# Minimizing electricity cost by optimal location and power of battery energy storage system using wild geese algorithm

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**ABSTRACT**

The mismatch between load demand and supply power may increase when distributed generation based on renewable energy sources is connected to the distribution system (DS). This paper shows the optimal battery energy storage system (BESS) placement problem on the DS to minimize the electricity cost. Diverse electricity prices are considered for normal, off-peak and peak hours in a day. Wild geese algorithm (WGA) is applied to optimize the location and power of the BESS. The problem and the efficiency of WGA is validated on the 18-bus DS four scenarios consisting of the DS without BESS placement, the DS with BESS placement, the DS existing photovoltaic system (PVS) without BESS placement and the DS existing PVS with BESS placement. The numerical results show that optimal BESS placement is an effective solution for minimizing electricity cost on the DS with and without PVS. In addition, the results have also shown that WGA is a potential method for the BESS placement problem.



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## 1. INTRODUCTION

In recent years, installation of distributed generations using renewable energy resource like photovoltaic system (PVS) on the distribution system (DS) brings many technical benefits such as power loss reduction, voltage improvement and the DS's performance enhancement. However, due to the uncertainty of the primary energy source, they may increase the mismatch between load demand and generation power that leads to waste of energy [1], [2]. In addition, the high demand for electricity during peak hours also increases the electricity cost. To overcome this situation, using battery energy storage system (BESS) is an effective solutions to decrease electricity cost.

The suitable BESS placement on the DS can help to obtain the technical benefits such as voltage drift and power loss reduction [3], power loss reduction [4], [5], line loading and voltage deviation reduction [6] and the economic benefits like energy loss cost reduction [7], investment and generation cost reduction [8], investment and annual cost reduction [9] and reduction operation cost consisting of capital, maintenance and BESS cycle costs [10]. Because of BESS's capability to shift the load graph and the high difference in electricity prices between time frames of the day, efficient use of BESS will save electricity costs. To maximize the efficiency of the BESS, it needs to be installed in the right location and its operating power at each time needs also to set at the suitable level. However, the BESS placement problem is a complex problem due to its nonlinear and discrete characters that requires the effective solving methods.

Up to now, the BESS placement problem is mainly solved by the metaheuristic methods due to the flexibility nature of these methods. According to Salee and Wirasanti [11], genetic algorithm (GA) is used to the BESS placement for voltage deviation and power loss reduction. Research by Saini and Gidwani [12], GA is also applied for searching the optimal location and size of BESS to obtain the maximum cost of environmental emission, energy price arbitrage and power loss. Research by Faisal *et al.* [13] particle swarm optimization (PSO) is presented to optimize BESS power in a day to reduce the power demand and energy cost. PSO is used for the BESS placement to reduce the fluctuation of supplied power [14]. In addition, some recent developed algorithms have also been proposed to the BESS installation optimization problem to meet different objectives such as coyote optimization algorithm [4], gravity search algorithm [15], whale optimization algorithm [5], grey wolf optimizer [16] and inherited competitive swarm optimization [3]. The contribution of the above methods is worthy of recognition but there is no effective method for all problems. According to Wolpert and Macready [17] the no-free-lunch theorem has shown the demand of diversity in methods for optimal problems. This is the motivation for this study to apply a new method for the BESS placement.

Wild geese algorithm (WGA) is a recent metaheuristic algorithm that is taken from the idea of coordination in migration, food searching and mortality of wild geese [18]. WGA has demonstrated its ability for finding the optimal value of test functions [18]. However, its performance for the BESS problem is still a question. Thus, in this work, WGA is applied for the BESS placement problem for minimizing the electricity cost on the DS with and without PVS. The considered time is a day which is spilt to normal, off-peak and peak hours with different electricity prices. The considered problem and the efficiency of WGA is validated on the 18-bus DS with four scenarios consisting of the DS without BESS placement, the DS with BESS placement, the DS existing PVS without BESS placement and DS existing PVS with BESS placement. The contributions of this study are summarized as follows: i) consider the optimal location and power of BESS on the DS with and without PVS to minimize the electricity cost; ii) propose the application of new method based on WGA to the optimal BESS placement problem; and iii) evaluate effectiveness of scenarios consisting of the DS with BESS placement and the DS existing PVS with BESS placement for minimizing electricity cost of the 18-bus DS.

