Day-ahead Optimal Scheduling Strategy of Microgrid with EVs Charging Station

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***Abstract*—Microgrid with electrical vehicles (EVs) can reduce the power requirement of charging station to main grid and also can balance the power between microgrid and its important load by using EVs as mobile energy storages. A day-ahead optimal scheduling strategy of microgrid including photovoltaic, wind turbine, diesel generation and important and shiftable loads, with EVs charging station, is presented in this paper. The optimization objectives are minimizing the operation cost of the microgrid and the charging cost of the EVs charging station considering that the microgrid and charging station belong to different stakeholders, and the constraints include the active power balance between load demands and generation, the maximum/minimum output power of photovoltaic, wind turbine and diesel generation, the maximum charging power and the charging time. A mixed-integer linear programming (MILP) is used. Three aspects are considered: 1) Establish mathematical model of output power and operation cost of distributed generators; 2) Make a real-time electricity price strategy considering the interests of both EVs and microgrid, then the coordinated charging/discharging model of EVs station is explored. 3) Propose a day-ahead optimal scheduling model and make the constraints. Two cases considering different weather conditions are implemented and the simulation results show that the coordinated charging and vehicle-to-microgrid (V2MG) can reduce the operation and charging cost of microgrid and EVs charging station and ensure the power balance between microgrid and its important loads.**

Keywords—microgrid, EVs charging station, day-ahead optimal scheduling, real-time electricity price strategy, mixed integer linear programming, coordinated charging, vehicle-to-microgrid (V2MG)

I. INTRODUCTION

Driven by the increased electricity demand and stricter environmental requirements, microgrid technology is dedicating to develop effective solutions for the future smart grid and global energy interconnection. Microgrid energy management system (EMS) can effectively integrate distributed generations, energy storing devices and controllable loads, thus improve the stability and economy of the system. In the microgrid system with the charging station of electric vehicles, the volatility of renewable energy and the random charging of EVs are likely to cause the power mismatch between generation and consumption. In order to improve the energy utilization and reduce operating costs, this paper proposes a two-stage day-ahead optimization scheduling strategy based on the orderly charging. Also, the real-time electricity price was set up. The proposal of V2MG system has been verified by simulation eventually.

At present, the scheduling strategy can be roughly divided into three types: heuristic, static and dynamic. A non-linear optimization model for dynamic economic dispatching has been addressed in previous works, such as [1-3]. Reference [4] presents the modeling and design of an online energy management system. Reference [5] selects two basic strategies of cyclic charging and load tracking. On this basis, it determines the priority of power generation under current load according to economic principles, which is belongs to static optimization. Aiming at the demand-side management such as charging of electric vehicles, reference [6] proposed a modeling method that minimizes the user's charging cost and makes the initial charging time early as a control target based on the market electricity price. In reference [7], a PSO algorithm is proposed and establish a microgrid-based scheduling model. Reference [8-9] put forward a strategy of dynamic electricity price. The relatively reasonable electricity price control measures were adopted according to the characteristics of distributed generations. This strategy can fully mobilize the enthusiasm of EVs owners to participate in microgrid energy management.

The paper is organized as follows: Section II presents the structure of the microgrid with the electric vehicles charging station and the mathematical model of each distributed generation. Section III describes the strategy of real-time electricity price and the orderly charging / discharging of electric vehicles. Section IV includes the mathematical model of the day-ahead scheduling of V2MG system. Section V presents the results of simulation case and Section VI concludes the paper.

II. SYSTEM MODEL

A typical configuration of microgrid with the electric vehicle charging station studied in this paper is shown in Fig. 1. The distributed power grid is composed by wind turbine (85kW), photovoltaic (100kW) and diesel generator (60kW). The important loads should remain supplied and the shiftable loads can be disconnected under certain conditions. The electric vehicle charging station plays an important role in balancing supply and demand of the renewable energy microgrid system

