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Joint Scheduling and Capacity Optimization of ESS and EV Batteries in Grid-Connected and Islanded Microgrids

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Abstract

The increased penetration of renewable energy sources in microgrids brings significant uncertainty in power generation, which needs additional buffering and flexibility. Energy storage systems (ESS) are the conventional solution to compensate for this variability; however, their high capital cost limits large-scale deployment. Electric vehicles (EVs), equipped with onboard batteries, provide a promising complementary storage resource when integrated into microgrid scheduling. In this paper, we develop an optimal configuration model for battery storage capacity in grid-connected and islanded microgrids considering the participation of EVs in energy dispatch. The model jointly optimizes the ESS sizing, micro-turbine operation, renewable generation use, and EV charging/discharging strategy. To find the minimum required ESS capacity, an improved mixed-integer programming approach is applied and benchmarked against a particle swarm optimization solution. The simulation results of two representative scenarios show that the involvement of EVs could reduce ESS capacity requirements by up to 33% and decrease daily operating costs. Meanwhile, the improved MIP method provides faster convergence and more practical capacity configuration suitable for engineering deployment. The results confirm that EVs can serve as flexible storage resources, facilitating microgrid economic dispatch and reducing the cost of conventional ESS installations.

Keywords: Microgrid; Electric vehicle; Energy storage unit; Capacity optimization

الجدولة المشتركة والتهيئة المثلى لسعات أنظمة تخزين الطاقة وبطاريات المركبات الكهربائية في الشبكات المصغّرة المتصلة بالشبكة والمعزولة عنها

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الملخص :

تشهد الشبكات المصغّرة ارتفاعاً متزايداً في الاعتماد على مصادر الطاقة المتجددة، وهو ما يؤدي إلى تقلبات كبيرة في القدرة المولّدة ويستدعي حلولاً فعّالة لتعزيز المرونة التشغيلية. تُعدّ أنظمة تخزين الطاقة التقليدية (ESS) الوسيلة الأساسية لمعالجة هذه التقلبات، إلا أنّ تكلفتها الاستثمارية المرتفعة تحدّ من إمكانية نشرها على نطاق واسع. في هذا البحث، يُقترح نموذج أمثل لتحديد السعة المثلى لبطاريات التخزين في الشبكات المصغّرة بنمطَي التشغيل المرتبط بالشبكة والمعزول عنها، مع الأخذ في الاعتبار مشاركة المركبات الكهربائية في عملية الجدولة. يعتمد النموذج على تحسين تكاملي لكل من سعة منظومة التخزين، وتشغيل التوربينات الصغيرة، واستغلال مصادر الطاقة المتجددة، واستراتيجيات شحن وتفريغ بطاريات المركبات. ولتحقيق أفضل أداء اقتصادي، تم توظيف خوارزمية برمجة محسّنة (Improved MIP) ومقارنتها بخوارزمية (PSO)أظهرت نتائج المحاكاة أنّ إشراك المركبات الكهربائية في الجدولة يسهم في تقليل السعة المطلوبة لمنظومات التخزين الثابتة بنسبة تصل إلى 33%، مع خفض التكلفة التشغيلية اليومية، مما يؤكد جدوى المركبات الكهربائية كمصادر تخزين مرنة تدعم الجدولة الاقتصادية للشبكات المصغّرة.

Introduction

In order to make full use of the abundant clean and renewable energy resources in different places, provide "low carbon electricity" to customers, and achieve the goal of "energy saving and emission reduction in many countries, the distributed power generation and supply system is connected to the large grid in the form of microgrid [1] [2-3]. Alternatively, it can be operated independently [4], which is a very effective way to a distribute power generation and supply [4-5]. Recently, the use of electric vehicle (EV) has been widely received attention to reduce the emission of polluting es and dependence on oil resources. EV is battery-powered [6], which can reduce the emission and improve energy efficiency and is an effective way to solve energy and environmental problems. Access of EVs in microgrids may become an effective mode to alleviate current energy demand and environmental protection based on the advantages of both [7].

In the microgrid, distributed energy sources are very different from conventional energy sources. The main characteristics of these sources are the uncertainty and difficulty of controlling the output power of renewable energy sources such as wind and photovoltaic. To ensure safe and stable system operation, the energy storage unit system (ESS) becomes an important part of the microgrid system [8].

Capacity optimization of SSEs is one of several research areas for microgrid optimization, where many research on the problem of capacity optimization of microgrid ESS have been made. However, the EV is connected to the microgrid, because the EV has its own energy storage device, it is equivalent to adding an additional ESS to the microgrid. although, the EV after charging, in essence, ultimately draws power from the microgrid and increases the total load of the system, if the internal energy storage device of the EV can participate in the optimal scheduling of the microgrid after being connected to the microgrid, then under certain conditions EV can also act as microgrid ESS [9] and become the object of microgrid optimal dispatching, thus supplementing the original ESS of microgrid and possibly reducing the capacity of the original microgrid ESS, thus saving the input cost of ESS. Therefore, the capacity optimization allocation of microgrid ESS becomes a new research content after the EV is connected to the microgrid.

In the literature [10-11], a mathematical model for battery capacity optimization under the condition of including two power sources with completely random output, solar and wind, is considered; in the literature [12], an ESS capacity optimization problem based on the customer's time of use (TOU) rate is studied; in the literature [13], energy storage units are used as optimization variables and the first input cost and average daily operating cost are calculated and converted to the objective function In the literature [14], a mixed integer programming algorithm is used to quickly find the optimal value of energy storage unit capacity from the perspective of engineering practice, but the optimization of ESS after EV connection is not considered in the above literature; in the optimization after EV connection to microgrid, the literature [15] models and discusses the microgrid with EV switching station and battery storage station as energy storage units respectively. The results show that EVs as energy storage units can reduce the input of energy storage units in microgrid and make microgrid more economical through coordinated optimization, but the configuration of ESS capacity of microgrid is not analyzed; literature [16] establishes three objective optimization functions and models of EVs after EV access in distributed generation system, and optimizes the configuration of energy storage unit capacity in three different However, the literature only established the off-grid operation model, but did not study the optimization of ESS under the grid-connected operation condition after EV access.