## 2. PROBELM FORMULAR OF THE BESS PLACEMENT

In the peak hours, the electricity demand is the highest. Thus, to meet the demand, many high-cost power plants must be used. Meanwhile, during off-peak hours, the power plants may operate at too low capacity. This issue causes economic inefficiencies. In this case, BESS placement is one of the effective solutions to shift the load demand from peak hours to off-peak hours. Therefore, in this study, the optimal location and power of BESS in the DS existing PVS is considered to minimize electricity cost in a day. The objective ($obj$) of the problem is defined as (1):

$$min\ obj = \sum_{j=1}^{H} P_{G,j}.t_j.p_j \tag{1}$$

where, $P_{G,j}$ (kW) is the power supplied from the grid at the interval $j$. $t_j$ (hour) is duration of the interval $j$. $p_j$ (\$/hour) is electricity price in the interval $j$. $H$ is number of intervals in a day. In this work, $t_j$ is chosen to 1. Thus, $H$ is set to 24.

The constraints of the BESS placement are as follows:

- Active power balance [8]:

$$P_{G,j} + P_{PVS,j} + P_{BG,j} = P_{L,j} + \Delta P_j \tag{2}$$

where, $P_{G,j}$, $P_{PVS,j}$ are active power of the grid and PVS at the interval $j$, respectively. $P_{L,j}$ is the active power of load demand and $\Delta P_j$ is the active loss of the DS at the interval $j$. $P_{BG,j}$ is the BESS power that receives/supplies from/to the grid at the interval $j$. It is determined as (3):

$$P_{BG,j} = \begin{cases} -\frac{P_{B,j}}{\eta_c} & ;\ if\ P_{B,j} > 0\ (charging) \\ P_{B,j}.\eta_d & ;\ if\ P_{B,j} < 0\ (discharging) \\ 0 & ;\ if\ P_{B,j} = 0\ (idle) \end{cases} \tag{3}$$

where, $P_{B,j}$ is the BESS power at the interval $j$. $\eta_d$ and $\eta_c$ are discharging and charging efficiencies. The value of $\eta_d$ and $\eta_c$ is chosen to be 0.9 [19].

- Voltage and current: At each interval, BESS placement does not cause negative affect to voltage and current profile of the DS:

$$0.95 \leq V_{i,j} \leq 1.05; i = 1, \dots, N_b \quad (4)$$

$$k_{I,s,j} = {I_{s,j}}/{I_{s,rated}} \leq 1; s = 1, \dots, N_{br} \quad (5)$$

where, $V_{i,j}$ and $I_{s,j}$ are the $i$th node voltage and the $s$th branch current at the interval $j$. $N_b$ and $N_{br}$ are number of buses and branches. $k_{I,s,j}$ is the load-carrying-factor of the $s$th branch at the interval $j$.

- Limit of BESS power and capacity: at each interval the BESS power and its capacity are not exceed its rated values [20], [21]:

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

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

where, $P_{B,rated}$ is the rated power of BESS. $[SoC_{min}, SoC_{max}]$ is the state-of-charge (SoC) limit of BESS that is selected to [20%, 90%] [2], [22]. $SoC_j$ is SoC at the interval $j$ that is defined as (8):

$$SoC_j = SoC_{j-1} + P_{B,j}.t_j \quad (8)$$

where, $SoC_{j-1}$ is SoC at the interval $(j-1)$. In addition, to help BESS ready for the next day, the SoC at the beginning $(SoC_0)$ and the end $(SoC_H)$ of the day has to be the same [8], [20], [23]:

