltage deviation. In research [14], cuckoo search is also used for optimizing BESS placement to reduce the net present cost. Furthermore, some other algorithms are also successfully used for the BESS placement problem to satisfy different objectives such as tabu search algorithm [15], evolutionary algorithm [16], genetic algorithm [17], grey wolf optimization [18] and equilibrium optimization [19]. In addition to the contribution of the considered problems, the above studies have contributed significantly in term of solving methods. However, there is no method that works well for all problems. The No-Free-Lunch theorem has shown that searching new methods of the optimal problems still needs to be encouraged [20].

The growth optimizer (GO) is inspired from the learning and reflection processes in the society of each individual in his growth processes [21]. Learning is the process of procuring knowledge from the outside world. Reflection is the checking process of the deficiencies and turning the learning phase to improve the growth of individual. From two rules, GO has two mechanisms for generating new solutions. The learning mechanism that creates new solutions based on information of five individuals helps GO avoid converging to local extremes. The reflection mechanism uses different techniques to create new solutions relied on the information of elite individuals. According to Zhang *et al.* [21], GO has demonstrated the high effectiveness for the benchmark functions. However, its quality to the optimal BESS placement problem is also a worthy question.

Therefore, GO is proposed for the optimal BESS placement considering the different penetration of PVS and WT in the DS to minimize the electricity cost bought from the grid and satisfy the constraints consisting of power balance, voltage and current limits, BESS power and capacity limit and DG power limit. The electricity cost is divided into three different prices for the off-peak, normal and peak hours. The 18-node DS with four cases including the DS existing low penetration of PVS and WT without BESS placement, the DS existing low penetration of PVS and WT with BESS placement, the DS existing high penetration of PVS and WT without BESS, as well as the DS existing high penetration of PVS and WT with BESS is used to optimized location and operational power of BESS. The work's contributions are as follows: i) examine the optimal BESS location and power with different penetration of DGs in the DS to reduce the electricity cost; ii) propose the new method of optimal BESS placement based on the GO algorithm; and iii) validate effectiveness of cases consisting of the DS existing different penetration of PVS and WT without and with the BESS placement for optimizing the electricity cost.

The paper's organization includes introduction in here. Model of the considering problem shown in section 2. Steps of GO for finding the optimal BESS placement presented in section 3. The results and discussion as well as conclusion shown in sections 4 and 5, respectively.

2. MODEL OF THE BESS PLACEMENT CONSIDERING PENETRATION OF DGs FOR ELECTRICITY COST REDUCTION

The considered objective (O) is minimizing the electricity cost from the grid. It is defined as (1),

$$\min \mathrm{O} = \sum_{k=1}^{T} \mathrm{P_{F,k}} . \mathrm{t_k} . \gamma_\mathrm{k} \tag{1}$$

where $P_{F,k}$ is the supplied power of the feeder at interval k. t_k is duration of interval k that is chosen to 1 in this work while T is number of intervals that is set to 24. γ_k is electricity price at interval k.

The constraints of the considered problem are as follows:

a) Power balance [7]:

$$\mathrm{P_{F,k}} + \mathrm{P_{DGs,k}} = \mathrm{P_{L,k}} + \mathrm{P_{BF,k}} + \mathrm{Ploss_k} \tag{2}$$

where, $P_{F,k}$, $P_{DGs,k}$ are active power of feeder and DGs at period k. $P_{L,j}$ and $Ploss_k$ are the active load power and loss of the DS at period k. $P_{BF,k}$ is the BESS power which feeds to the DS at period k. It is defined as in (3),

$$P_{BF,k} = \begin{cases} \frac{P_{B,k}}{\eta_c} & ;\ \text{if } P_{B,k} > 0 \text{ (charging mode)} \\ -P_{B,k}.\eta_d & ;\ \text{if } P_{B,k} < 0 \text{ (discharging mode)} \\ 0 & ;\ \text{if } P_{B,k} = 0 \text{ (idle mode)} \end{cases} \quad (3)$$

where $P_{B,k}$ is the BESS power at period k. η_d and η_c are discharging and charging efficiencies those values are set to 0.9 [22].