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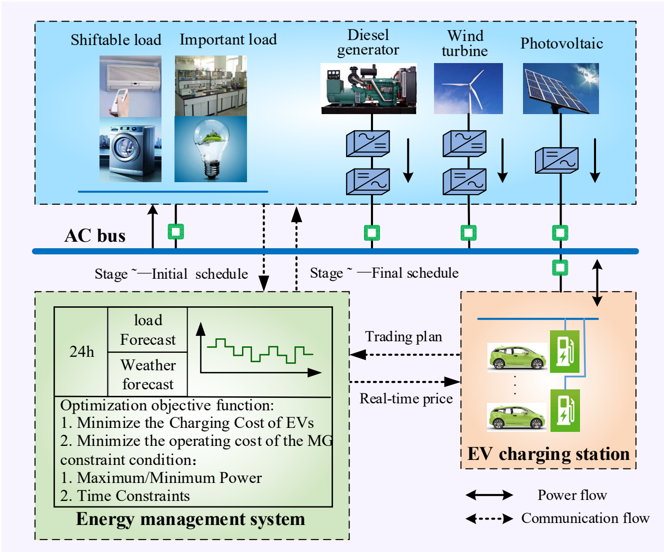


Fig. 1. Configuration of microgrid with EV charging station

by guiding the charging time and power of the EVs. The energy management system is the core part of the optimization process, which stores data, establishes and solves mathematical models based on actual problems. Taking the system as an example, the paper studies the day-ahead optimal scheduling strategy of microgrid with EVs charging station.

The proposed strategy considers the benefit both microgrid and car owners. According to the forecast data of weather and internal load in the next 24 hours, the initial generation plan of microgrid is formulated. Then setting the charging/discharging price based on the cost of generation or transfer shiftable loads caused by the access of electric vehicles to the microgrid. A ordered charging mathematical model is also defined in order to minimize the cost of charging cost. Once the station loads is solved, the data is uploaded to the microgrid. Thus the optimization procedure adjusts the initial power generation plan considers minimize operating cost and the result of day-ahead optimal scheduling strategy of microgrid with EVs charging station is obtained.

A. Model of distributed generation

Photovoltaic could convert solar energy into electrical energy. The output characteristics P_{PV} are related to temperature and light intensity and the generating cost C_{PV} is calculated by P_{PV}. The proposed function can be written as,

$$P_{PV}=P_{STC}G_c\left[1+k_p(T_c-T_r)\right]/G_{STC} \tag{1}$$

$$C_{PV}=P_{PV}\times\left(M_{PV}+I_{PV}\right) \tag{2}$$

Where P_{STC} and G_{STC} are the maximum measured power and light intensity under standard test condition. k_P is the power-temperature coefficient, the general value is -0.0047/K. Taking 298.15K as reference temperature T_r. G_C, T_C is light intensity and ambient temperature in practical work of photovoltaic array. M_{PV} is the maintenance factor, I_{PV} is the cost factor of initial investment expenditure combined with its service life.

In practical operation, P_{PV} must be limited to the maximum under the optimal conditions.

The output power of wind turbine is related to wind speed. Thus the output characteristics P_{WT} is defined as,

$$P_{WT}=\begin{cases}0 & v\le v_{ci}\\ k_{w1}v^3-k_{w2}P_{WT\_rated} & v_{ci}<v\le v_r\\ P_{WT\_rated} & v_r<v\le v_{co}\\ 0 & v>v_{co}\end{cases} \tag{3}$$

Where v_{ci} is the cut-in speed, v_{co} is the cut-out speed, v_{ci} is the rated wind speed. P_{WT_rated} is the output power of wind turbine at the rated wind speed, $k_{w1}=P_{WT\_rated}/(v_r^3-v_{ci}^3)$, $k_{w2}=v_{ci}^3/(v_r^3-v_{ci}^3)$. In a way, the output power P_{WT} of wind turbine at different wind speed conditions can be calculated. Then the generating cost C_{WT} are defined as,

$$C_{WT}=P_{WT}\times\left(M_{WT}+I_{WT}\right) \tag{4}$$

Where M_{WT} is the maintenance factor, I_{WT} is the cost factor of initial investment expenditure combined with its service life.

The boundaries related to the power of wind turbine are prescribed. The minimum is 0 and and the maximum is limited to the output power under the optimal conditions.

The diesel generator is used as standby power supply in microgrid and it plays a major role in maintaining security and stability of the system at long-time work. The lowest operating power level of diesel generators is 30% of the rated power P_{DG_rate}. Once below this value, the unit fuel consumption will be more expensive, which will also affect the service life of diesel generator. The highest efficiency operating point of diesel generator is when the output power equals 75% of the rated power. The operation cost of diesel generator is related to output power and working stat, and can be written as,

$$C_{DG}=P_{DG}\times(M_{DG}+I_{DG}+E_{DG})+C_{fuel} \tag{5}$$

$$C_{fuel}=(k_{D1}P_{DG}+k_{D2}P_{DG\_rated})\times S_{DG} \tag{6}$$

Where M_{DG} is the maintenance factor, I_{DG} is the initial investment expenditure. E_{DG} is the environmental factor, which is determined by the cost of energy consumption and pollution discharge; C_{fuel} is the fuel cost. S_{DG} describes the start-stop state of diesel generator, 0 represents the shutdown process, 1 represents the startup process. Considering the actual load of diesel generator, the minimum value of output power is P_m, and the maximum value is limited to P_{DG_rate}.