In this paper, an optimization model of the ESS capacity of grid-connected and off-grid microgrids with PV, wind and micro- turbine power generation is developed, and solved with an improved mixed integer programming algorithm by analyzing two cases of whether EVs participate in system scheduling. By solving the established model and comparing with related research results, it is proved that EV participation in optimal scheduling can reduce the ESS input and figure out the minimum capacity of ESS.

2. Optimal Configuration Model of System Energy Storage Unit

2. 1 Mathematical model of photovoltaic power generation and wind power generation output

The photovoltaic output model follows the method described in [17]. Based on weather forecast data, the temperature coefficient of current, the reference solar irradiance and PV cell temperature, as well as the total solar radiation incident on the tilted surface of the PV array, are obtained. These parameters are then used to calculate the photovoltaic output power P_{pv}. The wind speed is assumed to follow a two-parameter Weibull distribution [18]. Using its corresponding probability density function, the wind speed v is derived, and subsequently, the output power of the wind generation system P_{w} is computed according to the model described in [19].

2. 2 battery storage model

To simplify the analysis, this study assumes that the battery terminal voltage remains constant during both charging and discharging processes [20]. The battery operates in two distinct modes charging and discharging. When the battery is discharging, it satisfies:

$$SoC_{batt}\,(t+1) = SoC_{batt}\,(t) - \Delta t\,\frac{P_{batt}^{d}}{\eta_d}, \quad \forall t \qquad (1)$$

When the battery is charged, it satisfies:

$$SoC_{batt}\,(t+1) = SoC_{batt}\,(t) + \Delta t\, P_{batt}^{c}\;\; \eta_c, \quad \forall t \qquad (2)$$

Where $\mathrm{SoC}_{\mathrm{batt}}(t)$denotes the state of charge of the battery at time t, $P_{c,\mathrm{batt}}$and $P_{d,\mathrm{batt}}$represent the battery charging and discharging power at time t, and $\eta_c$and $\eta_d$are the charging and discharging efficiencies, respectively. The cost of the energy storage system (ESS) includes both the initial capital investment and the annual maintenance expenses.

In practical applications, an ESS is composed of a battery pack, which itself consists of multiple individual battery modules. Therefore, the initial capital cost of the storage system, C_{ef}, included the purchase and installation cost of the battery pack, expressed in \$/kWh. Let $l$denote the battery lifetime (years) and $r$the annual financial interest rate. The annualized cost coefficient of the ESS, C_{ey}, can be obtained as:

$$C_{ey} = [\ (\frac{1+r)^{L}}{((1+r)^{L}-1)]C_{ef}} \qquad (3)$$

The annual maintenance cost factor of the energy storage system is denoted by C_m. Accordingly, the total daily operating cost of a battery storage unit with capacity $E_{ss}$is given by:

$$TC = \frac{C_Y * E_{BSS} + C_m * E_{BSS}}{365} \qquad (4)$$

2.3 EV Model

In this paper, it is assumed that all EVs connected to the microgrid are dispatchable, and each vehicle departs from the microgrid with a fully charged battery. After operating for one day and reconnecting to the system, the initial state of charge at the beginning of recharging is given by:

$$SoC_{ev} = \left(1 - \frac{L_D}{L_R}\right) 100\% \qquad (5)$$

Where $l_d$represents the actual distance traveled by the electric vehicle in one day with a full battery charge, and $L_r$denotes the maximum distance the vehicle can travel under full charge conditions. The daily travel distance $l_d$is assumed to follow a log-normal distribution, expressed as:

$$f(l) = \frac{1}{l\sigma_l\sqrt{2\pi}} \exp\left(-\frac{(ln\, l-\mu_l)^2}{2\sigma_t^2}\right) \qquad (6)$$

The operating state of the EV battery is divided into two modes charging and discharging [21]. When the EV is discharging, it satisfies:

$$SoC_{ev}\ (t+1) = SoC_{ev}\ (t) - \Delta t \frac{P_{ev}^{d}}{\eta_d}, \quad \forall t \qquad (7)$$

When charging the battery, meet:

$$SoC_{ev}\ (t+1) = SoC_{ev}\ (t) + \Delta t\ P_{ev}^{c}\ \ \eta_c, \quad \forall t \qquad (8)$$

Where $\mathrm{SOC_{ev}}(t)$denotes the state of charge of the EV battery at time t;

$P_{c,\mathrm{ev}}$and $P_{d,\mathrm{ev}}$represent the charging and discharging power of the EV battery at time t;

and $\eta_c$and $\eta_d$are the charging and discharging efficiencies, respectively.
The parameter Δtdenotes the duration of each time period.

2. 4 Microgrid operation optimization objective function

The primary objective of the microgrid's economic operation is to minimize both the fuel cost of the micro-turbine and the cost of electricity purchased from the main grid [22]. The objective function can therefore be expressed as:

$$\min F = \sum_{t=0}^{T} [\, C_u P_u(t) + C_t P_t(t) - C_S P_S(t)]\, \Delta\, t + TC \qquad (9)$$

Where $P_u(t)$, $P_t(t)$, and $P_s(t)$represent, respectively, the power imported from the public grid during time period t, the power generated by the micro-turbine, and the power exported from the microgrid to the public grid during time period t. The parameter $\Delta t$is set to one hour. The coefficients C_u, C_t, and $C_s$denote the unit price of electricity purchased from the grid, the unit fuel cost of the micro-turbine, and the unit revenue from selling electricity back to the grid, respectively, with units of $/kWh. The term $TC$is computed using Equation (4) and represents the total daily operating cost of the energy storage system.

