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Article

Bi-level Planning Model for Optimal Battery Energy Storage Allocation Considering Optimal Daily Scheduling Using Mixed-Integer Particle Swarm Optimization

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Abstract. This paper proposes a bi-level optimization (BLO) approach for optimal battery energy storage system (BESS) allocation (OBA) in distribution network (DN) considering optimal BESS daily scheduling (OBDS). The objective is to obtain the best locations and daily scheduling of BESSs that minimize total energy loss in DNs. In the upper-level of the proposed BLO method, the OBA is solved by mixed-integer particle swarm optimization (MIPSO). Meanwhile, the OBDS is solved as a sub-problem by particle swarm optimization in the lower-level of BLO. The proposed BLO based OBA considering OBDS algorithm had been tested with IEEE 33-bus radial distribution test system using load profile of Thai's power system during summer, winter, and rainy seasons comparing to mixed-integer genetic algorithm (MIGA) method. The simulation result showed that the proposed lower-level OBDS can efficiently minimize the total daily loss by BESS scheduling. Moreover, the proposed algorithm can also achieve the optimal placement of BESS.

Keywords: Battery energy storage system, daily loss minimization, optimal daily scheduling, optimal placement, particle swarm optimization, radial distribution system.

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1. Introduction

Nowadays, the demand for electricity is increasing with dramatical characteristics. The effects of renewable energy resources on distribution networks (DNs) have necessitated a change in traditional power distribution system development, operation, and management. The electrical system has become more complex under high distributed energy resources (DERs) conditions. As a result, the distribution system planning and management are playing more significant role in the development of the future energy system in accordance with the smart grid philosophy, which includes extensive use of information/communication technologies and innovative control systems to enable the realization of smart distribution systems, active demand participation, and energy storage system (ESS) [1]. Accordingly, ESS has become one of the most challenging and complex issue of the electricity industry both for the electric utilities and end-users applications. Among several different types of ESSs being used, battery energy storage system (BESS) is one of the most widely used ESS, especially for DERs managements. In practice, ESS can be used to reduce the electrical system peak demand and power loss [2]. Moreover, when considering how to implement the widespread integration of renewable energy resources (RERs), the application of ESS is essential [3]. Figure 1 explains that the system demand can be handled efficiently if storage is incorporated into the electrical network. The common operation of BESS is to store the energy during light load condition and discharge the energy during peak load period, avoiding the operation of a peaking plant that only operates for a few hours per day as well as reducing the cost of electricity.

In DNs, power loss minimization is important issue in both planning and operation. Therefore, many researches have been done under the objective of minimizing power loss in power transmission and distribution systems. For example, reference [4] used switch capacitor banks and voltage control, such as automatic load tap changing (ALTC) transformers, PV generator, reactive power adjustment, capacitive and reactive compensation to minimize loss. Consequently, fuzzy multi-objective method using genetic algorithm (GA) [5], particle swarm optimization (PSO) [6], and Locust Search method (LS) [7] are also proposed for distribution system loss minimization. Distribution system reconfiguration (DSR) is also interesting for power loss reduction and voltage profile improvement. In [8], modified particle swarm optimization (MPSO) is used to solve the distribution system reconfiguration for real power loss minimization.

Meanwhile, the optimal placements of distributed generators (DGs) for DN loss minimization are proposed by many researches [9-10]. However, the DGs allocations are subjected to many factors and mainly depended on geographical condition, in practice.

The more realistic issue is the optimal placement of capacitor bank (CB) with the aim of minimizing total loss [11-15], because CB can be installed mostly all over the DN. However, the study for DGs and CBs allocation are usually based on single loading condition of the system without considering the daily load profile (DLP).

Similar to other resources, BESS can be feasibly solved particularly in terms of optimizing the available capacity, increasing reliability, balance the fluctuations in supply and meet the ever-growing demand of electricity [16], as well as real power loss minimization. For that reason, when properly allocated, BESS provide benefit in significant reductions on power loss [17].

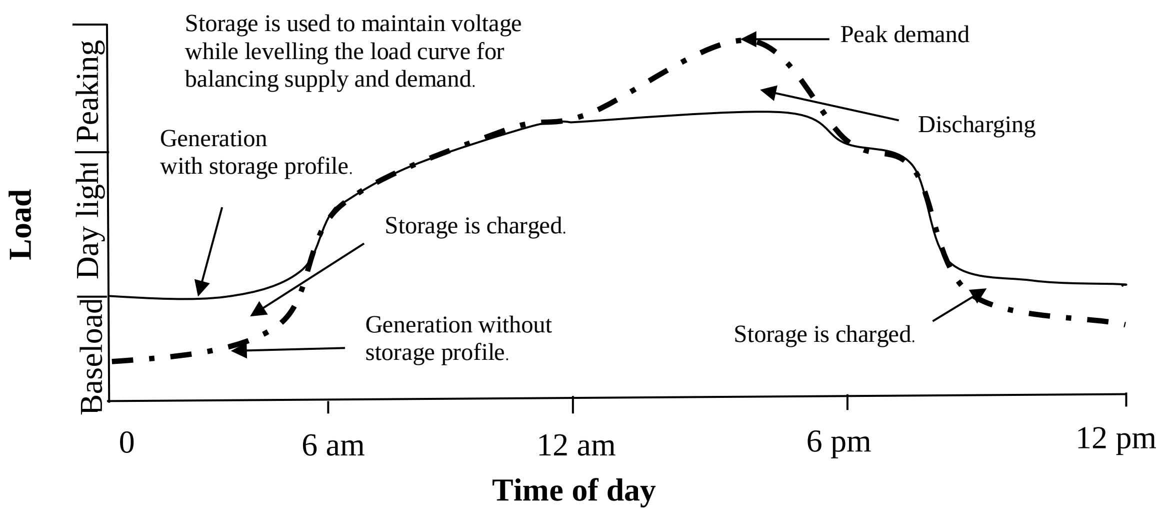

Fig. 1. Typical conceptual operation of BESS.

The frameworks for efficient operation scheduling of battery energy storage systems (BESSs) in distribution systems in conjunction with RERs has been proposed by many researches. The authors in reference [18] used Tabu search algorithm for BESS daily optimal operation considering net present value for fuel and CO2 emissions economic evaluation. In [19], a method for the optimal scheduling of distributed energy storage units was proposed. The simulation studies showed that levelling the load curve with an energy storage system can reduce transmission losses in a distribution system by Lagrange relaxation model. The optimum BESS scheduling algorithm considering multivariate forecasting model incorporating very-short-term and short-term forecasting models was proposed in [20]. The mathematical models for RERs and BESS are integrated into the problem in [21] for solving multiple objective functions which are loss, imbalanced power at the substation, total energy costs, and peak demand minimization of DN. Reference [22] presented the reliability and cost-based sizing of solar-wind-battery storage system for an isolated hybrid power system considering reliability indices and total life cycle cost. Meanwhile, a renewable energy-based power generation system facilitated by storage has been proposed in [23] with practical case study.

In practice, to obtain the desired placement of RERs are difficult due to the RERs usually requires specific installation locations and areas. Meanwhile, the BESSs require least installation area for located at the best benefit to the DN. Many proposed researches showed that optimal siting and sizing of BESS can help keep voltages within the range, line ampacity and also minimize energy losses in the IEEE radial distribution test system. Therefore, the location of the BESS in the system are also the key challenges in integrating the BESS and RERs to the power system network [24]. To locate a suitable site and location for the installation of BESSs, the research study in [25-26] investigated the system losses and power quality challenges related with high Photovoltaic (PV) deployment in a grid network, and developed an algorithm-based BESS capacity optimization and placement methodology. Moreover, many techniques had been proposed optimal placement of the BESS, such as,

heuristic techniques [27], the exchange market algorithm (EMA) [26-28] and PSO [29-30]. However, to obtain the best solution of BESS optimal location, the optimal operation of BESS should be incorporated in the problem and, therefore, the complex mixed-integer optimization techniques are required.