B. Load Prediction of Electric Vehicles Based on Monte Carlo method

The use of private electric vehicles is determined by the owner, which is random, but it will show regularity when the number of samples is large enough. The main factors affecting the charging load of electric vehicles include: charging quantity, start charging time. In the case of disorderly charging, the electric vehicle will be charged when it reaches the charging station, and leaves the charging station when it is fully charged. For the charging station built in the working area, the owners start charging as soon as they arrive at the company, and the roundtrip power consumption is the daily charging demand. According to the historical data, it can be concluded that the

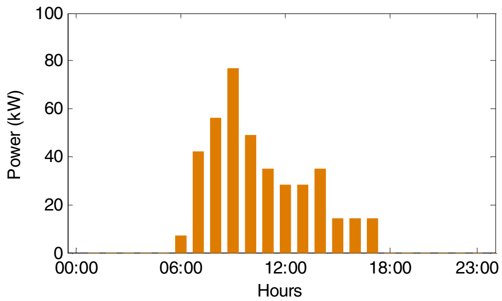


Fig. 2. EVs Load of uncoordinated charging

charging characteristics of EVs at the charging station in the working area approximately satisfy the normal distribution,

$$f(x)=\frac{1}{\sigma\sqrt{2\pi}}\exp[-\frac{(x-\mu)^2}{2\sigma^2}] \tag{7}$$

In the formula, the start charging time T_{star}~N(8.4,3.3), charging quantity Q_{need}~N(11.9,5.8). Assuming that there are 20 private cars in the working area, the load forecasting data of electric vehicles in this area are shown in Fig. 2. Therefore, the average daily demand of electric vehicle group based on the behavior habits of users in the region is about 350 kW.

III. Optiminzation Problem

In this proposed approach, a Mixd Integer Linear Programming (MILP) problem is defined in order to minimize the cost of micogrid and electric vehicles.

A. Price-fixing model

The charging price is based on generating cost of the microgrid. Once the electric vehicles reaches the charging station, the microgrid would change the initial schedule to charge them based on satisfying the internal important load in the system. Three ways are included: Increasing the output power of diesel generator, transfering shiftable loads or surplus renewable energy power generation. Since the cost curve of diesel generator and the penalty for not charging shiftable loads is non-linear, the average cost is calculated. In order to guide the electric vehicles to charge in good weather condition, it does not take into account the cost of surplus renewable energy.

In this way, the charging price C_{charge_t} has been defimed as,

$$C_{charge\_t}=k_{pf}C_{cost\_grid\_t} \tag{8}$$

Where k_{pf} is beneficial coefficient, which represents the expected revenue of the microgrid system through the construction of electric vehicle charging station. $C_{cost\_grid\_t}$ is generation cost of microgrid.

The discharging price $C_{discharge\_t}$ has been defimed as,

$$C_{discharge\_t}=C_{buy}+C_{loss}+C_{sub\_t} \tag{9}$$

C_{buy} is the unit purchase cost of electric vehicles, this paper uniformly sets the cost to 0.5 yuan / kWh.

C_{loss} is discharging loss of electric vehicles. It is assumed that each electric vehicle is discharged at most one time per day, the depth of discharge is limited to 20% of the rated capacity, and only vehicles with SOC above 80% are selected to participate in the discharging process. Then the average C_{loss} is as follows,

TABLE I. Discharge Price of Electric Vehicles

Reserve Capacit (kW)	Discharge Price (yuan)
$P_{reserve}$<10	2.35
10≤$P_{reserve}$<20	2.15
20≤$P_{reserve}$<30	1.95
30≤$P_{reserve}$<40	1.75
40≤$P_{reserve}$<50	1.55
$P_{reserve}$≥50	1.35

$$C_{loss}=\int_{0.8}^{0.6}(k_{l1}soc^3-k_{l2}soc^2-k_{l3}soc+k_{l4})d(soc) \tag{10}$$

C_{sub_t} is the government subsidy. A large number of electric vehicles accessing the grid can create certain environmental and social benefits for energy conservation and emission reduction. Therefore, the government should introduce policies to encourage users to actively participate in V2G and promote the development of electric vehicle market. A tiered pricing subsidy has be set according to the reserve capacit of microgrid, so that electric vehicle users can benefit from V2G.