b) Voltage and current: the voltage and current of the DS must be in their ranges during operation of BESS:

$$0.95 \leq V_{i,k} \leq 1.05 \ ; i = 1, \dots, n_{bus} \quad (4)$$

$$K_{I,j,k} \leq 1 \ ; j = 1, \dots, n_{br} \quad (5)$$

where, $V_{i,k}$ and $K_{I,j,k}$ are respectively the voltage amplitude of node i and current amplitude of branch j at interval k. n_{bus} and n_{br} are respectively number of buses and branches. $K_{I,j,k}$ is the load-carrying-factor of branch j at period k.

c) Power and capacity limit of BESS: These values are not exceed their rated value at each interval [9], [23]:

$$|P_{B,k}| \leq P_{B,rated} \quad (6)$$

$$SoC_{min} \leq SoC_k \leq SoC_{max} \quad (7)$$

where, $P_{B,rated}$ is the BESS rated power. $[SoC_{min}, SoC_{max}]$ is the state-of-charge (SoC) limits of BESS which are chosen to [20%, 90%] of the BESS capacity [1], [24]. SoC_k is SoC at interval k that is calculated as in (8),

$$SoC_k = SoC_{k-1} + P_{B,k}.t_k \quad (8)$$

where, SoC_{k-1} is SoC at interval $(k-1)$. Furthermore, SoC at the beginning (SoC_0) and the day end (SoC_T) should be the same for BESS to be ready for next day [7], [9], [25].

$$SoC_0 = SoC_T \quad (9)$$

d) DG power limit: To limit the DG power generating back to the feeder, the power of the DGs that generates to grid is limited as (10).

$$P_{DGs,k} \leq P_{L,k} + P_{BF,k} \quad (10)$$

The constraint (6) is maintained by modifying the candidate solutions. Meanwhile the constraint (10) is maintained by adjusting the DGs power to $P_{L,k} + P_{BF,k}$ when the DGs power is greater than $P_{L,k} + P_{BF,k}$. Thus, the fitness function (F) including the objective and constrains (4), (5), (7) and (9) is as (11),

$$F = O + \alpha.\Big(\sum_{k=1}^{T}\sum_{i=1}^{n_{bus}} \max(V_{i,k} - 1.05, 0) + \sum_{k=1}^{T}\sum_{i=1}^{n_{bus}} \max(0.95 - V_{i,k}, 0) + \sum_{k=1}^{T}\sum_{j=1}^{n_{br}} \max(K_{I,j,k} - 1, 0) + \sum_{k=1}^{T} \max(SoC_{min} - SoC_k, 0) + \sum_{k=1}^{T} \max(SoC_k - SoC_{max}, 0) + |SoC_0 - SoC_T|\Big) \quad (11)$$

where, α is the penalty factor.

3. METHOD

The GO is developed based on learning and reflective behavior. The first operator helps GO avoid trapping into a local optimum by using of information of different individuals while the second one support GO improving the global convergence by using three different techniques for each dimension. The details of GO for the optimal operation of BESS on the DS as follows:

Step 1: Generate randomly the candidate

In GO, each individual of the population is considered as a candidate of the optimal problem. In order to map with the BESS placement problem, the variable $C_{i,1}$ presents the installed location of BESS while the variables $C_{i,2}$ to $C_{i,25}$ present the BESS power in each interval of the day. It is created at the beginning of the algorithm as (12),

$$C_{i,j} = \text{round}\left(\text{rand}\left(C_{U,j} - C_{L,j}\right) + C_{L,j}\right); i = 1,2, \ldots, N \quad (12)$$

where, $C_{i,j}$ is the variable j of candidate i. $C_{U,j}$ and $C_{L,j}$ are the upper and lower values of the variable j. N is the poulation size.

Step 2: Evaluate the quality of each candidate

From the candidate, the DS's data is updated. Then, the output power of DGs is adjusted to $P_{L,k} + P_{BF,k}$ if their values exceed sum of load demand and BESS power. From the updated parameter of the DS, the load-flow program relied on Matpower [26] is performed. The fitness value of the candidate is determined by using (11) as the power balance constraint in (2) is fulfilled. Otherwise, the bad value is assigned to the fitness value.