This paper, therefore, proposes the optimal planning model for BESS allocation. The proposed method formulates the problem into bi-level optimization (BLO) including optimal BESS allocation (OBA) as an upper-level optimization problem and optimal BESS daily scheduling (OBDS) as a lower-level optimization sub-problem. In this paper, the total energy loss of DN during BESS annual operation is used as the objective. The PSO [31], with mixed-integer formulation, is used to solved the proposed BLO based OBA considering OBDS. The modified IEEE 33-bus distribution test system is used to test the proposed method with Thai's power system load profile during summer, winter, and rainy seasons. The cases study with different BESS conditions including high penetration of photovoltaic power plant (PVPP) are investigated.

The organization of this paper is as follows: Section 2. addresses the system modeling. The proposed BLO based OBA considering OBDS is given in Section 3. The simulation result on the radial distribution IEEE-33 bus test system are illustrated in Section 4. Lastly, the conclusion is given in Section 5.

2. System Modelling

2.1. Power flow model

The modern distribution grid is usually including active resources, such as renewable power stations and ESS, not only passive load demand as shown in Fig. 2. Therefore, the power flow equations with DERs can be expressed as

$$P_{Gi}^{h}-\left(P_{Di}^{h}-\left(\frac{\eta_c}{\eta_c}\right)C_{ess,i}^{h}-P_{RE,i}^{h}\right) = \sum_{j=1}^{NB}\left|V_i^h\right|\left|V_j^h\right|\left|y_{ij}\right|\cos\left(\theta_{ij}-\delta_{ij}^{h}\right),$$

$$\text{for } i=1,\ldots,NB, h=1,\ldots,24, \tag{1}$$

$$Q_{Gi}^{h}-Q_{Di}^{h}=-\sum_{j=1}^{NB}\left|V_i^h\right|\left|V_j^h\right|\left|y_{ij}\right|\ sin(\theta_{ij}-\ \delta_{ij}^{h}),$$
$$\text{for } i=1,\ldots,NB, h=1,\ldots,24, \tag{2}$$

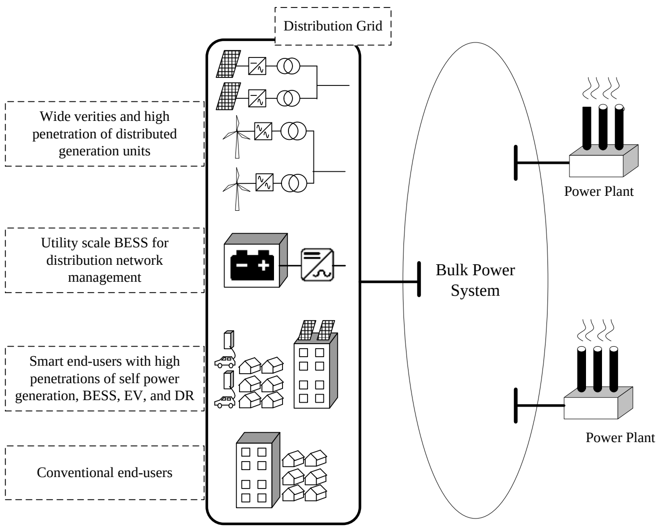

Fig. 2. A structure of distribution system with DERs.

where

P_{Gi}^h, Q_{Gi}^h are the real power and reactive of generator connected bus *i* in each hour, respectively,

P_{Di}^h, Q_{Di}^h are the real power and reactive power at bus i in each hour, respectively,
$|V_i|^h$ is the voltage magnitude of bus i,
$|y_{ij}|$ is the magnitude of the y_{ij} element of Y_{bus},
θ_{ij} is the angle of the y_{ij} element of Y_{bus},
$C^h_{ess,i}$ is the power scheduling of BESS in hour h,
η_c, η_d are the charging and discharging efficiency of BESS,
$P^h_{RE,i}$ is real power from RER stations i at hour h.

2.2. BESS State of Charge (SOC) Model

In this part, the model of BESS includes the energy capacity, the capacity of power charging and discharging, considering efficiency of charging and discharging is illustrated [18]. The ESS state of charge (SOC) is represented as [31],

$$\boldsymbol{ES} = \left[ES_i^1, \ldots, ES_i^h, \ldots, ES_i^{24}\right], \quad \text{for } i\ 1, \ldots, NBESS, h = 1, \ldots, 24, \tag{3}$$

$$0 \le ES_i^h \le ES_i^{h,max}, \quad \text{for } i = 1, \ldots, NBESS, h = 1, \ldots, 24, \tag{4}$$

$$\boldsymbol{C_{bess}} = \left[C_{bess,i}^1, \ldots, C_{bess,i}^h, \ldots, C_{bess,i}^{24}\quad\right], \quad \text{for } i = 1, \ldots, NBESS, h = 1, \ldots, 24, \tag{5}$$

$$C_{bess,i}^{h,\min} \le C_{bess,i}^h \le C_{bess,i}^{h,\max} \quad \text{for } i = 1, \ldots, NBESS, h = 1, \ldots, 24, \tag{6}$$

$$C_{bess,i}^h = \begin{cases} ES_i^1, & h=1 \\ ES_i^h - ES_i^{h-1}, & h=2,\ldots,24 \end{cases} \quad \text{for } i = 1, \ldots, NBESS, h = 1, \ldots, 24, \tag{7}$$

$$C_{rate,i}^{h,\min} \le C_{rate,i}^h \le C_{rate,i}^{h,\max}, \quad \text{for } i = 1, \ldots, NBESS, h = 1, \ldots, 24, \tag{8}$$

$$C_{rate,i}^h = \frac{C_{bess,i}^h}{ES_i^{h,\max}} \times 100\% \quad \text{for } i = 1, \ldots, NBESS, h = 1, \ldots, 24, \tag{9}$$

$$SOC_i^{\min} \le SOC_i^h \le SOC_i^{\max} \quad \text{for } i = 1, \ldots, NBESS, h = 1, \ldots, 24, \tag{10}$$

$$SOC_i^h = \frac{ES_i^h}{ES_i^{h,max} 100\%} \quad \text{for } i = 1, \ldots, NBESS, h = 1, \ldots, 24, \tag{11}$$

where,
ES is matrix representing capacity of BESS,
ES_i^h is the capacity of i^{th} BESS at hour h,
C_{bess} is matrix of charge/discharge by BESS,
$C^h_{bess,i}$ is scheduling of i*th* BESS at hour h,
C^h_{rate} is the rate of charge/discharge by i^{th} BESS at hour h, and
NBESS is number of BESS, and
SOC^h_i is the state of charge by the i^{th} BESS at hour h.

The bus allocation of BESS is defined as,

$$B = \left[b_{bess,1}, \ldots, b_{bess,i}, \ldots, b_{bess,NESS}\right]^T, \quad 1 \le b_i \le NB \tag{12}$$

where
B is the matrix representing bus number with BESS,
$b_{bess,i}$ is the bus number connected of BESS, and
NBESS is number of BESS in the system.

3. BLO Problem Formulation

3.1. BLO Based OBA Considering OBDS

The proposed BLO based OBA considering OBDS include the lower-level OBDS sub-problem for BESS daily scheduling for total daily loss optimization and the upper-level OBA for optimal allocation of BESS, as shown in Fig. 3. In Fig. 3, the bus allocation for BESS (B) is the search variables from OBA sent to OBDS. Meanwhile, the BESS daily scheduling (C_{bess}) is the output of OBDS for coordination with OBA. The mixed-integer PSO (MIPSO) is used to solve the BLO based OBA considering OBDS problem.