When the microgrid operates in off-grid mode, both the imported power $P_u$and the exported power $P_s$are equal to zero.

2. 5 Constraints

By neglecting system losses, the following operational constraints must be satisfied:

1) Power balance constraints

$$P_u(t) + P_t(t) - P_s(t) + P_{batt}(t) + P_{ev}(t) = P_{load}(t) - P_{PV}(t) - P_{wt}(t),\ \forall t \qquad (10)$$

$$\begin{cases} 0 \le P_s(t) \\ 0 \le P_u(t) \end{cases} ,\forall t \qquad (11)$$

Where $P_{\mathrm{pv}}(t)$is the photovoltaic power output obtained from the hourly temperature and solar irradiance data of the given day, and $P_{\mathrm{wt}}(t)$is the wind turbine output derived according to the models presented in [18] and [19]. As indicated in Equation (9), during off-grid operation both the imported power from the public grid $P_u(t)$and the exported power to the grid $P_s(t)$are equal to zero.

2) Output constraint of micro turbine

$P_t^{min} \leq P_s(t) \leq P_t^{max} \ \ \forall t$ (12)

where: Ptmin , Ptmax are the minimum output power and maximum output power of the turbine.

3) Constraints on energy storage battery cells

Assuming that the battery terminal voltage remains essentially constant throughout the charging and discharging process, the battery output must also satisfy the following inequality constraints:

$$0 \leq P_{batt}^{d}(t) \leq P_{batt}^{dmax}(t), \quad \forall t \quad (13)$$

$$0 \leq P_{batt}^{c}(t) \leq P_{batt}^{cmax}(t), \quad \forall t \quad (14)$$

The battery capacity limit is restricted to:

$$SoC_{batt}^{min} \leq SoC_{batt}(t) \leq ESS, \quad \forall t \quad (15)$$

Where $P_{\mathrm{batt}}^{d,\mathrm{max}}$ and $P_{\mathrm{batt}}^{c,\mathrm{max}}$ denote the maximum discharge and charge power of the battery, respectively; $\mathrm{SoC}_{\mathrm{batt}}^{\mathrm{min}}$ represents the minimum allowable state of charge of the battery; and $\mathrm{SoC}_{\mathrm{batt}}^{\mathrm{max}} = ESS$corresponds to the maximum state of charge, which is equal to the battery capacity.

4) EV constraints

$$SoC_{ev}^{min} \leq SoC_{battev} \leq \ SoC_{ev}^{max} \ \ \forall t \quad (16)$$

$$0 \leq P_{ev}^{d}(t) \leq P_{ev}^{dmax}\ (t), \ \ \forall t \quad (17)$$

$$0 \leq P_{ev}^{c}(t) \leq P_{ev}^{cmax}\ (t), \ \ \forall t \quad 18)$$

Where $P_{\mathrm{ev}}^{d,\mathrm{max}}$and $P_{\mathrm{ev}}^{c,\mathrm{max}}$denote the maximum discharge and charge power of the EV battery, respectively;

$\mathrm{SoC}_{\mathrm{ev}}^{\mathrm{min}}$represents the minimum allowable state of charge of the EV battery; and

$\mathrm{SoC}_{\mathrm{ev}}^{\mathrm{max}}$represents the maximum allowable state of charge of the EV battery.

3 Optimization algorithm

3. 1 Improved mixed integer programming algorithm

The procedure for the improved mixed-integer programming algorithm is illustrated in Figure 1. The detailed steps are as follows:

1. Set ESS_{max}according to the scale of the microgrid. Determine $\Delta ESS$and other model parameters based on the actual project configuration.
2. Initialize the value of ESS.

3. Solve the optimization model in Equation (9).
4. If the current value of $ESS < ESS_{\max}$, update $ESS = ESS + \Delta ESS$, and return to Step 3. Repeat the process until a feasible solution satisfying $ESS \geq ESS_{\max}$ is obtained.

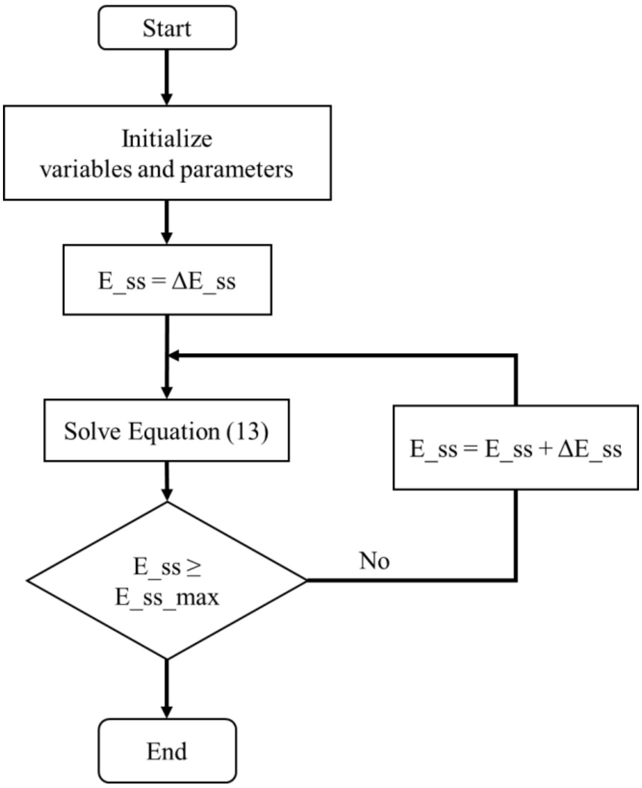

Fig. 1: Flowchart of the improved mixed integer programming algorithm

When solving Equation (9), the ESS capacity is considered as a decision variable, and the system becomes a six-variable nonlinear optimization problem. This problem can be solved using the particle swarm optimization (PSO) algorithm.