Step 3: Generate new population using learning mechanism

In this mechanism, the new candidates are generated using four gaps between candidates consisting of the gap between leader and elite (G_1), leader and bottom (G_2), elite and bottom (G_3), and the gap between two random candidates (G_4). These gaps are defined as (13),

$$\begin{cases} G_1 = C_{best} - C_{better} \\ G_2 = C_{best} - C_{worse} \\ G_3 = C_{better} - C_{worse} \\ G_4 = C_{L1} - C_{L2} \end{cases} \quad (13)$$

where C_{best} is the best candidate and C_{worse} is one of the next $(P_1 - 1)$ best candidates which is considered as an elite. P_1 is number of better candidates. C_{worse} is one of the worst candidate in the population. C_{L1} and C_{L2} are the random candidates.

The new candidates are generated as (14),

$$C_{i,new} = C_i + SF_i.(LF_1.G_1 + LF_2.G_2 + LF_3.G_3 + LF_4.G_4) \quad (14)$$

where LF_j $(j = 1, 2, 3, 4)$ is the learning factor. SF_i is the self-awareness of the growth process of each candidate. LF_j and SF_i are respectively determined as the (15) and (16),

$$LF_j = \frac{\|G_j\|}{\sum_{j=1}^{4}\|G_j\|}; j = 1, 2, 3, 4 \quad (15)$$

$$SF_i = \frac{F_i}{F_{max}} \quad (16)$$

where F_i is the fitness value of candidate C_i and F_{max} is the worst fitness value in the population.

The new candidates are evaluated the quality by using the procedures as shown in step 2. Then the population is updated as (17),

$$C_{i,new} = \begin{cases} C_{i,new}; if\ F(C_{i,new}) < F(C_i) \\ \begin{cases} C_{i,new}; if\ r_1 < P_2 \\ C_i \quad ; otherwise \end{cases} \end{cases} \quad (17)$$

where, r_1 is a random number in [0, 1]. P_2 is probability of new knowledge is retained if the candidate fails to update which is set to 0.1% [21]. In addition, the current best candidate (C_{best}) is also updated at the end of this mechanism.

Step 4: Generate new population using reflection mechanism

A candidate in the population is not only learning but also reflection. For his bad aspects, they should learn from outstanding candidates, meanwhile his good aspects should be kept. Based on this metaphor, the new candidates are generated as (18),

$$C_{i,j,new} = \begin{cases} \begin{cases} r_4.\left(C_{U,j} - C_{L,j}\right) + C_{L,j}; if\ r_3 < AF \\ r_5.\left(R_j - C_{i,j}\right) + C_{i,j} \quad ; otherwise \end{cases} ; if\ r_2 < P_3 \\ C_{i,j} \qquad\qquad\qquad\qquad\qquad ; otherwise \end{cases} \quad (18)$$

where, r_2, r_3, r_4, and r_5 are random numbers in range of [0,1]. P_3 is the probability of reflection that is fix to 0.3 [21]. R_j is the control jth of the leader or the elite. AF is attenuation factor that is defined as (19),

$$AF = 0.01 + 0.99(1 - {FEs}/{MaxFEs}) \quad (19)$$

where, FEs and $MaxFEs$ are respectively the current and maximum number of fitness evaluations. The new candidates are evaluated the quality by using the procedures as shown in step 2. Then the population is updated by using (6) and the current best candidate (C_{best}) is also updated at the end of this mechanism.
Step 5: Stop searching the optimal solution
Steps 3 to 4 are performed in turn until the number of candidate evaluation (FEs) evaluated reaches the maximum value ($MaxFEs$).

4. RESULTS AND DISCUSSION

The method of optimizing BESS location and power considering penetration of DGs based on GO is implemented on MATLAB. The proposed method is applied to find optimal BESS location and power on the 18-node DS. The DS's data referenced from [27] and its single-line diagram is shown in Figure 1. The scale of each load in each period is assumed as Figure 2. Furthermore, it is assumed that the PVS and the WT are placed to the bus 18 and 7, respectively. Their output power in the typical day is presented in Figure 3, wherein the PVS power is shown in Figure 3(a) and the WT power shown in Figure 3(b). The electricity rates in a day are referenced from Vietnam-Electricity-Corporation as in Table 1.