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

## 3. WGA FOR OPTIMAL LOCATION AND POWER OF BESS

Step 1: generate randomly the initial population. By applying WGA for the optimal BESS location and power problem, each wild goose is considered as the solution of the problem. For each BESS solution, the first variable indicates the location of BESS meanwhile the second to the last variables indicate the percentage of BESS rated power. Thus, the initial solution is created randomly as (10):

$$B_i = \text{round}(\text{rand}(B_H - B_L) + B_L); i = 1,2, \dots, N_{initial} \quad (10)$$

where, $B_H$ is the upper limit of each solution where the first variable is set to the number of buses of the DS and the rest ones are set to 100. $B_L$ is the lower limit of each solution where its first variable is set to 2 and the rest ones are set to -100.

Step 2: calculate the fitness value of each solution. If the constraint (6) is satisfied, the DS's data is updated based on the BESS solution. Then, the load-flow program based on Matpower [24] is run. If the power balance in (2) is satisfied, the fitness function of the solution is calculated as (11):

$$\begin{aligned} \text{FIT} = \text{obj} + \vartheta.\Big(&\textstyle\sum_{j=1}^{H}\sum_{i=1}^{N_b} max(V_{i,j} - 1.05, 0) + \sum_{j=1}^{H}\sum_{i=1}^{N_b} max(0.95 - V_i, 0) \\ &+ \textstyle\sum_{j=1}^{H}\sum_{s=1}^{N_{br}} max(k_{I,s} - 1, 0) + \sum_{j=1}^{H} max(SoC_{min} - SoC_j, 0) \\ &+ \textstyle\sum_{j=1}^{H} max(SoC_j - SoC_{max}, 0) + |SoC_0 - SoC_H|\Big) \end{aligned} \quad (11)$$

where, $\vartheta$ is the penalty factor. Relied on the fitness value of the solutions, the best goose $(G_{best})$ is determined. It is noted that the fitness value will be set by a high value if the constraints in (2) is violated.

Step 3: generate new solutions based on the migration and food searching mechanisms. To create the new population, the current solutions is arranged in fitness value ascending order. In the migration, the geese usually fly in the certain order. The goose position relies on the neighboring ones. Thus, the new velocity of each goose $(V_i^{t+1})$ is defined as (12):

$$\begin{aligned} V_i^{t+1} = &\text{r}_1 V_i^t + \text{r}_2(V_{i+1}^t - V_{i-1}^t) + \text{r}_3(P_i^t - B_{i-1}^t) + \text{r}_4(P_{i+1}^t - B_i^t) + \text{r}_5(P_{i+2}^t - B_{i+1}^t) \\ &- \text{r}_6(P_{i-1}^t - B_{i+2}^t) \end{aligned} \quad (12)$$

where, $V_i^t$, $B_i^t$ and $P_i^t$ are the current velocity, position and the best position of the goose $i$. $r_1$ to $r_6$ are random number in [0, 1]. [$V_{i-1}^t$, $B_{i-1}^t$, $P_{i-1}^t$] and [$V_{i+1}^t$, $B_{i+1}^t$, $P_{i+1}^t$] are the current velocity, position and the best position of the goose $(i-1)$ and $(i+1)$. [$P_{i+2}^t$, $B_{i+2}^t$] is the current position and the best position of the goose $(i+2)$.

In addition, the best goose will guide the movement of the population. Therefore, the new geese position based on the migration ($B_i^m$) is updated as (13):

$$B_i^m = P_i^t + r_7 r_8\Big((G_{best} + P_{i+1}^t - 2P_i^t) + V_i^{t+1}\Big) \quad (13)$$

Where, $r_7$ to $r_8$ are random number in [0, 1]. In the food searching process, each goose often move to the upfront one. Thus, the new geese position based on the food searching ($B_i^f$) is updated as (14):

$$B_i^f = P_i^t + r_9 r_{10}(P_{i+1}^t - P_i^t) \quad (14)$$

Where, $r_9$ to $r_{10}$ are random number in [0, 1]. Finally, the new population of WGA is generated as (15):

$$B_i^{t+1} = \text{round}\begin{pmatrix} B_i^m\ ;\ if \text{ rand} \le 0.5 \\ B_i^f\ ;\ otherwise \end{pmatrix} \quad (15)$$