4 Example analysis

4. 1 Example scheme 1

A grid-connected microgrid in a certain region is used as a case study for calculation and analysis. The microgrid consists of a photovoltaic (PV) array, a wind farm, a micro-turbine, and a battery energy storage system. The maximum output power of the PV array is 400 kW, the rated output power of the wind turbine is 200 kW, and the total maximum output power of the micro-turbine is 300 kW. The power generation cost of the micro-turbine is 0.13 \$/kWh. The energy storage system adopts lead-acid batteries, with an investment cost of 70.72 \$/kWh and an annual maintenance cost of 4.24 \$/kWh. The annual financial interest rate is $r = 0.033$, and the battery lifetime l is set to 3 years.

It is assumed that 20 EVs are connected to the microgrid. The total capacity of the onboard lithium batteries is $EVSoC_{max} = 400$ kWh, with a maximum charging and discharging power of 80 kW and a minimum allowable EV state of charge $EVSoC_{min} = 80$ kWh. To align with an EV charging cycle, the optimization horizon starts at 13:00 each day and ends at 13:00 on the following day. The initial state of charge of the EVs connected to the microgrid is determined using Equation (5).

Excluding EVs, the total load in the region is 600 kW. Over the 24-hour optimization horizon, the forecasted PV output P_v, wind power output P_w, and load demand P_{load} are shown in Figure 2, while the time-of-use electricity price of the main grid is given in Table 1. Based on the microgrid scale in this example, the maximum ESS capacity $ESS_{max}$is set to 600 kWh, and the ESS capacity step size $\Delta ESS$is set to 50 kWh.

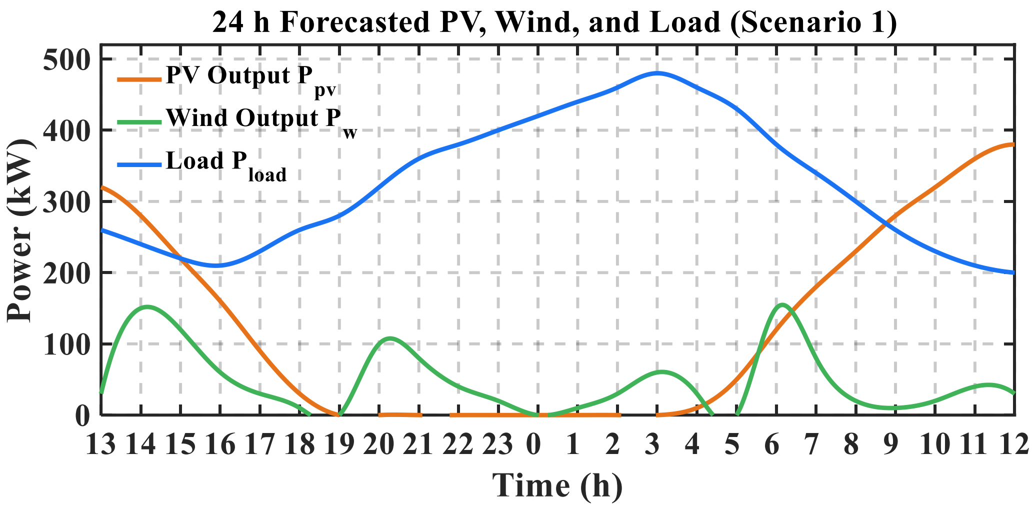

Fig. 2 DGs and the forecasted power of the load in 24 hours (scenario 1).

Table 1: The 24 hours electricity price in different

Time period	Peak time 8-11 o'clock, 18-21 o'clock	6-8 o'clock, 11-18 o'clock, 21-22 o'clock	Valley time 22 o'clock-6 o'clock the next day
Electricity purchase price	1.143	0. 685	0.333
Electricity price	0. 800	0.500	0.200

4. 1. 1 Calculation example

1) EV is not participating in scheduling

When EVs do not participate in scheduling, they are considered as additional loads equivalent to the EV charging power. It is assumed that EVs connect to the microgrid at 19:00 each day and disconnect at 07:00 the following morning. Upon connection, the vehicles begin charging at a constant rate. Under this scenario, P_{ev} in Equation (10) and the ESS capacity in Equation (9) are given as constants. The optimization model composed of Equations (1) (18) is then solved using the improved mixed-integer programming algorithm shown in Figure 1. The resulting optimal configuration of the energy storage system is presented in Figure 3. The minimum system operating cost obtained is 498.43 $, and the optimal ESS capacity is 300 kWh. Figure 4 illustrates the corresponding optimal scheduling of the system when the energy storage unit is configured at a capacity of 300 kWh.