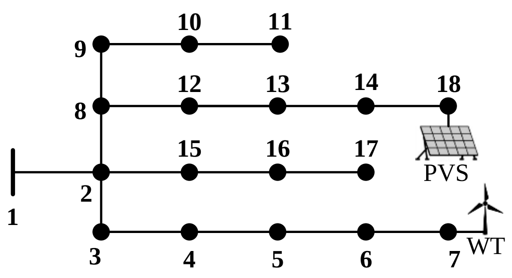


Figure 1. The 18-bus DS with PVS and WT

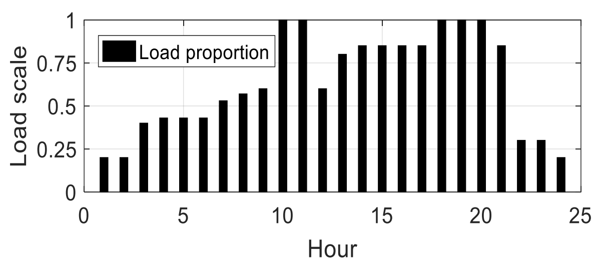


Figure 2. The load proportion of the DS at each hour

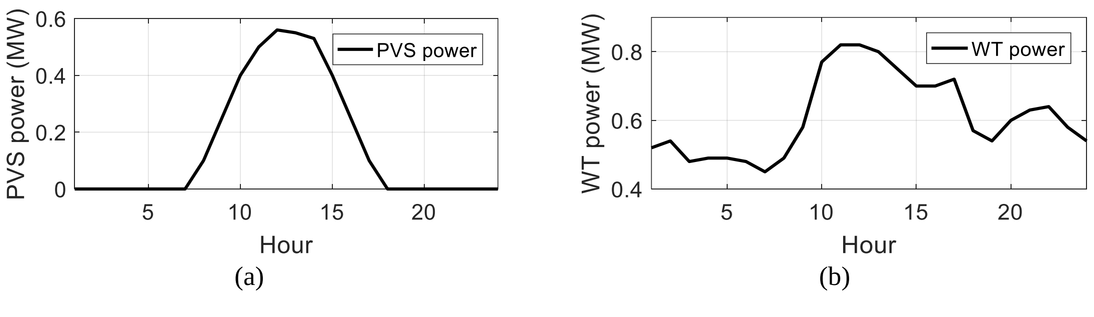


Figure 3. The output power of (a) PVS and (b) WT in the typical day

Table 1. The electricity rates for off-peak, standard and peak hours

Hour	Time (t)	Prices (p) ($/kWh)
Off-Peak	22:00 to 4:00	0.0454
Standard	4:00 to 9:00, 11:00 to 17:00 and 20:00 to 22:00	0.0700
Peak	9:00 to 11:00 and 17:00 to 20:00	0.1289

To evaluate the efficiency of optimal BESS placement for the DS with DGs. Four cases are considered as follows:
Case 1: The DS existing low penetration of DGs as their power shown in Figure 3 and without BESS
Case 2: The DS existing low penetration of DGs as their power shown in Figure 3 and with BESS
Case 3: The DS existing high penetration of DGs as their output power increases as five times as their power in case 1 and without BESS placement
Case 4: The DS existing high penetration of DGs with their output power increases as five times as their power in case 1 and with BESS placement

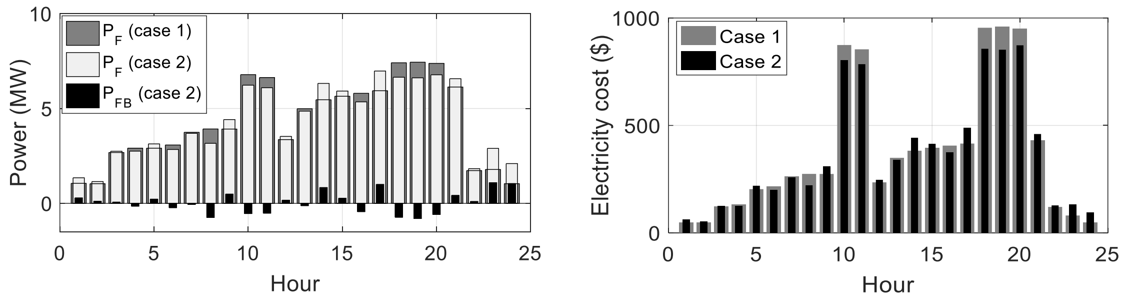
To search the BESS location and power, the GO parameters consisting of N, P_1 and $MaxFEs$ are set to 30, 5, and 6000 respectively. Furthermore, to prove the potential of the GO, the well-known particle swarm optimization (PSO) is applied to compared with GO. Due to creating one population in each generation, the population size of PSO is twice as large as that of GO. For the penalty coefficient, a very high value compared to the objective function value will cause the algorithm to fail for convergence, otherwise if this value is too small it may lead to these constraints being ignored. Based on repeated experiments, this value is chosen to be 1000. For the BESS parameters, the $P_{B,rated}$, its capacity and SoC_0 are chosen to 1 MW, 5 MWh, and 3.75 MWh, respectively. The GO-based proposed method is run in 20 times. Then, the best candidate in all runs is treated as the result.