Then, each new goose is evaluated the fitness value by (11) and the best position of each is renewed as (16) and (17):

$$P_i^{t+1} = \begin{cases} B_i^{t+1}\ ;\ if\ FIT_i^{t+1} < FIT_{p,i}^t \\ P_i^t\ \ ;\ otherwise \end{cases} \quad (16)$$

$$FIT_{p,i}^{t+1} = \begin{cases} FIT_i^{t+1}\ ;\ if\ FIT_i^{t+1} < FIT_{p,i}^t \\ FIT_{p,i}^t\ \ ;\ otherwise \end{cases} \quad (17)$$

Finally, the $G_{best}$ is also updated by comparing its value with the best one of new geese.

Step 4: decrease the population size. The weaker goose in the population will be died and the population size will be reduced to the final number of geese ($N_{final}$) as (18):

$$N = round\left(N_{initial} - \left(N_{initial} - N_{final}\right)\frac{FE_t}{FE_{max}}\right) \quad (18)$$

Step 5: stop finding new solutions. Relied on the new number of geese, steps from 2 to 4 continues to execute until the number of fitness evaluation ($FE_t$) is equal to the maximum value $FE_{max}$.

## 4. RESULTS AND DISCUSSION

The WGA-based method of searching BESS location and power is built in MATLAB. The effective of the proposed method is evaluated on the 18-bus DS as shown in Figure 1. The DS's parameters and peak load demand are taken from [25]. It is assumed that the scale of each load in each interval is shown in Table 1. The load demand of the system in the 24-hour period is demonstrated in Figure 2(a). In addition, to validate the efficiency of BESS in case of existing the renewable energy source on the DS, the PVS is assumed to be installed at node 18 an its power in the typical day is shown in Table 2 and Figure 2(b). The time-of-use electricity consists of the standard, off-peak and peak hours as well as the price for each is taken from Vietnam-electricity-corporation that is displayed in Table 3. Four scenarios are considered as follows: i) scenario 1: the DS without BESS placement; ii) scenario 2: the DS with BESS placement; iii) scenario 3: the DS existing PVS without BESS placement; and iv) scenario 4: the DS existing PVS with BESS placement.

For the WGA's parameters, the initial and final population size are selected to 60 and 20, respectively. The maximum number of evaluations of the fitness function is selected to 10,000. The penalty factor $\vartheta$ is chosen to 1,000. For each case, the WGA is performed independently in 20 runs and the best result in these runs is considered as the result of the problem.

The optimal results of location and power of BESS in each hour obtained by WGA for scenarios are presented in Table 4. In scenario 1, the total used electrical energy purchased from the grid is 121.4704 MWh corresponding to the amount of $10523.5441. In scenario 2, after installing BESS at node 5 with power for hours of the day of {-25, -4, -18, 47, 12, 15, 19, 6, -10, -5, -100, 7, -6, 90 , 6, 50, 4, -66, -9, -16, 11, -8, 4, -4}, the total energy purchased from the grid is 122.0709 MWh which is 0.605 MWh higher than that of scenario 1. However, the total cost of purchasing electricity has decreased from $10523.5441 to $10456.1232. The amount of savings in the day is $ 67.4209 corresponds to 0.64% compared to that of scenario 1. Figure 3(a) shows that during the peak hours such as 9:00 to 11:00 and 18:00 to 20:00, BESS has switched to discharging mode to reduce the electricity cost from the grid while in off-peak hours with the lower price, BESS is changed to charging mode for storing energy. Figure 3(b) demonstrates that the SoC of BESS is always within the allowable limit of [1, 4.5 MWh]. In addition, the SoC value at the end of the day is equal to 3.5 MWh which is equal to the SoC value at the beginning of the day. This ensures that BESS is ready to operate the next schedule. The voltage and current configurations in scenario 1 are shown in Figure 4(a) and Figure 4(b), respectively while the voltage and current configurations in scenario 2 are shown in Figure 4(c) and Figure 4(d), respectively. These figures show that the voltage and current at each interval are always within the allowable limits. This shows that BESS placement do not adversely affect these indicators.