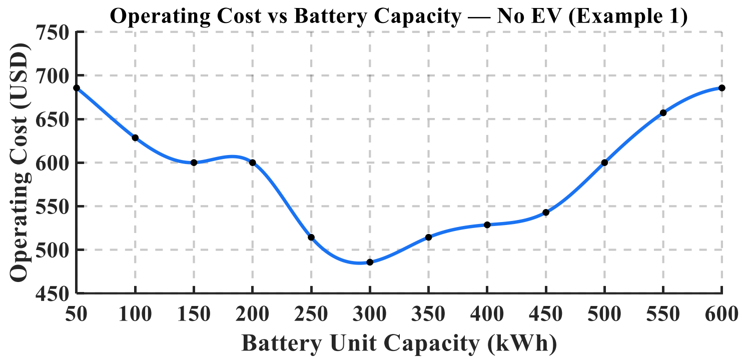

Fig. 3 The solved results of the improved mixed integer programming method under the scheduling condition without EV (scenario 1).

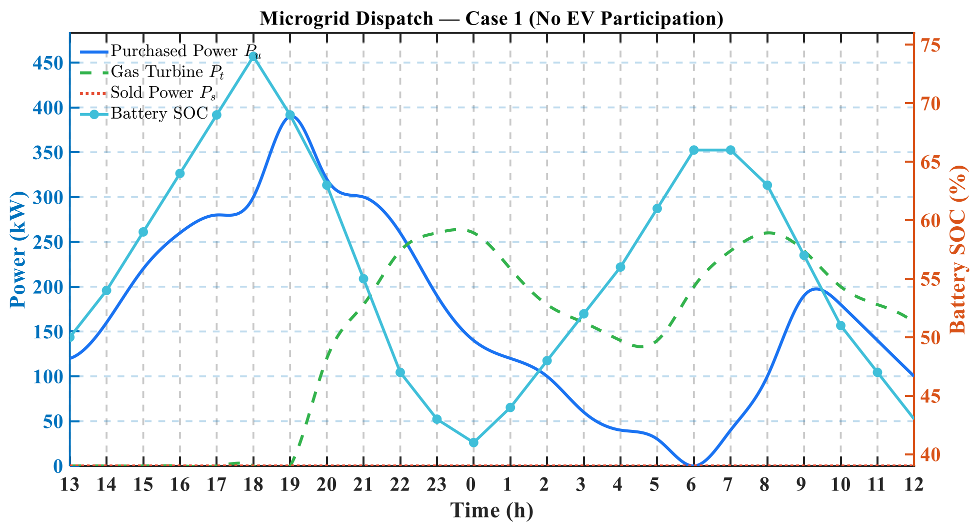

Fig. 4 The scheduling results for the 300 kWh energy storage system under the scheduling condition without EV (scenario 1).

By taking the ESS capacity in Equation (9) as a decision variable, the optimization model composed of Equations (1)–(18) is solved using the PSO algorithm. The optimal total system operating cost obtained is 491.28$, and the corresponding optimal ESS capacity is 267.6 kWh. The resulting optimal scheduling of the system under this configuration is shown in Figure 5.

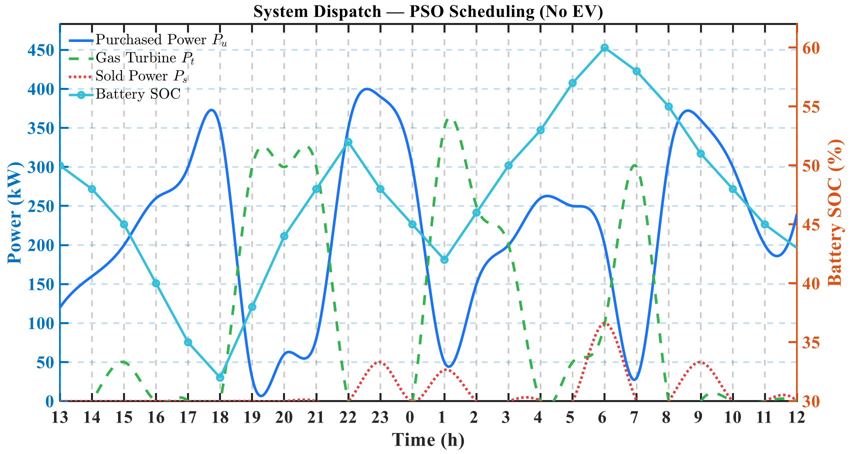

Fig.   5 System optimization results with PSO under the scheduling condition without EV

2) EV participation in scheduling

When EVs participate in dispatching, they function as additional energy storage units for the microgrid under certain operating conditions. The improved mixed-integer programming algorithm illustrated in Figure 1 is applied to solve the optimization model. The resulting optimal ESS configuration is shown in Figure 6. The minimum system operating cost obtained is 477.91 $, and the corresponding optimal ESS capacity is 200 kWh. Figure 7 presents the optimal scheduling results of the system when the energy storage unit capacity is configured at 200 kWh.

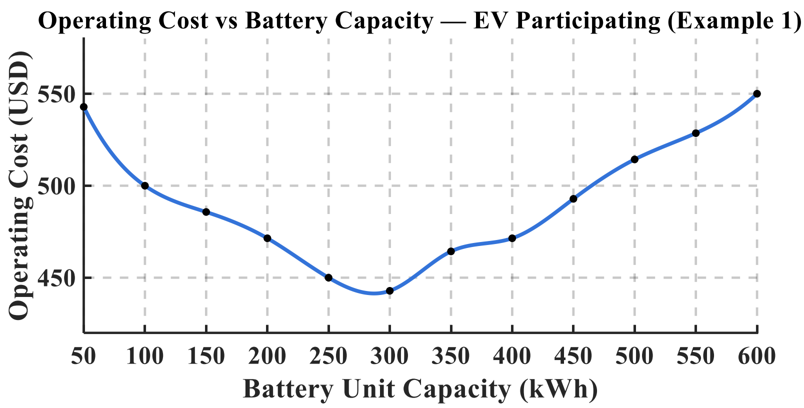

Fig.6: The solved results of the improved mixed integer programming method under the scheduling condition with EV (scenario 1).