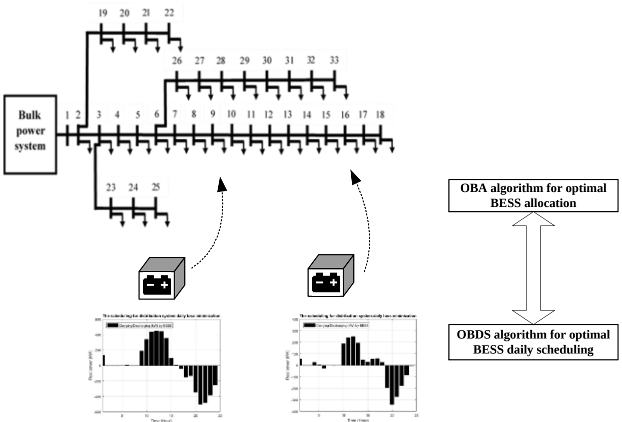

Fig. 3. The proposed BLO based OBA considering OBDS computation.

In the upper-level OBA, the objective function can be represented as,

Minimize

$$TAL = D^s E^s_{loss,total}(\boldsymbol{B}, \boldsymbol{C}^s_{bess}) + D^r E^r_{loss,total}(\boldsymbol{B}, \boldsymbol{C}^r_{bess}) + D^w E^w_{loss,total}(\boldsymbol{B}, \boldsymbol{C}^w_{bess}). \tag{13}$$

where
TAL is total annual loss,
D^s, D^r, and D^w are the number of days in summer, rainy, and winter, respectively,
$E^s_{loss,total}$, $E^r_{loss,total}$, $E^w_{loss,total}$ are the average total daily losses in summer, rainy, and winter, respectively.
$E^s_{loss,total}$, $E^r_{loss,total}$, and $E^w_{loss,total}$ are obtained from the lower-level OBDS.

The objective function distribution system daily loss minimization problem is formulated as follows:

Minimize

$$E^k_{loss,total} = \sum_{h=1}^{24} P^{k,h}_{loss}\,(\boldsymbol{B}, \boldsymbol{C}^k_{bess}) \quad \text{, for } k = s, r, \text{ and } w. \tag{14}$$

The Newton-Raphson power flow is used to solve for the system hourly loss ($P^{k,h}_{loss}$) using Eqs. (1) and (2). The operating constraints are the power generation constraints, line flow limit constraints, and the bus voltage limit constraints, as in Eq. (15)-(18).

$$P^{\min}_{Gi} \le P^h_{Gi} \le P^{\max}_{Gi} \quad \text{, for } i = 1,...,NG,\ h = 1,\ldots,24 \tag{15}$$

$$Q^{\min}_{Gi} \le Q^h_{Gi} \le Q^{\max}_{Gi} \quad \text{, for } i = 1,...,NG,\ h = 1,\ldots,24, \tag{16}$$

$$|f^h_i| \le f^{max}_i \text{, for } i = 1,...NL,\ h = 1,\ldots,24, \text{ and} \tag{17}$$

$$\left|V^{\min}_i\right| \le \left|V^h_i\right| \le \left|V^{\max}_i\right| \text{, for } i = 1,...,NL,\ h = 1,\ldots,24. \tag{18}$$

where
P_{Gi}^{min}, P_{Gi}^{max} are the minimum and maximum real power generation limit at bus i ,
Q_{Gi}^{min}, Q_{Gi}^{max} are the minimum and maximum reactive power generation limit at bus i ,
P_{Gi}^h is the real power generation limit at bus i in hour h,
Q_{Gi}^h is the reactive power generation limit at bus i in hour h,
NG is total number of generators,
f_i^{max} is the MVA flow limit of line i ,
f_i^h is the MVA flow of line of line i in hour h, and
$|V_i^{min}|$, $|V_i^{max}|$ are the minimum and maximum voltage magnitude for bus i.

3.2. MIPSO for BLO Based OBA Considering OBDS

3.2.1. Upper-level OBA

The upper-level for optimal allocation of BESS has the computational steps as follows:

Step 1: Set $t = 1$, initial set of particles (p_{ui}^t) for bus that connected with BESS (**B**) as Eq. (12).

Step 2: The rounding technique is introduced as an efficient method for finding location of ESS. $b_{ess,i}$ is position of particle representing the bus number for BESS placement, each particle is rounded during the iteration process, as follows:

$$b_{bess,i} = \begin{cases} b^{\max}_{bess,i},\ if\ \ b_{bess,i} + 0.5 \ge b^{\max}_{bess,i} \\ b^{\min}_{bess,i},\ if\ \ b_{bess,i} - 0.5 < b^{\min}_{bess,i} \end{cases}, \tag{19}$$

$$b^{\max}_{bess,i}, b^{\min}_{bess,i} \in \{\text{integer}\},\ i = 1,\ldots, NBESS. \tag{20}$$

Step 3: Obtain the TAL in Eq. (13) by **the lower-level OBDS**.

Step 4: Obtain $pbest_{ui}^t$ and $gbest_u^t$ from the particle that provides minimum TAL of the population i and minimum TAL among all populations. Then compute the upper-level velocity and update the particle position by,

$$v_{ui}^{t+1} = wv_{ui}^t + c_1r_1(pbest_{ui}^t - p_{ui}^t) + c_2r_2(gbest_u^t \ \ - p_{ui}^t), \tag{21}$$

$$p_{ui}^{t+1} = p_{ui}^t + v_{ui}^{t+1}\ , \tag{22}$$

where
w is the inertia weight factor decreasing from 0.9-0.4,
c_1, c_2 are the acceleration constants, which are 2.00,
r_1, r_2 are the uniform random values,
v_{ui}^t is the velocity of particle i at iteration t for upper-level OBA,

Step 5: If computation reach maximum number of iterations, go to Step 6, else, $t = t+1$ and go to Step 2.

Step 6: Stop.

3.2.2. Lower-level OBDS

In the OBDS, the optimal daily scheduling of BESS (ES) considering the allocation (B) from upper-level OBA is obtained by PSO algorithm. In the computation, ES^h_i is used to calculate $C^h_{bess,i}$ in each hour. Therefore, if $C^h_{bess,i} <$ 0, the BESS is in discharging condition, if $C^h_{bess,i} > 0$, the BESS is in charging condition shown in Figs. 4 and 5.

The lower-level OBDS computational steps are as follows:

Step 1: Obtain the bus allocation **(B)** from Step 3 of upper-level OBA.

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Step 2: set $n = 1$, initial set of particles (q_i^t) for BESS schedule (**ES**).

Step 3: Calculate $C^h_{bess,i}$ and $E^k_{loss,total}$ for $k = s, r,$ and w.

Step 4: Obtain $pbest_{li}^n$ and $gbest_l^n$ from the particle that provides minimum $E^k_{loss,total}$ of the population i and minimum $E^k_{loss,total}$ among all populations. Then compute the lower-level velocity and update the particle position by,

$$v_{li}^{n+1} = wv_{li}^n + c_1r_1(pbest_{li}^n - p_{li}^n) + c_2r_2(gbest_l^n - p_{li}^n) \quad (23)$$

$$p_{li}^{n+1} = p_{li}^n + v_{li}^{n+1} \quad (24)$$

where, v_{li}^t is the velocity of particle i at iteration t for lower-level OBDS,

Step 5: If computation reach maximum number of iterations, go to Step 6, else, $n = n+1$ and go to Step 2.

Step 6: Stop.