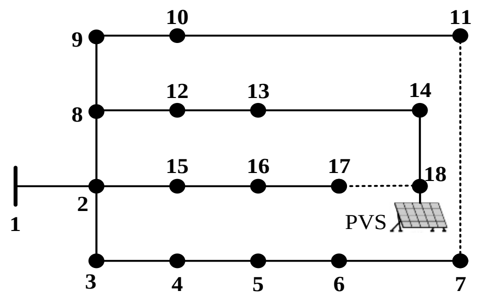
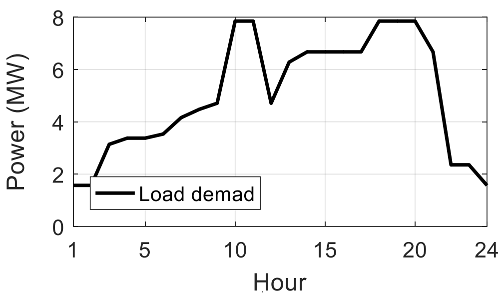


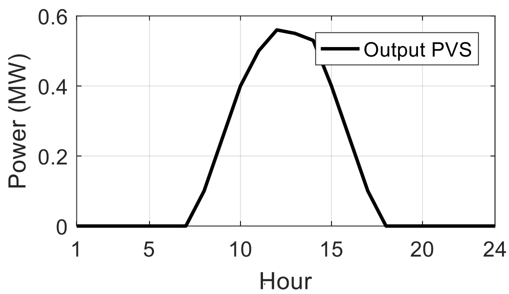

Figure 1. The 18-bus DS

Table 1. Load scale at each hour

| Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load scale | 0.20 | 0.20 | 0.40 | 0.43 | 0.43 | 0.43 | 0.53 | 0.57 | 0.60 | 1.00 | 1.00 | 0.6 |
| Hour | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Load scale | 0.80 | 0.85 | 0.85 | 0.85 | 0.85 | 1.00 | 1.00 | 1.00 | 0.85 | 0.30 | 0.30 | 0.2 |




(a)




(b)

Figure 2. The graph of (a) load demand and (b) PVS power in the considered day

Table 2. PVS power in a typical day

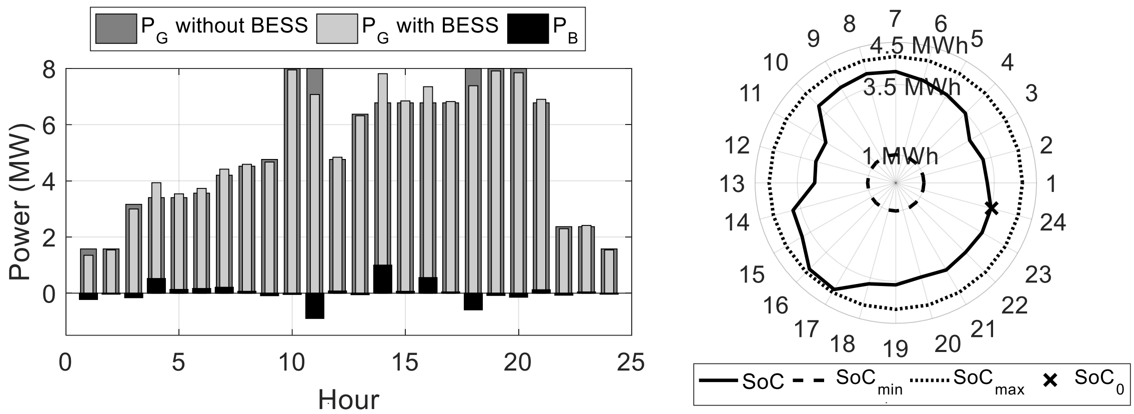
| Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PVS (MW) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.10 | 0.25 | 0.40 | 0.50 | 0.56 |
| Hour | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| PVS (MW) | 0.55 | 0.53 | 0.40 | 0.25 | 0.10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Table 3. The standard, peak and off-peak hours and the price for each