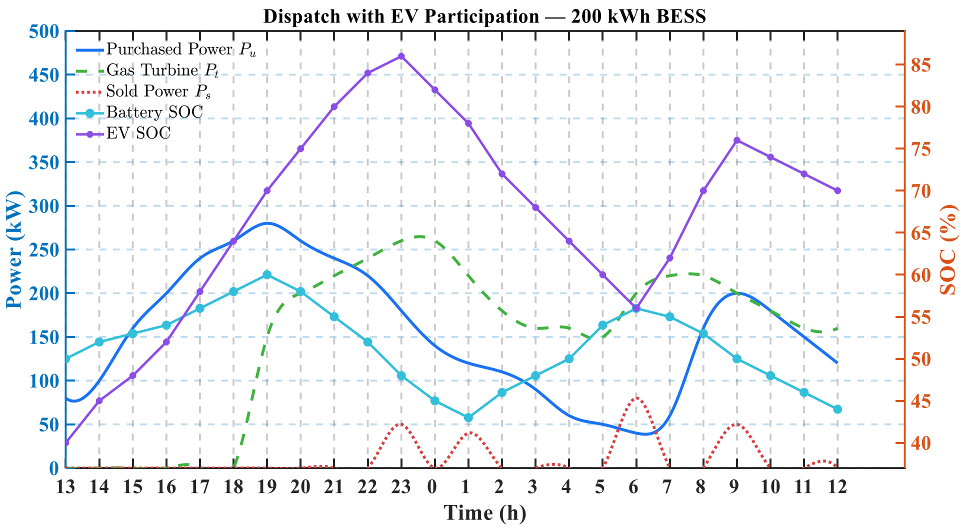

Fig.7: The scheduling results for the 200 kWh energy storage system under the scheduling condition with EV (scenario 1).

When the model is solved using the PSO algorithm, the optimal total system operating cost is 477.51 $, and the corresponding ESS capacity is 243.9 kWh. The optimal scheduling results under this configuration are illustrated in Figure 8.

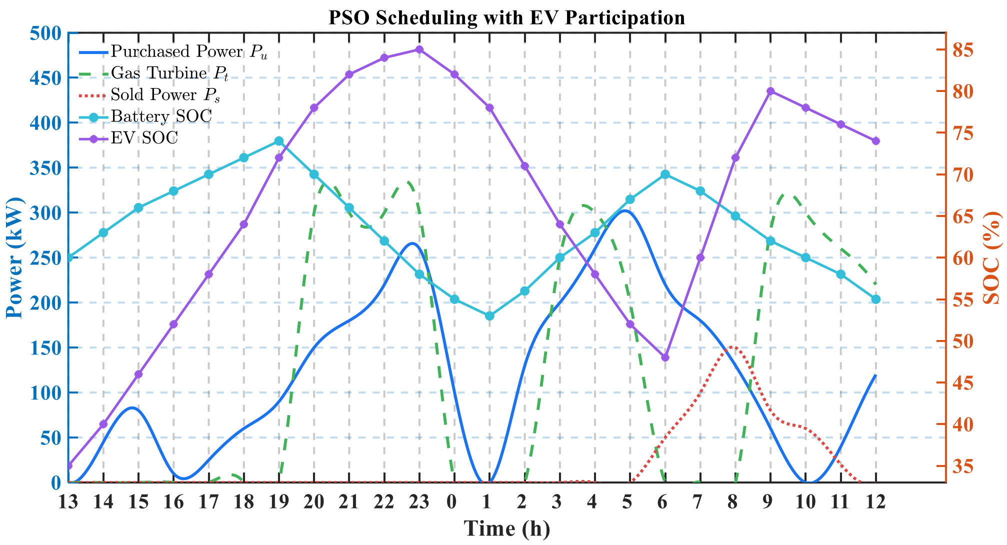

Fig. 8 System optimization results with PSO under the scheduling condition with EV

5. 1. 2 Analysis of results

A comparison of the two optimization approaches, as summarized in Table 2, leads to the following conclusions.

1. When EVs do not participate in scheduling and are connected to the microgrid solely as loads, the total system demand increases, which consequently results in higher operating costs.

2. When EVs are dispatched as auxiliary energy storage units and supply power to the microgrid load, the required capacity of the stationary battery storage unit decreases. As a result, the overall operating cost of the system is reduced.

3. Although the improved mixed-integer programming method does not always yield the global optimal solution when compared with the PSO algorithm, it offers practical advantages in engineering applications. In real systems, energy storage batteries are typically composed of discrete modular units with fixed capacities (e.g., 10 kWh or 50 kWh). The improved mixed-integer programming approach therefore provides more realistic and implementable ESS configuration strategies.

Table 2. Result comparison for different methods (scenario 1).

EV	**Optimization**	**Energy storage unit capacity configuration kWh**	**System operating cost/$**
Not participating in scheduling	Improved mixed integer programming	300. 0	498.43
	PSO algorithm	267. 6	491.28
Participate in scheduling	Mixed integer programming	200	477.91
	PSO algorithm	243.9	477.51

4. 2 Calculation scenario 2

Referring to the parameters of the off-grid microgrid example in [16], the maximum output power of the photovoltaic (PV) array is 80 kW, the rated output power of the wind turbine is 1,200 kW, and the total maximum output power of the micro-turbine is 60 kW. The electricity generation cost of the micro-turbine is 0.13 $/kWh. The energy storage system uses battery packs with an investment cost of 77.23 $/kWh and an annual maintenance cost of 4.24 $/kWh. The annual financial interest rate is $r = 0.033$, and the battery lifetime $l$is set to 3 years.