The results of finding the optimal location and operating power of BESS relied on the GO method are presented in Table 2. In case 1, as BESS is not installed on the DS, the total electricity bought from the grid in the day is 102.7318 MWh corresponding to the electricity cost of 9033.3202 $. After performing optimization of BESS position and power by using the GO method as shown in case 2, the optimal BESS location is selected at node 13 and its power shown by percentage of the BESS's rated power for each hour is {-30, 15, -41, 55, -96, 54, -19, 48, 25, -77, -93, -55, 11, 62, 29, 57, 97, -70, -98, -58, 34, 63, 1, 86}. Then, the electricity cost of the day buying from the grid is 8862.4577$. This cost is 170.8625$ corresponding to 1.89% lower than that of the case of none of BESS installation as shown in case 1. The power of feeder and BESS as well as the electricity cost gained by the GO method are shown in Figure 4.

Although the total amount of energy receives from the grid during the day is 103.9224 MWh, that is 1.1906 MWh higher than that of the case of without BESS installation. However, from Figure 4(a), the consumption power during peak hours such as from 10:00 to 11:00 and from 18:00 to 20:00 is significantly reduced due to discharging mode of BESS. At these intervals, BESS has supplied power to the DS to reduce power consumption at a high price level. Meanwhile, BESS is switched to charging mode during the normal and off-peak hours like from 22:00 to 3:00 with lower electricity costs. This contributes to reduce the electricity cost during the peak hours. Figure 4(b) shows that electricity costs during the above peak hours are decreased significantly while they are only increased slightly during the off-peak hours. Figure 5 shows that the load during the peak hours has been remarkably reduced thanks to the power supplied from the BESS. The figure also shows that the total output capacity of two DGs in a day is smaller than the load demand at all times of the day, so there is no need to cut down the DGs capacity. Figure 6 shows that at all intervals of the day, the Soc is within 20% to 90% of its rated capacity. Furthermore, the capacity at the day end is equal to 3.75 MWh, that is the same capacity as the beginning of the day. This helps to BESS ready for operation in the next day. The voltage and current profile of the system after BESS placement is are shown in Figure 7. Figures 7(a) shows that at all times the voltage of buses is always within the allowed limit of 0.95 to 1.05 pu. Figure 7(b) shows that the load-carrying factor of the branches at all times of the day is less than one.

Table 2. The optimal BESS parameters obtained by GO and PSO for the considered cases

Case	Method	BESS location	Ratio of BESS power to its rated power in percentage ($\frac{P_{B,k}}{P_{B,rated}}.100\%$)	Energy from the grid (MWh)	Cut-down DGs capacity (MWh)	Electricity cost ($)	Saving cost ($)	Saving cost (%)
Case 1		-	-	102.7318	0	9033.3202	-	-
Case 2	GO	13	-30, 15, -41, 55, -96, 54, -19, 48, 25, -77, -93, -55, 11, 62, 29, 57, 97, -70, -98, -58, 34, 63, 1, 86	103.9224	0	8862.4577	170.8625	1.89%
	PSO	9	67, -21, 1, -3, -100, 4, -40, -100, 100, -47, -3, 24, 28, 1, 11, 26, -5, -73, -18, -100, 100, -46, 94, 100	103.9426	0	8919.8276	113.4926	1.26%
Case 3		-	-	37.6429	7.34	3705.7305	5327.59	58.98%
Case 4	GO	15	17, 11, 5, 7, -49, -58, -14, -51, 85, -99, -84 41, 41, 50, -34, 46, 66, -97, -48, -35, 41, 72, 46, 41	36.0156	4.3511	3392.3946	5640.926	62.45%
	PSO	18	-49, 58, 54, 0, -39, -100, 72, -43, 99, -100, -100, -45, 87, 77, 100, -100, -100, -44, -100, 2, 100, 31, 44, 96	37.4357	5.1716	3490.8555	5542.465	61.36%