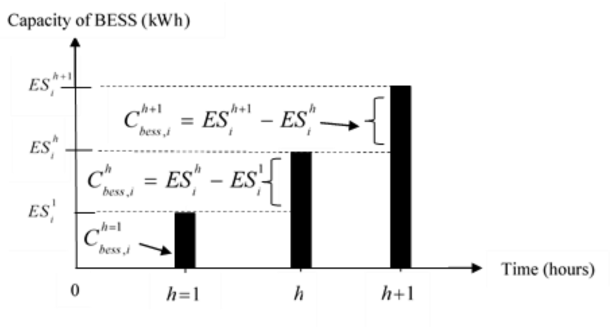

Fig. 4. The capacity of power charging.

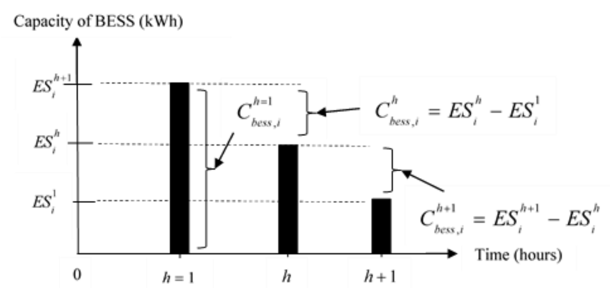

Fig. 5. The capacity of power discharging.

Note that the last capacity of BESS is set to the same condition of its initial capacity, in the computation.

4. Results and Discussion

In this section, the simulation results of the proposed BLO based OBA considering OBDS are presented. The proposed method was tested with IEEE 33-bus radial distribution test system [6] with some modification for cases study. The IEEE 33-bus radial distribution test system, as shown is Fig. 6.

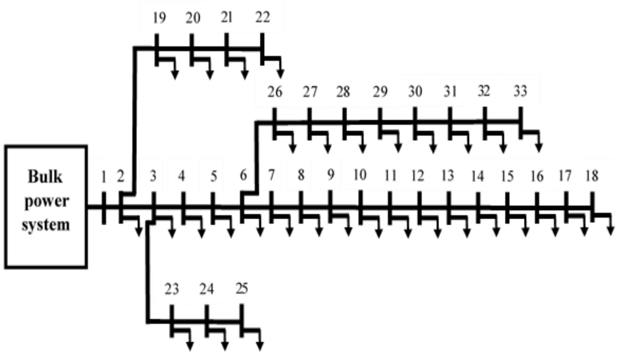

Fig. 6. IEEE 33-bus radial distribution test system.

This test system is composed of 33 buses and 32 lines, with the point of connection to bulk power system at bus 1. The voltage supplied by certain substation is 12.66 kV, while the remaining 32 load buses consume a total active and reactive power of 3,715.00 kW and 2,300.00 kVAR, respectively. The Thailand daily load curve is used as the system load profile including peak days of summer season (April 14th, 2018), rainy season (September 9th, 2018) and winter season (January 1st, 2018). Daily load curves of the test system are shown in Figs. 7-9.

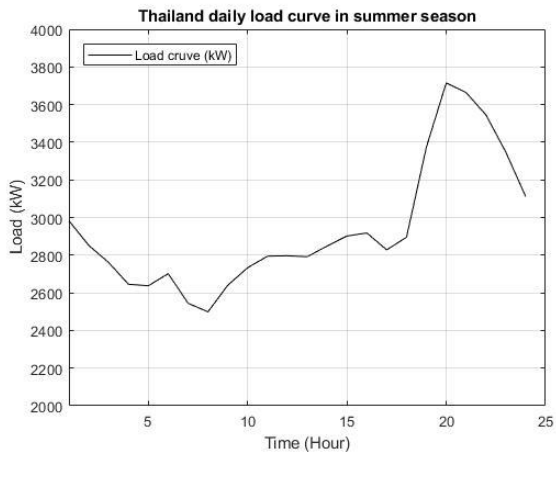

Fig. 7. Thailand daily load curve in peak days of summer season.

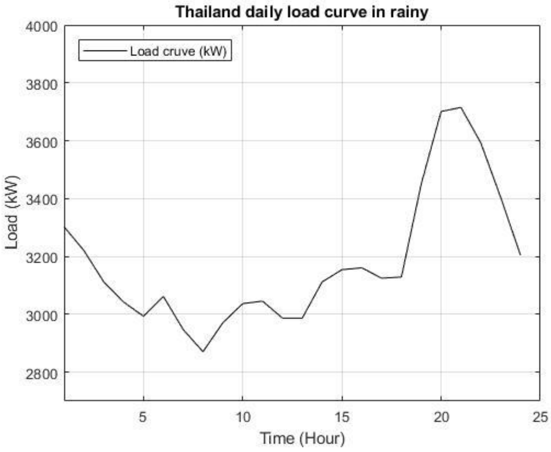

Fig. 8. Thailand daily load curve in peak days of rainy season.

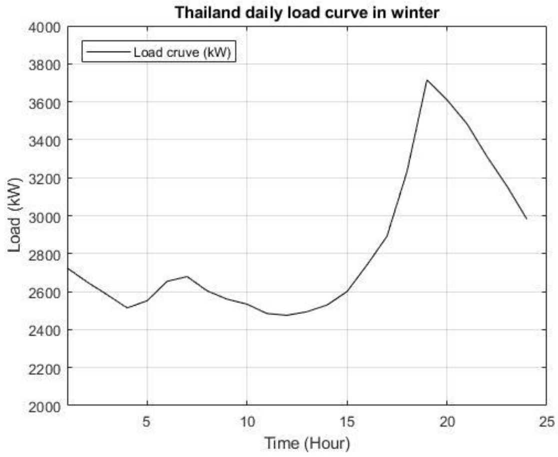

Fig. 9. Thailand daily load curve in peak days of winter season.

The simulation study includes,

1. Case 1: Base case of the original IEEE 33-bus radial distribution test system,
2. Case 2: The modified IEEE 33-bus radial distribution test system with PV stations,
3. Case 3: The OBA considering OBDS for single BESS of the modified IEEE 33-bus radial distribution test system with PV stations, and
4. Case 4: The OBA considering OBDS for multiple BESS of the modified IEEE 33-bus radial distribution test system with multiple BESS and PV stations.

4.1. Case 1

In this case, the load profile in Figs. 7 – 9 are used to calculate 24 hour demands at each bus of the IEEE-33 bus system. The total system daily loss are 3114.82 kWh, 3648.86 kWh and 2877.70 kWh, in summer, rainy, and winter seasons, respectively.

4.2. Case 2

In this case, the IEEE 33-bus radial distribution test system considers only PV stations, a total of six PV stations with the rated of 500 kW_p are added at buses 3, 8, 14, 25, 30, and 31, [15], as shown in Fig. 10. The PV power generation profile is based on the solar irradiance of Thailand. The system daily loss with PV stations are 2470.48 kWh, 2845.82 kWh, and 2346.35 kWh in summer, rainy, and winter seasons, respectively. The total daily loss and consumption from utility of Case 2 are lower than those of Case 1.

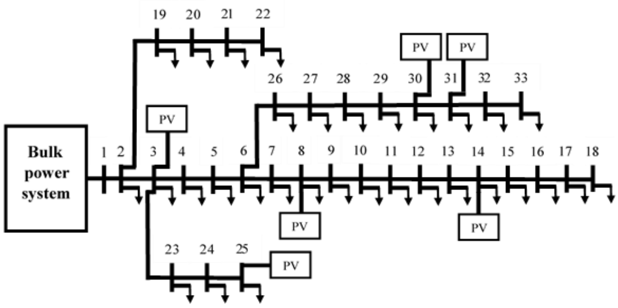

Fig. 10. The modified IEEE 33-bus radial distribution test system with PV stations.