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

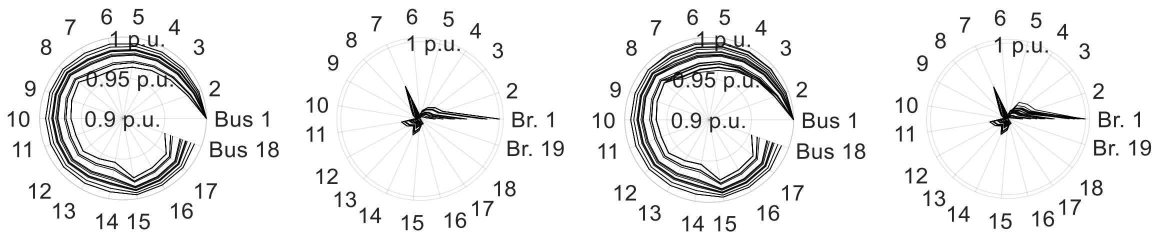
Table 4. The optimal results gained by WGA for scenarios

| Scenario | BESS location | Power (%) in each hour | Energy from the grid (MWh) | Electricity cost ($) | Saving cost ($) | Saving cost (%) |
|---|---|---|---|---|---|---|
| Scenario 1 | - | - | 121.4704 | 10523.5441 | - | - |
| Scenario 2 | 5 | -25, -4, -18, 47, 12, 15, 19, 6, -10, -5, -100, 7, -6, 90, 6, 50, 4, -66, -9, -16, 11, -8, 4, -4 | 122.0709 | 10456.1232 | 67.4209 | 0.64 |
| Scenario 3 | - | - | 117.6948 | 10203.6109 | 319.9332 | 3.04 |
| Scenario 4 | 6 | -11, 26, 45, 26, -1, -59, -34, -13, -24, -22, -49, 41, -1, 30, 68, -33, 21, -42, -30, 0, -17, -61, 100, 40 | 118.5684 | 10122.759 | 400.7851 | 3.81 |



(a) (b)

Figure 3. Power and SoC of BESS (a) power and (b) SoC in the day for scenario 2



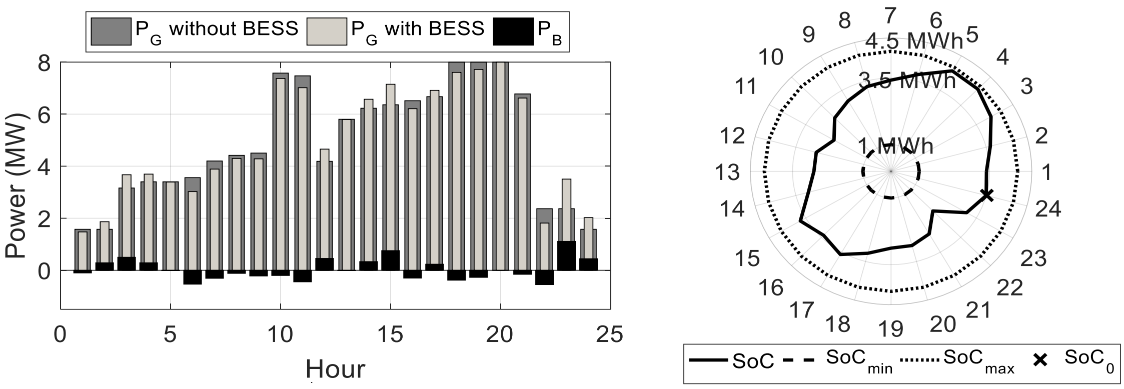
(a) (b) (c) (d)

Figure 4. Voltage and current of the DS without PVS in the day (a) voltage for scenario 1, (b) current for scenario 1, (c) voltage for scenario 2, and (d) current for scenario 2