(a) (b)

Figure 4. Feeder and BESS power and electricity cost for case 2; (a) power and (b) electricity cost

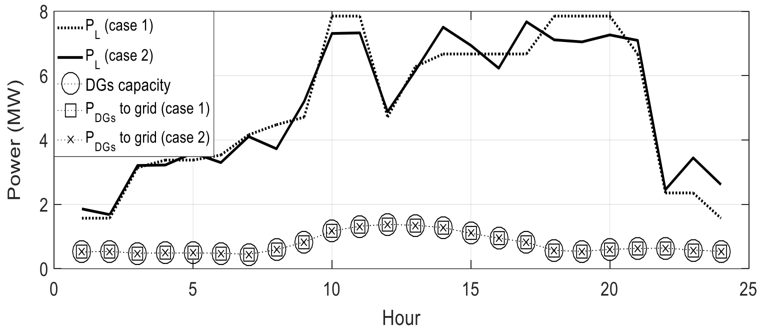


Figure 5. Load graph and DGs power for case 2

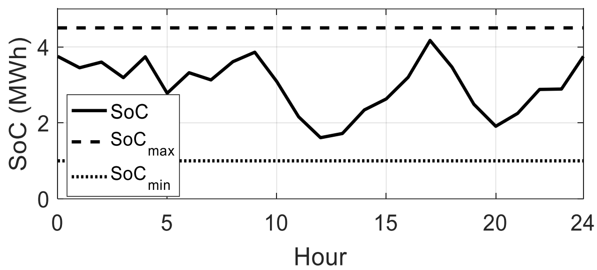
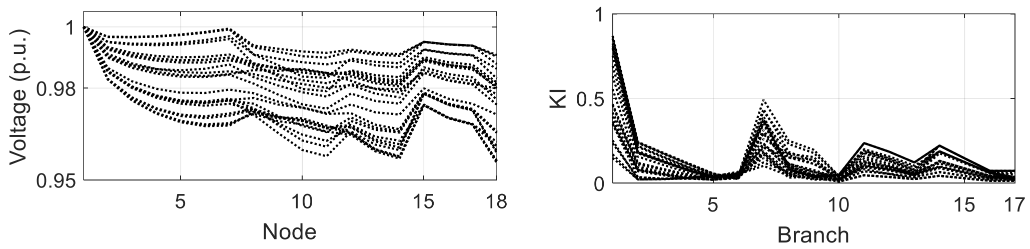


Figure 6. SoC of BESS in case 2



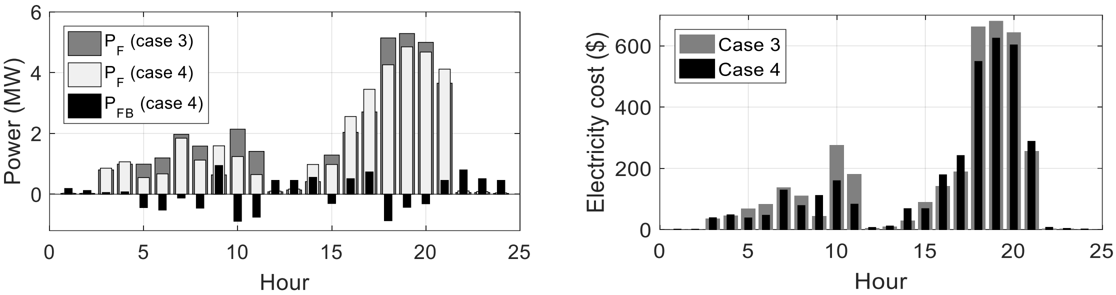
(a) (b)

Figure 7. Voltage and current factor in case 2 (a) voltage amplitude and (b) current factor

In case 3, electricity cost is significantly reduced compared to case 1 with a reduction of about 58.98% due to the high capacity of DGs. However, due to the large amount of DGs capacity, to ensure the condition that the DG power back to the grid is zero, the total DG capacity is cut down to 7.34 MWh. In this case, after optimizing the BESS position and power as in case 4, the optimal BESS installation position is selected at node

15 and the operating power in each hour is {17, 11, 5, 7, -49, -58, -14, -51, 85, -99, -84, 41, 41, 50, -34, 46, 66, -97, -48, -35, 41, 72, 46, 41}. Then, the day's cost of electricity from the grid has been decreased from 3705.7305 to 3392.3946 $, which is 313.3359 $ corresponding to 8.46% lower than that of the case 3 without BESS.