4.3. Case 3

In this case, the optimal placement of the single BESS was investigated by solving for minimum daily loss. The 3000 kW BESS is used to test the proposed BLO based OBA considering OBDS. The charging and discharging efficiency of BESS, in this paper are 95% [18]. The result shown that the optimal location for BESS is at bus 14, shown in Fig. 11.

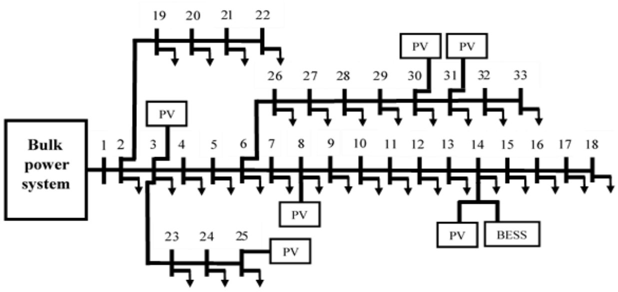

Fig. 11. The modified IEEE 33-bus radial distribution test system with single BESS and PV stations.

Figure 12 shows the convergence of the proposed method. The daily losses with PV stations and single BESS, are 2288.76 kWh in summer season, 2669.08 kWh in rainy season and 2155.30 kWh in winter season. The schedules of BESS are shown in Figs. 13-15.

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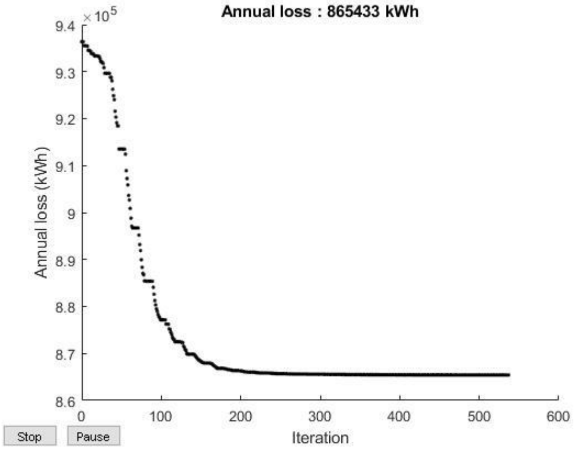

Fig. 12. Annual loss in each iteration for Case 3.

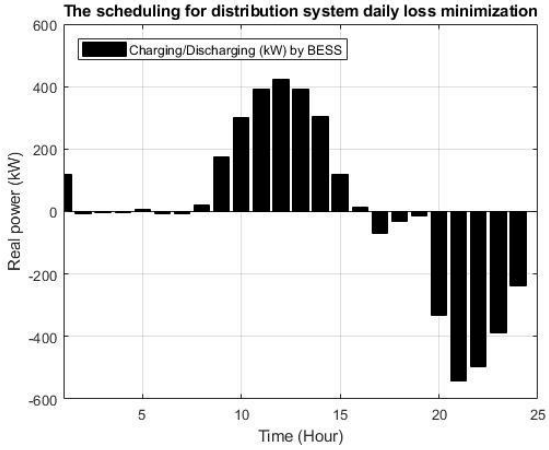

Fig. 13. The scheduling for distribution system daily loss minimization in summer season obtained from the lower-level OBDS for Case 3.

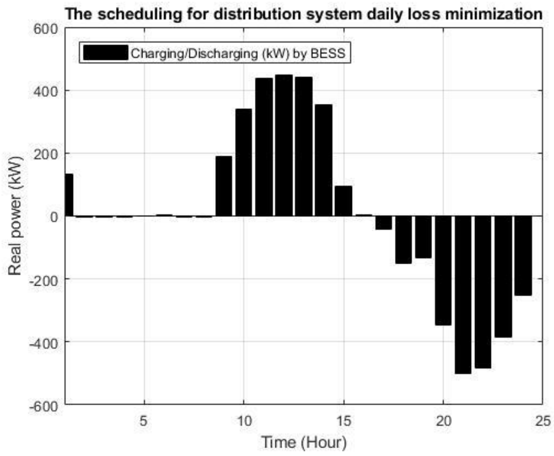

Fig. 14. The scheduling for distribution system daily loss minimization in rainy season obtained from the lower-level OBDS for Case 3.

The proposed method converged to the best value, in approximately 540 iterations. Figs. 13-15, show scheduling of BESS for total daily loss minimization with the BESS at bus 14. The state of charge by BESS as shown in Figs. 16-18. Figures 19-21 demonstrate the distribution system load profile comparison of IEEE 33 buses system with and without PV stations and single BESS. The total daily losses of Case 3 are lower than those of Case 2.

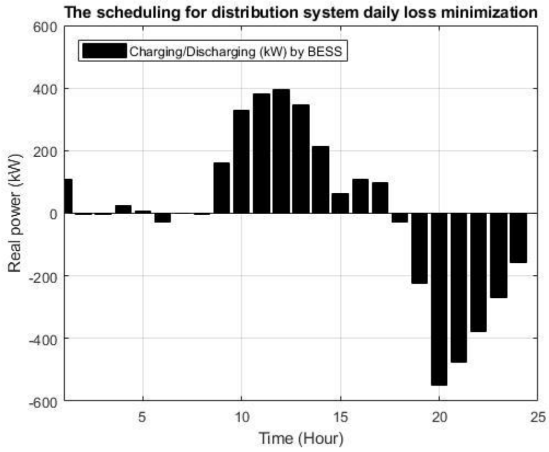

Fig. 15. The scheduling for distribution system daily loss minimization in winter season obtained from the lower-level OBDS for Case 3.

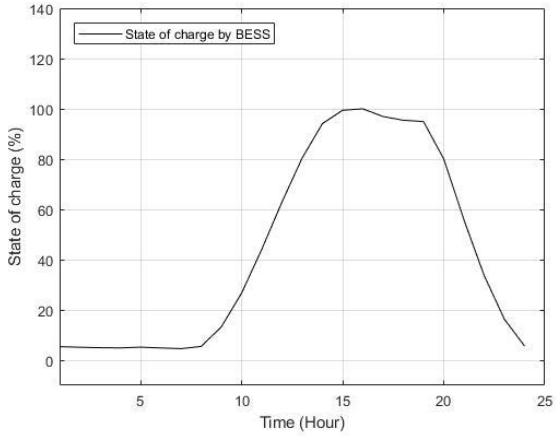

Fig. 16. The state of charge by BESS in summer season obtained from the lower-level OBDS for Case 3.

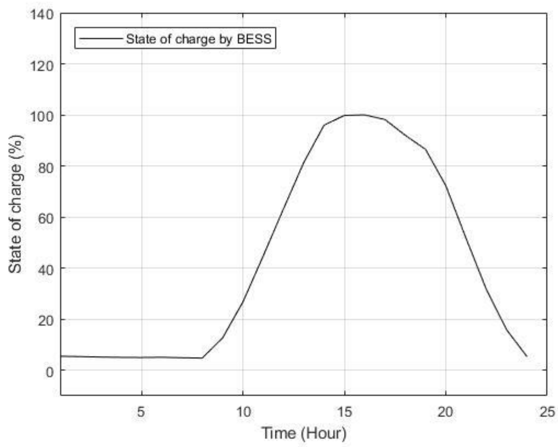

Fig. 17. The state of charge by BESS in rainy season obtained from the Lower-level OBDS for Case 3.