The reserve capacit $P_{reserve}$ is defined as,

$$P_{reserve}=P_{DG\_r}+P_{tran\_r} \tag{11}$$

Where P_{DG_r} is the reserve power of the diesel generator, P_{tran_r} is the shiftable loads still charged. $P_{reserve}$ reflects the demand of microgrid for discharge of electric vehicles. Less reserve capacity would have a greater impact on the operation of the microgrid due to fluctuations of load and weather factors. Thus the user will be given a higher subsidy when the value of $P_{reserve}$ is small. The discharge price is shown in TABLE Ⅰ.

B. Coordinated charging/discharging model

In order to ensure proper behavior of the EV station, two modes are determined by the distributed generation energy and load power of microgrid. Mode Ⅰ is discharging; Mode Ⅱ is charging. Electric vehicles are converted in two modes depending on the weather condition. The discharge power of mode Ⅰ is only compensates for the important load that may not be able to supply. The objective of mode Ⅱ is to minimize total charge cost and the function can be expressed as,

$$\min C_{EV}=\sum_{t=0}^{23}C_{charge/discharge\_t}P_{EV\_t}T_t \tag{12}$$

Thus the optimal time T_t and power P_{EV_t} of coordinated charging/discharging are obtained. The uniting dispatch of the group of electric vehicle charging station makes users reduce charging expenditure based on the mentioned price.

Regarding the feasibility, the constraints are,

$$0\le P_{EV\_t}\le P_{\max\_t} \tag{13}$$

$$T_{reach}\le T_{EV\_t}\le T_{away} \tag{14}$$

The charging/discharging load per hour cannot over the upper limit of the charging station, and the charging time should be within working hours.

C. Day-ahead optimal scheduling model

The objective function is to minimize the economic cost C_{sum} of the microgrid. A two-stage scheduling model using MILP is employed as follows,

$$\min C_{sum} = \begin{cases} C_{PV} + C_{WT} + C_{DG} + C_{loss} & stage \text{ I} \\ C_{PV} + C_{WT} + C_{DG} + C_{loss} - C_{EV} & stage \text{ II} \end{cases} \tag{15}$$

C_{PV}, C_{WT}, C_{DG} denotes the operating cost of photovoltaic, wind turbine and diesel generator, which had been defined. C_{loss} indicates the penalty cost of transferring shiftable loads and it can be written as,

$$C_{loss} = k_{l1} \frac{W_{loss}^2}{W_{most}} + k_{l2} W_{loss} \tag{16}$$

Together with the objective function, some constraints should be defined to allow the problem to get feasible solutions. To start with, the power balance in the system can be written as,

$$P_{less} + P_{EV} \le P_{WT} + P_{PV} + P_{DG} \le P_{most} + P_{EV} \tag{17}$$

In the formula, P_{most} is the total load in the microgrid, including the shiftable load P_{tran} and the important load P_{less}. P_{EV} takes values of 0 and P_{EV_t} in stage ˜ and stage ˜ , respectively.

The power value of renewable power sources at each time must be less than or equal to the maximum power that can be provided for them, thus the constraints are,

$$0 \le P_{WT} \le P_{WT\_max} \tag{18}$$

$$0 \le P_{PV} \le P_{PV\_max} \tag{19}$$

Besides, the constraints related to the diesel generator are,

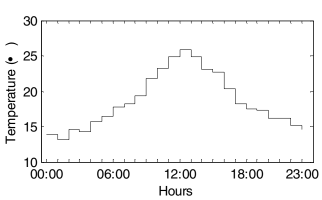
$$\begin{cases} 0 & stop \\ P_{DG\_min} \le P_{DG} \le P_{DG\_max} & run \end{cases} \tag{20}$$

IV. CASE STUDY

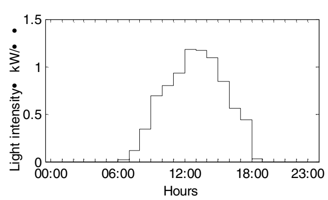
A. Case 1:

This paper takes the small microgrid with electric vehicle charging station in the working area as the research object, and texts the two-stage day-ahead optimal scheduling strategy based on matlab.