The installation of PVS in scenario 3 has provided a part of the power to the DS that helps to reduce the power supplied from the grid by 3.7756 MWh from 121.4704 MWh to 117.6948 MWh. The electricity cost from the grid has been reduced by about $319.9332 corresponding to the reduction of 3.04% compared to the scenario 1. When optimizing installation location and BESS power on the DS with PVS in scenario 4, the energy supplied from the grid is reduced by 2.902 MWh from 121.4704 MWh to 118.5684 MWh. The electricity cost has been reduced by 400.7851 MWh corresponding to the reduction of 3.81% compared to the initial cost. Compared to scenario 3, the optimization of installation location and power of BESS has made the total amount of power supplied from the grid increasing from 117.6948 to 118.5684 MWh corresponding to the increase of 0.8736 MWh. However, the total electricity cost has been reduced by $80.8519 from $10203.6109 to $10122.759 corresponding to the reduction of 0.79% compared to scenario 3.

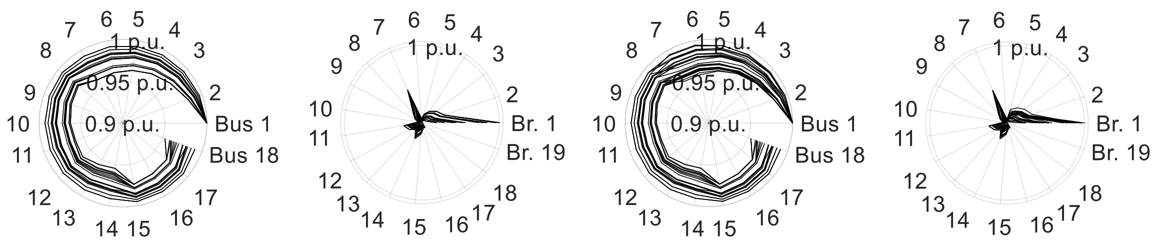
Similar to the scenario 2, Figure 5(a) shows that most of the peak hours, BESS has switched to discharging mode to supply power to the DS while in the off-peak hours, BESS is charged for energy storage. Figure 5(b) shows that BESS's SoC is always within the allowable limit and the SoC value at the end of the day is equal to the SoC value at the beginning of the day. The voltage and current configurations in case 3 are shown in Figure 6(a) and Figure 6(b), respectively while the voltage and current configurations in case 4 are shown in Figure 6(c) and Figure 6(d), respectively. The figures shows that the voltage and current at each time are always within the allowable limits.

The statistical results consisting the maximum ($FIT_{max}$), minimum ($FIT_{min}$), mean ($FIT_{mean}$), and standard devitation ($STD$) of the fitness values as well as calculated time ($T_{cpu}$) of WGA for scenario 2 and scenario 4 are shown in Table 5 and Figure 7. The results show that the difference between the mean value and the minimum value in scenario 2 and scenario 4 is 44.3382 and 59.8785, respectively corresponding to about 0.42% and 0.59% respectively. In addition, the difference between the maximum value and the minimum value in two scenarios is 86.5073 and 118.7086, respectively corresponding to about 0.83% and 1.17%, respectively. The small differences between the minimum value with the mean value as well as the maximum value show the reliability in each run of WGA for the optimal BESS placement problem. Furthermore, to evaluate the suitability of WGA for the BESS optimization problem, the PSO algorithm is also implemented for the problem to compare with WGA in term of the statistical results. Based on the population size parameters and the maximum number of evaluations of the fitness function of WGA, the population size of PSO is selected to be 37. The results in Table 5 show that the $FIT_{max}$ value of WGA for scenario 2 and scenario 4 is respectively 300.34 and 530.7691 lower than those of PSO. Similarily, the $FIT_{min}$ value of PSO for both of scenarios is also 66.27 and 55.4968 higher than those of WGA and the $FIT_{mean}$ value of WGA is 29.61 and 81.6086 lower than those of PSO. In addition, the $STD$ of fitness values in 20 runs of WGA is also lower than that of PSO for both cases. The mean convergence characteristics of the WGA and PSO for scenario 2 and scenario 4 displayed respectively Figure 7(a) and Figure 7(b) show that WGA often converges to better values compared to PSO. This confirms the stability and suitability of WGA for this problem.