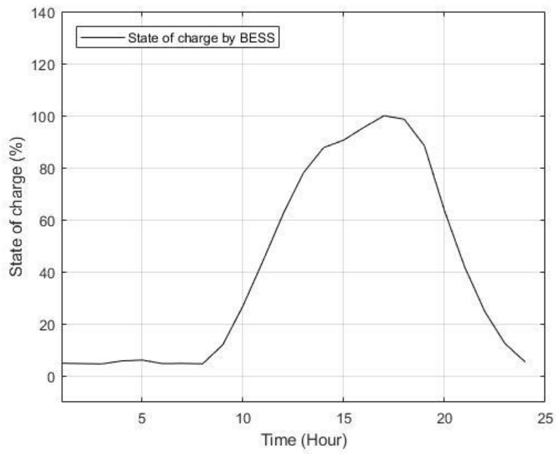

Fig. 18. The state of charge by BESS in winter season obtained from the lower-level OBDS for Case 3.

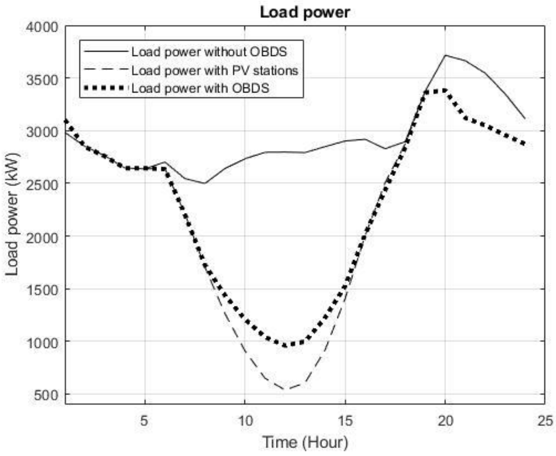

Fig. 19. The comparison of power load with and without OBDS by MIPSO method in summer season for Case 3.

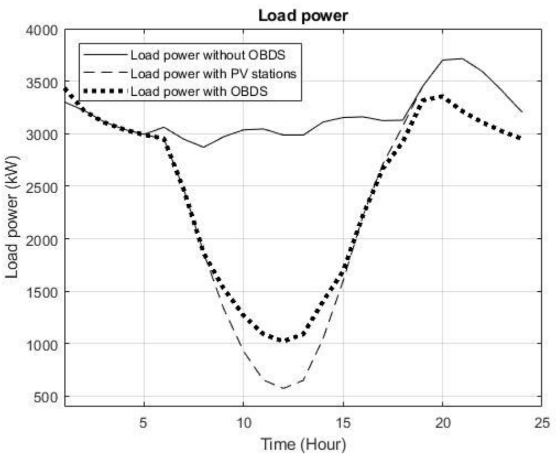

Fig. 20. The comparison of power load with and without OBDS by MIPSO method in rainy season for Case 3.

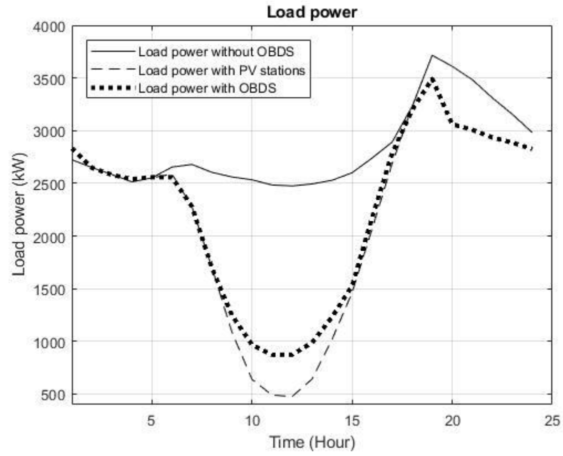

Fig. 21. The comparison of power load with and without OBDS by MIPSO method in winter season for Case 3.

4.4. Case 4

In This case, the optimal placement for multiple BESSs for minimum annual loss using the proposed method had been investigated. The two sets of 1500 kW BESS is used in this case. The propose BLO based OBA considering OBDS is used to optimally scheduling of energy storage system for allocate the BESSs in the IEEE 33-bus radial distribution test system with PVs.

As shown in Fig. 22, Bus14 and Bus 31 were resulted for optimal placement of BESS. The daily losses of Case 4 are reduced to 2259.21 kWh, 2635.59 kWh, and 2131.12 kWh, in summer, rainy, and winter seasons, respectively. Figure 23 shows the convergence of BLO base OBA considering OBDS, in 920 iterations. The distributed BESSs, in Case 4, can reduce daily losses from single BESSs in Case 3. The scheduling of distributed BESSs of Case 4 are shown in Figs. 24-29.

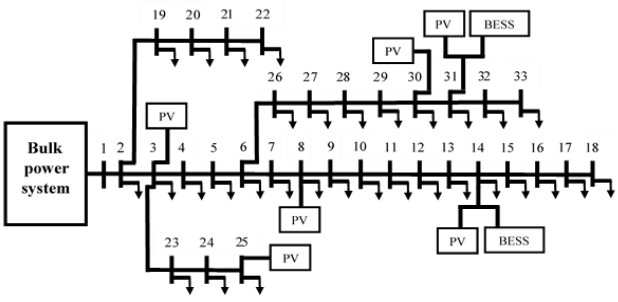

Fig. 22. The modified IEEE 33-bus radial distribution test system with distributed BESS and PV station.

From Figs. 24-29, the BESSs charge the energy during minimal load requirements (PV stations supply more power than necessary) and discharge the energy back to the system during peak hours, with the best location of

BESSs at bus 14 and 31. The state of charge by BESS as shown in Figs. 30-35.

Therefore, the proposed method is efficiency minimize the daily loss at distribution system by scheduling the BESSs. The comparison on load profile of IEEE 33-bus radial distribution test system with and without PV stations and BESSs are shown in Figs. 36-38. for summer, rainy, and winter seasons, respectively.

Table 1. addresses the summary results of Cases 1-4 of the modified IEEE 33-bus radial distribution test system. The mixed-integer genetic algorithm (MIGA) is also used to solve for Case 4 in order to compare with the proposed method. The results showed that MIPSO can provide the lower loss condition than that of MIGA. The proposed BLO base OBA considering OBDS using MIPSO can successfully allocate and provide the optimal daily scheduling of BESSs for loss minimization in DN.

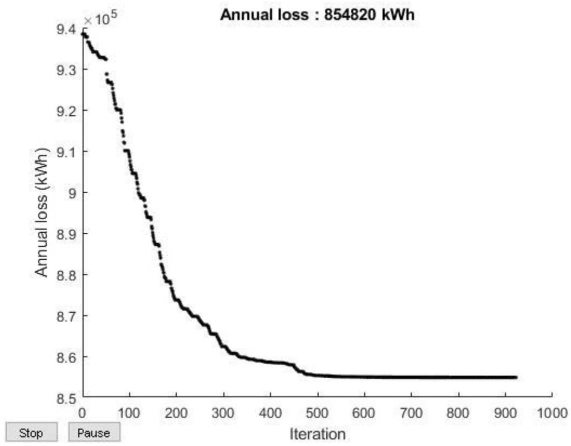

Fig. 23. Annual loss in each iteration for Case 4.

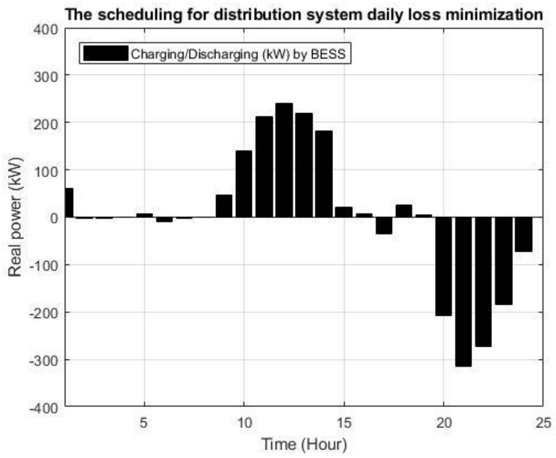

Fig. 24. The scheduling for distribution system daily loss minimization of BESS at bus 14 in summer season obtained from the lower-level OBDS for Case 4.