The power of feeder and BESS as well as the electricity cost gained by the GO method for case 4 are displayed in Figure 8. Figure 8(a) shows the consumption power during the peak intervals like 10:00 to 11:00 and 18:00 to 20:00, BESS is changed to discharge state to supply power to the DS for helping to reduce power consumption from the grid. While during the off-peak hours from 22:00 to 3:00, BESS is changed to the charging state. Figure 8(b) shows that the electricity cost is decreased sharply during the peak hours and increased slightly during other periods, as the DS needs more energy to charge BESS. Figure 9 shows that the load graph during the peak hours is significantly reduced by the power supplied from the BESS. Figure 9 also shows that the amount of DG capacity being cut down as the DGs capacity is greater than the load demand such as from 1:00 to 2:00, 12:00 to 13:00 and 22:00 to 24:00 has been significantly reduced because in these periods, BESS is switched to charge state to store energy from the DGs. Thus, the cut-down DG capacity has been reduced from 7.34 to 4.3511 MWh corresponding to the reduction of 40.72%. As shown in Figure 10, the SoC is always within the allowed limits at each interval and the capacity at the day end backs to the initial value. The voltage and current profile after BESS placement in case 4 are displayed in Figure 11. Figures 11(a) and 11(b) show the non-violation of voltage and current constraints.



(a) (b)

Figure 1. Feeder and BESS power and electricity cost for case 4 (a) power and (b) electricity cost

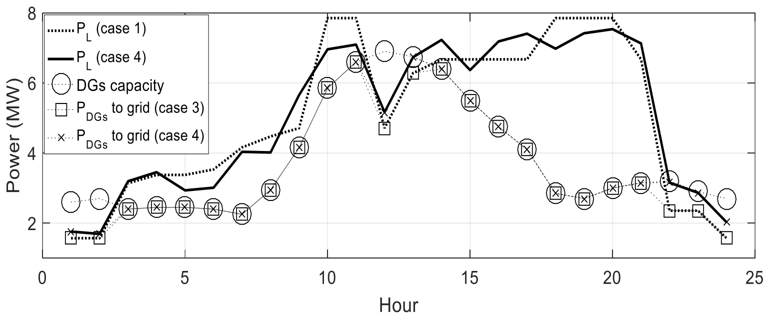


Figure 9. Load graph and DGs power for case 4

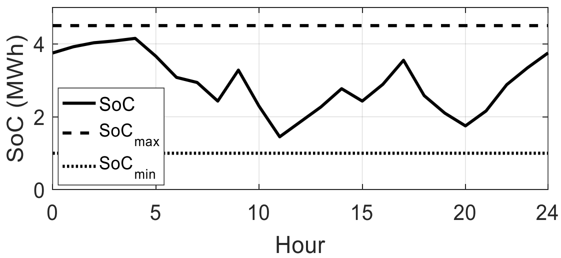


Figure 10. SoC of BESS in case 4

In comparison with PSO, the results in Table 2 show that the saving electricity cost of the day in case 2 and case 4 of GO is respectively 0.63% and 1.09% higher than those of PSO. In addition, the statistical results in Table 3 presents that the difference between the mean (F_{mean}) and the minimum (F_{min}) fitness value is relatively small. Specifically, the mean value in case 2 and case 4 is higher than the minimum value of 43.6315 and 108.3225 corresponding to about 0.49% and 3.19%, respectively. Similarly, the worst fitness value (F_{max}) of the two cases is higher than the minimum value by 1.24% and 6.13%, respectively. For PSO, the F_{mean}, F_{min}, F_{mean}, and standard-deviation (STD) values of PSO are higher than those of GO. The average convergence characteristics of GO and PSO over 20 runs are presented in Figure 12, wherein the convergence curve for case 2 and case 4 are displayed Figures 12(a) and 12(b), respectively. The figures also show reliability of GO for the considered problem, where the mean characteristics are lower than those of PSO.