(a) (b)

Figure 5. Power and SoC of BESS (a) power and (b) SoC in the day for scenario 4




(a) (b) (c) (d)

Figure 6. Voltage and current of the DS without PVS in the day (a) voltage for scenario 3, (b) current for scenario 3, (c) voltage for scenario 4, and (d) current for scenario 4

Table 1. The performance of WGA the optimal BESS placement in two scenarios

| Scenario | Method | $FIT_{max}$ | $FIT_{min}$ | $FIT_{mean}$ | $STD$ | $T_{cpu}$ (s) |
|---|---|---|---|---|---|---|
| Scenario 2 | WGA | 10542.6305 | 10456.1232 | 10500.4614 | 28.6100 | 651.5828 |
| | PSO | 10842.9661 | 10522.3956 | 10530.0684 | 111.1475 | 670.1664 |
| Scenario 4 | WGA | 10243.6046 | 10124.896 | 10184.7745 | 39.206566 | 641.2391 |
| | PSO | 10774.3737 | 10180.3928 | 10266.3831 | 230.5589 | 636.9773 |

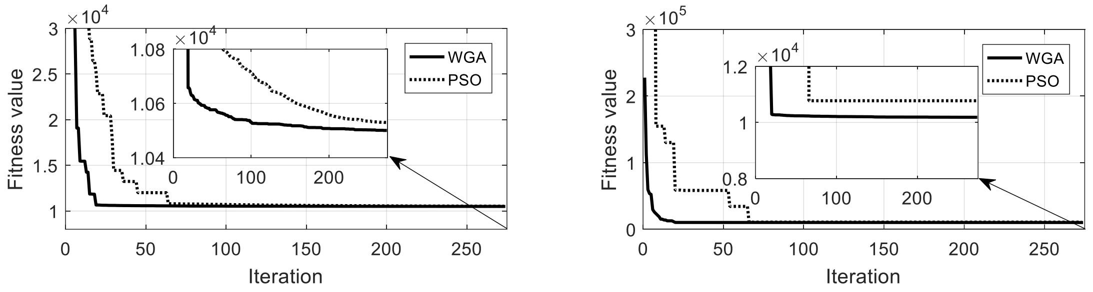



Figure 7. Fitness curves (a) for scenario 2 and (b) for scenario 4 of WGA and PSO for the 18-bus DS

## 5. CONCLUSION

In this work, application of WGA for the optimal BESS location and power problem has been proposed for reducing energy cost in the day. Based on the different electricity price for the normal, off-peak and peak hours. The optimal location and operational power of BESS have been optimized. The calculated results on the 18-bus DS for the four scenarios consisting of the DS without BESS placement, the DS with BESS placement, the DS existing PVS without BESS placement and the DS existing PVS with BESS placement have been shown that in scenario of the DS with BESS placement, the energy cost has been reduced by 0.64% compared to the DS without BESS placement. For the DS with PVS, the optimal BESS placement has been reduced 0.79% of energy cost compared to the DS existing PVS without BESS placement. The calculated results have also demonstrated that optimal BESS placement on the DS existing PVS is the best solution for reduction energy cost.The energy cost reductions compared to the original scenario of this scenario is 3.81% while this number is respectively 3.81% and 0.64% for the DS existing PVS without BESS placement and the DS with BESS placement scenarios. Furthermore, in this work, WGA has been first applied for the optimal BESS placement problem. The statistical results gained by WGA for the considered problem with the small differences between the mean and min fitness values and the better performance compared to PSO show that WGA is an effective method for the optimal BESS placement problem on the DS. For future work, the problem considering to the BESS investment cost should be considered.

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