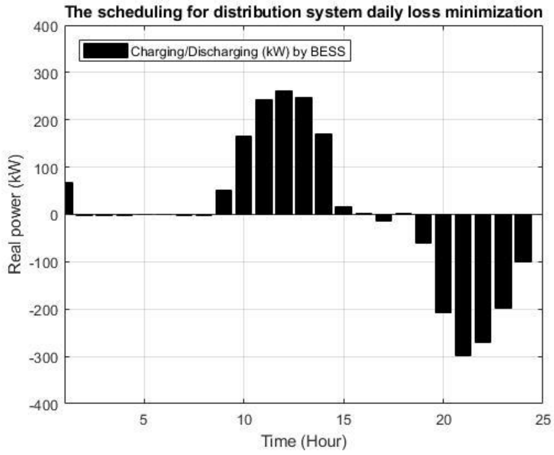

Fig. 25. The scheduling for distribution system daily loss minimization of BESS at bus 14 in rainy season obtained from the lower-level OBDS for Case 4.

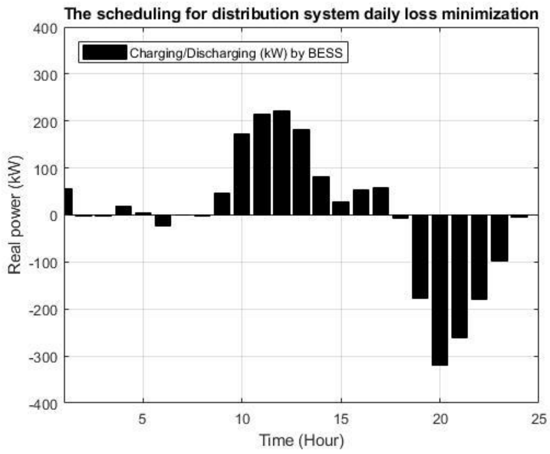

Fig. 26. The scheduling for distribution system daily loss minimization of BESS at bus 14 in winter season obtained from the lower-level OBDS for Case 4.

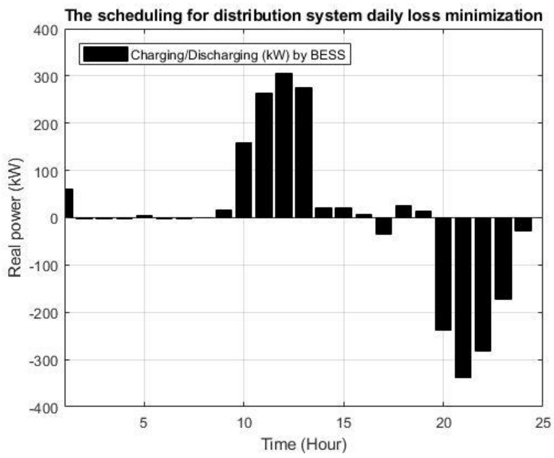

Fig. 27. The scheduling for distribution system daily loss minimization of BESS at bus 31 in summer season obtained from the lower-level OBDS for Case 4.

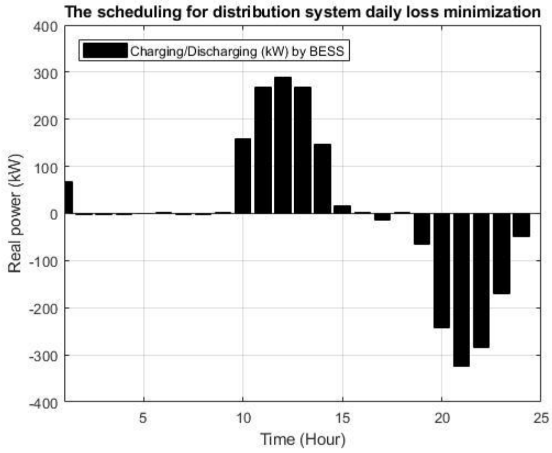

Fig. 28. The scheduling for distribution system daily loss minimization of BESS at bus 31 in rainy season obtained from the lower-level for Case 4.

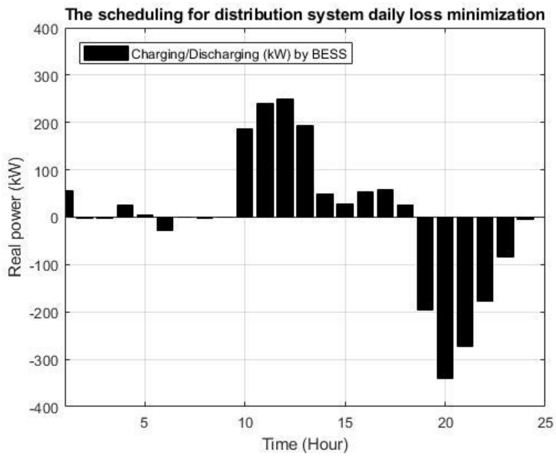

Fig. 29. The scheduling for distribution system daily loss minimization of BESS at bus 31 in winter season obtained from the lower-level OBDS for Case 4.

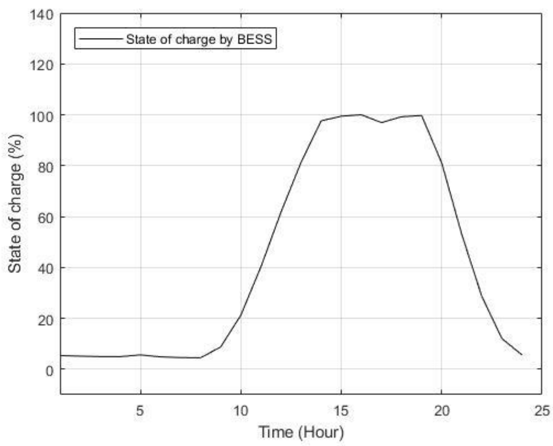

Fig. 30. The state of charge by BESS at bus 14 in summer season obtained from the lower-level OBDS for Case 4.

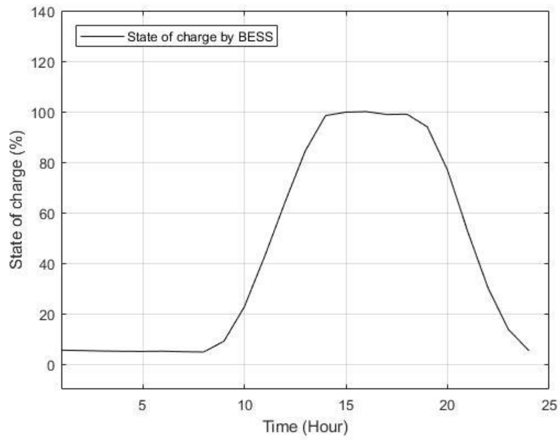

Fig. 31. The state of charge by BESS at bus 14 in rainy season obtained from the lower-level OBDS for Case 4.

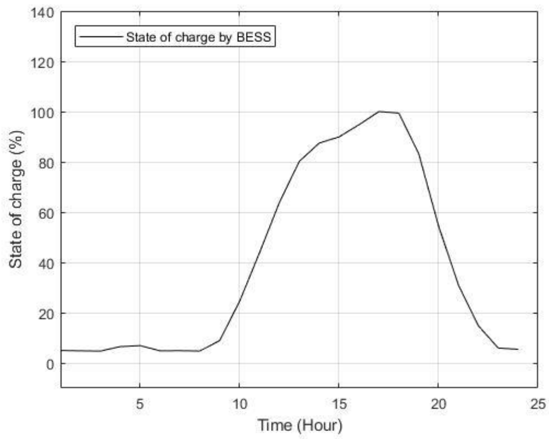

Fig. 32. The state of charge by BESS at bus 14 in winter season obtained from the lower-level OBDS for Case 4.