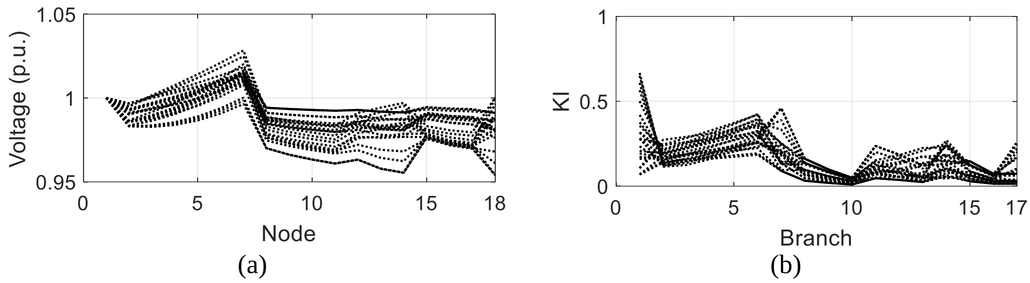


Figure 2. Voltage and current factor in case 4 (a) voltage amplitude and (b) current factor

Table 3. The GO and PSO performance for the BESS placement problem

Case	Method	F_{max}	F_{min}	F_{mean}	STD	$Time$ (s)
Case 2	GO	8997.079	8887.2174	8930.8489	35.3389	389.8125
	PSO	9135.7853	8919.8276	9027.7968	59.050365	391.1375
Case 4	GO	3600.1878	3392.3946	3500.7171	53.0014	402.4328
	PSO	4045.7148	3496.7891	3656.8623	123.44173	410.207

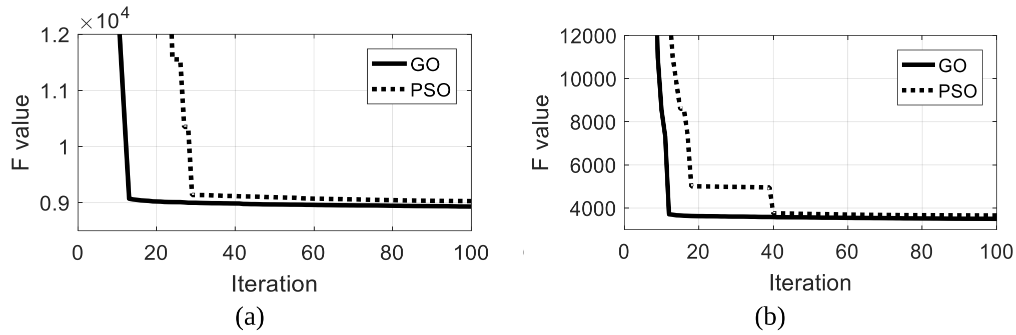


Figure 12. Convergence curve of GO and PSO for case 2 and case 4 (a) case 2 and (b) case 4

5. CONCLUSION

In this work, the location and power of BESS on the distribution system considering to penetration levels of DG capacity is optimized to reduce electricity cost from the feeder using GO algorithm. Relied on the different electricity rates for different intervals and the output DG power, installation position and power of BESS are optimized. The obtained results on the 18-bus DS in four cases including the DS existing low penetration level of DGs without BESS, the DS existing low penetration of DGs with BESS, the DS existing high penetration of DGs without BESS and the DS existing high penetration of DGs with BESS have been demonstrated the effectiveness of BESS for reducing the electricity cost. For the DS existing low penetration of DGs, the electricity cost has been decreased by 1.89% compared with the DS existing low penetration level of DGs without BESS placement. For the DS existing high penetration level of DGs with BESS placement, the electricity cost has been saved by 8.46% compared with the DS existing high penetration of DGs without BESS placement. In addition, the optimal placement of BESS has also significantly reduced the cut-down DG capacity as the DGs capacity is greater than the load demand. For the DS existing high penetration of DGs with BESS placement, the optimal BESS placement has helped to reduce the cut-down DG capacity by 40.72% compared to the DS existing high penetration of DGs without BESS placement. Thus, the optimal BESS placement is a powerful solution to reduce electricity costs and reduce the cut-down capacity of DGs when their capacity is greater than the load demand. Furthermore, GO has been first proposed for the problem of optimizing location and power of BESS. The statistical results of GO for the BESS placement problem with the low differences between the minimum fitness value and the average one and the better performance compared with PSO show the concordance of GO for the BESS placement problem. For future work, the considered problem can be applied on practical DSs and the proposed GO method can be applied to the optimal BESS placement to meet other objectives.

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