It is assumed that 40 EVs are connected to the microgrid. The total capacity of their onboard lithium batteries is $\mathrm{EVSOC_{max}} = 800$ kWh, and the maximum charging/discharging power of a single EV is 3.6 kW. The minimum allowable EV state of charge is $\mathrm{EVSOC_{min}} = 160$ kWh.

Excluding EVs, the total system load is 800 kW. Over the 24-hour optimization horizon, the forecasted PV power output P_v, wind power output P_w, and load demand P_{load} are presented in Figure 9. Based on the scale of the microgrid in this case, the maximum ESS capacity $ESS_{\max}$ is set to 600 kWh, and the ESS capacity increment ΔESS is set to 50 kWh.

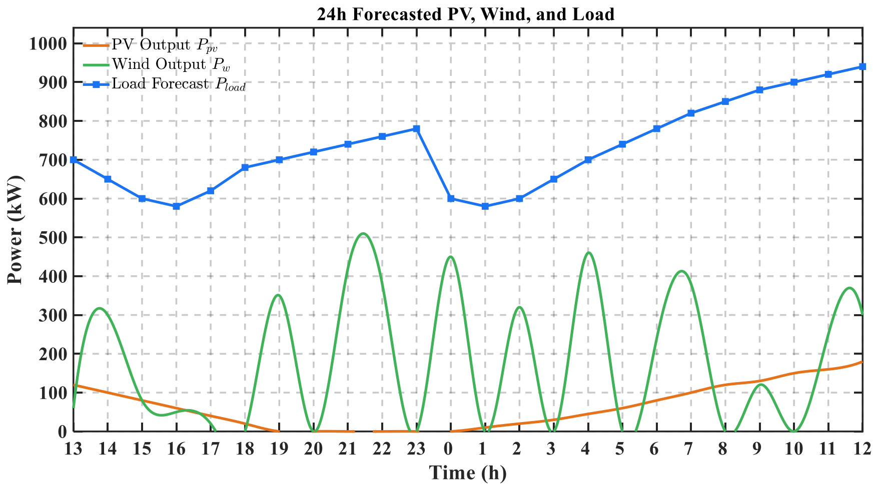

Fig. 9 DGs and the forecasted power of the load in 24 h (scenario 2)

4. 2. 1 Calculation scenario

1) EV does not participate in scheduling

Using the improved mixed-integer programming algorithm illustrated in Figure 1, the optimal configuration of the energy storage unit is obtained as shown in Figure 10. The resulting minimum system operating cost is 970.64 $, and the corresponding optimal ESS capacity is 400 kWh. Figure 11 presents the optimal scheduling results of the system when the ESS capacity is set to 400 kWh.

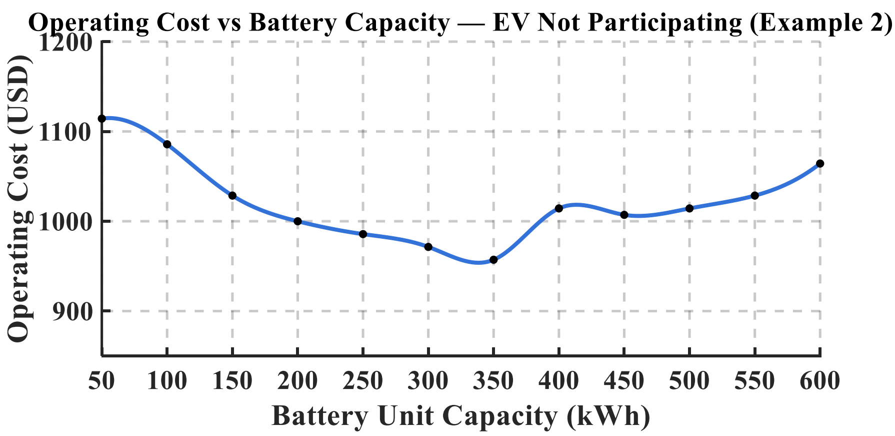

Fig. 10 The solved results of the improved mixed integer programming method under the scheduling condition without EV (scenario 2).

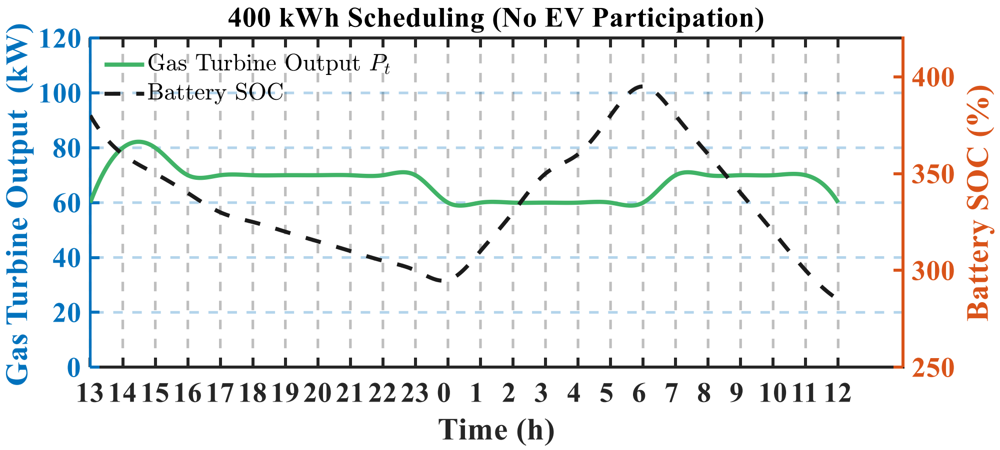

Fig. 11 The scheduling results for the 400 kWh energy storage system under the scheduling condition without EV (scenario 2).