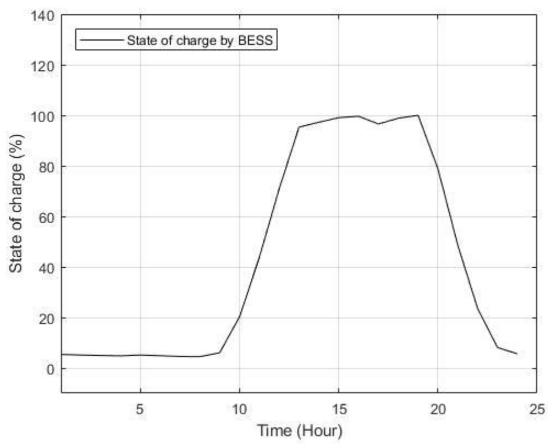

Fig. 33: The state of charge by BESS at bus 31 in summer season obtained from the lower-level OBDS for Case 4.

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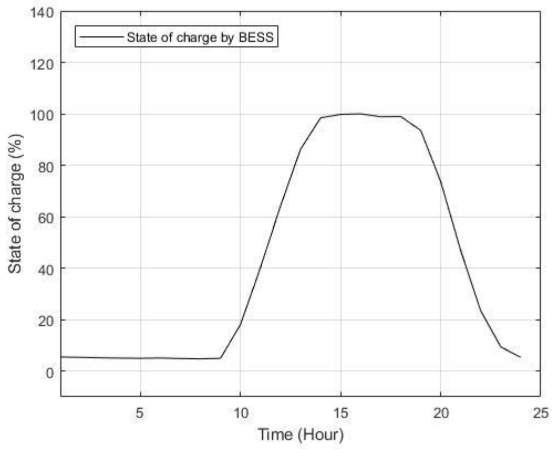

Fig. 34: The state of charge by BESS at bus 31 in rainy season obtained from the lower-level OBDS for Case 4.

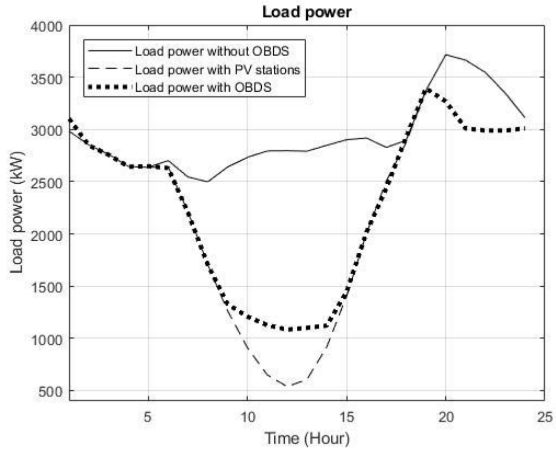

Fig. 36. The comparison of power load with and without OBDS by MIPSO method in summer season for Case 4.

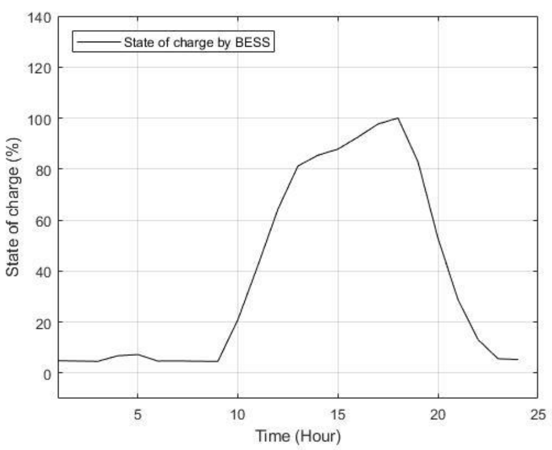

Fig. 35. The state of charge by BESS at bus 31 in winter season obtained from the lower-level OBDS for Case 4.

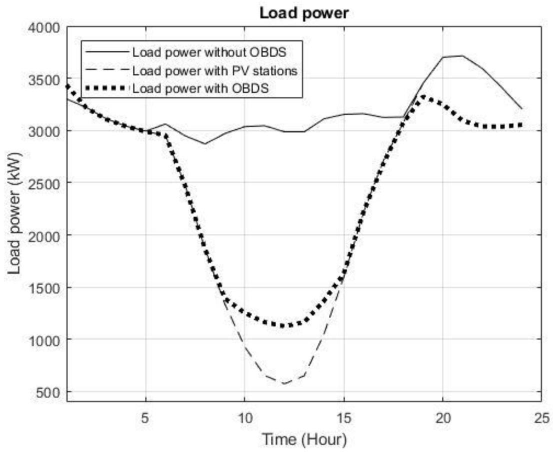

Fig. 37. The comparison of power load with and without OBDS by MIPSO method in rainy season for Case 4.

Table 1. Results of modified IEEE 33-bus radial distribution test system of Cases 1-4 solved by MIPSO and MIGA.

Case	**Solver**	**Annual loss (kWh)**	**Daily loss (kWh/day)**			**Loss Reduction (%)**
			Summer	**Rainy**	**Winter**	
Case 1	-	1173034.83	3114.82	3648.86	2877.70	**0.00**
Case 2	-	932288.37	2470.48	2845.82	2346.35	**20.52**
Case 3	MIPSO	865433.06	2288.76	2669.08	2155.30	**26.22**
Case 4	MIPSO	854820.04	2259.21	2635.59	2131.12	**27.13**
Case 4	MIGA	893743.74	2370.90	2739.29	2235.64	**23.81**

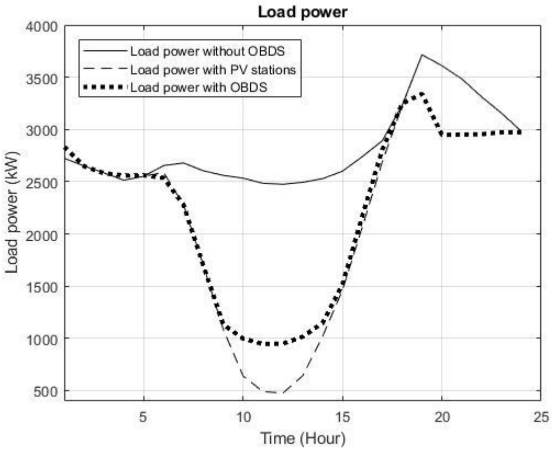

Fig. 38. The comparison of power load with and without OBDS by MIPSO method in winter season for Case 4.

5. Conclusions

In this paper, the BLO based OBA considering OBDS is proposed and solved by MIPSO. The proposed method had been tested with the modified IEEE 33-bus radial distribution test system, with PV stations and BESS using practical load profile. The results shown that the proposed lower-level OBDS can successfully minimize the daily loss by BESS optimal scheduling. Meanwhile, the proposed upper-level OBA can provide the optimal placement for BESSs, considering the OBDS.in each season. Therefore, the proposed method can be potentially used for both planning and daily operation of BESSs.

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Author Contributions

Keerati Chayakulkheeree developed the theoretical formalism and supervised the project. Korawitch Kaiyawong performed the analytic calculations. Korawitch Kaiyawong and Chakit Plongkrathoke performed the numerical simulations and data preparation. Korawitch Kaiyawong, Chakit Plongkrathoke and Keerati Chayakulkheeree contributed to the final version of the manuscript.

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