2) EV participation in scheduling

When EVs participate in dispatching, they act as additional energy storage resources for the microgrid under specific operating conditions. Using the improved mixed-integer programming algorithm presented in Figure 1, the optimal configuration of the energy storage unit is obtained, as shown in Figure 12. The minimum system operating cost in this case is 905.62 $, and the corresponding optimal ESS capacity is 300 kWh. Figure 13 illustrates the optimal dispatching results of the system when the ESS capacity is configured to 300 kWh.

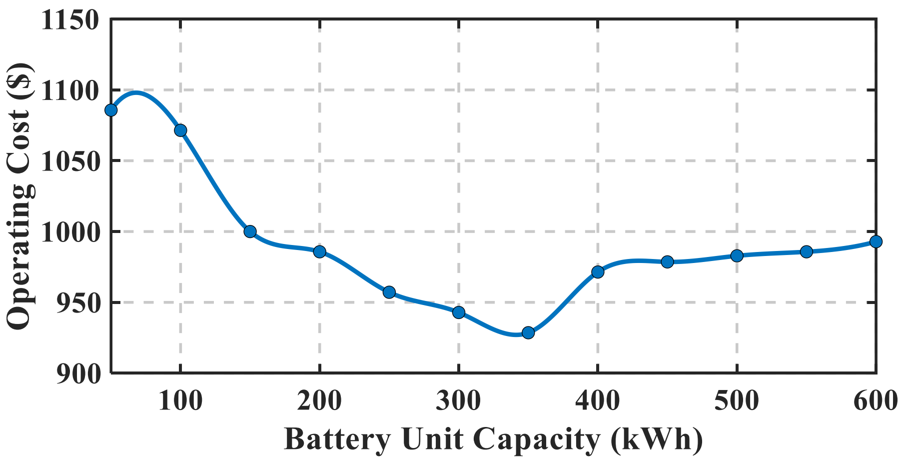

Fig. 12 The solved results of the improved mixed integer programming method under the scheduling condition with EV (scenario 2)

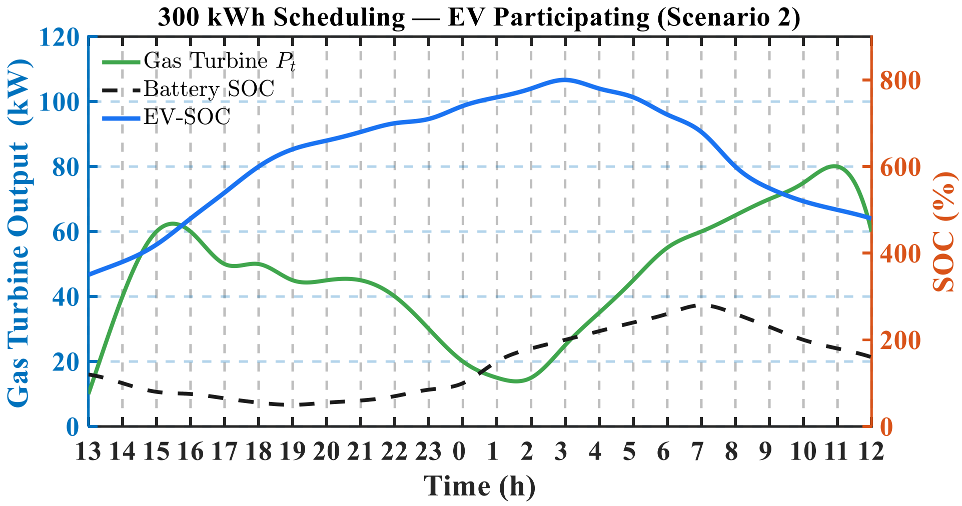

Fig. 13 The scheduling results for the 300-kWh energy storage system under the scheduling condition with EV (scenario 2).

4. 2. 2 Analysis of results

Literature [16] applies a tabu search method to solve four different objective functions in off-grid mode under both EV participation and non-participation scenarios, and compares the resulting ESS configurations when EVs are included in the scheduling process. In the tabu search–based off-grid model, the optimal ESS capacity is 300.55 kWh. In contrast, in the model proposed in this paper, when EVs participate in scheduling under off-grid conditions, the optimal ESS capacity is 300 kWh. Under similar microgrid parameters, both approaches yield identical ESS configurations when EVs are involved in dispatching.

The proposed model is suitable for both off-grid and grid-connected operation, which enhances its applicability. In the improved mixed-integer programming approach, the ESS capacity is treated as a predefined parameter rather than a decision variable. Compared with tabu search and the PSO algorithm, this reduces the dimensionality of the optimization problem by one variable, simplifies the solution process, and improves computational efficiency.

5 Conclusion

Starting from the economic dispatch of a microgrid integrated with EVs, this paper proposes an optimal configuration model for the capacity of the microgrid energy storage system (ESS). Two scenarios were analyzed: one in which EVs participate in system scheduling and another in which EVs are treated only as loads. The model was developed with reference to existing research and solved using an improved mixed-integer programming method. The optimal ESS capacity under different operating conditions was obtained and evaluated. The following conclusions can be drawn, providing guidance for future research on EV integration in microgrids:

1. When EVs act as auxiliary energy storage devices and participate in microgrid scheduling, the required ESS capacity decreases, which in turn reduces the overall operating cost of the microgrid. EV participation enhances flexibility by providing distributed storage capability, thereby improving system performance and economic efficiency.

2. The improved mixed-integer programming algorithm offers a simple and efficient solution process, reducing computational complexity and improving convergence speed. Owing to its discrete capacity adjustment approach, the method provides practical engineering guidance for optimal battery capacity configuration, consistent with real-world modular ESS deployments.

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