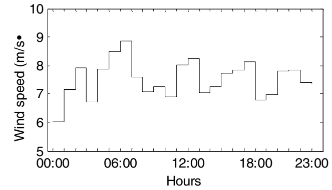
Date of typical day are predicted, including temperature, light intensity, wind speed and loads, which is shown in Fig. 3. The proposed strategy is simulated in this scenario.



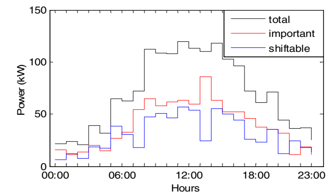
(a) Temperature



(b) Light intensity

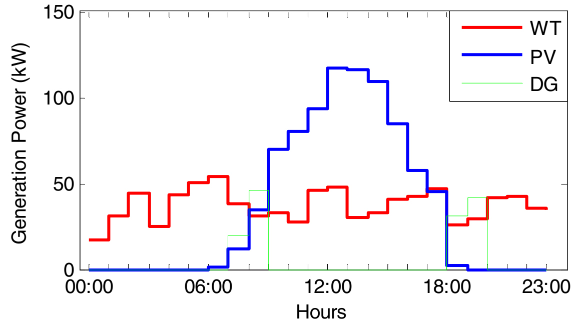


(c) Wind speed

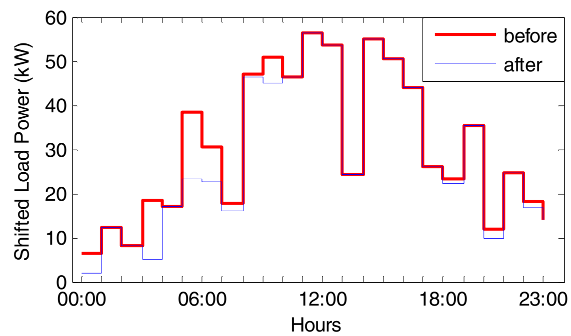


(d) Loads distribution

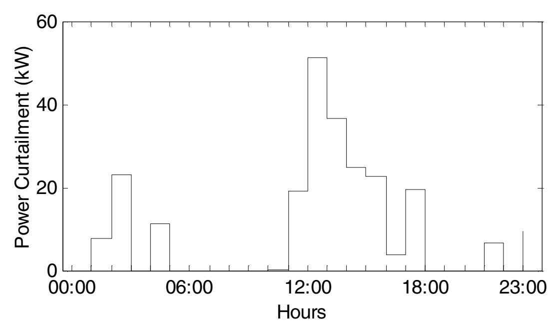
Fig. 3. Date of typical day



(a) Distributed generation



(b) Shifted load power



(c) Power curtailment of renewable energy generation

Fig. 4. Simulation results of stage ˜

The optimization calculation of stage ˜ is performed based on the predicted data, and the simulation results are shown in Fig. 4. It shows that in the absence of EVs, there is a serious abandonment of renewable energy power generation. Then the price model and the charging/discharging model had been solved, the results are shown in Fig. 5 and Fig. 6.

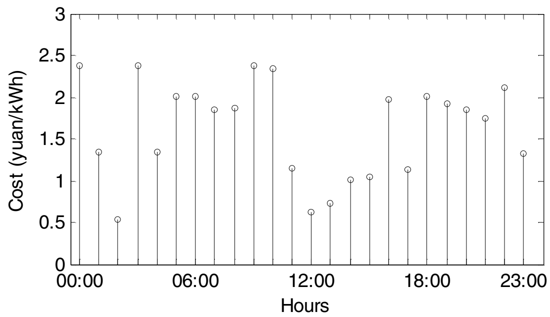


Fig. 5. Charging price in 24h

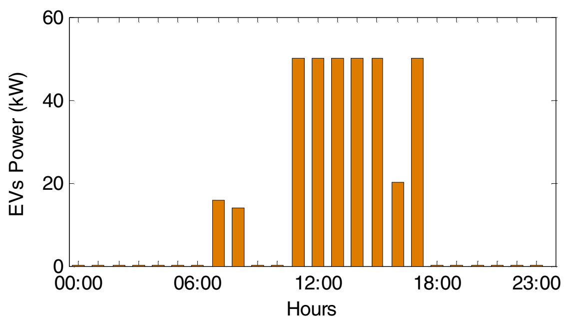
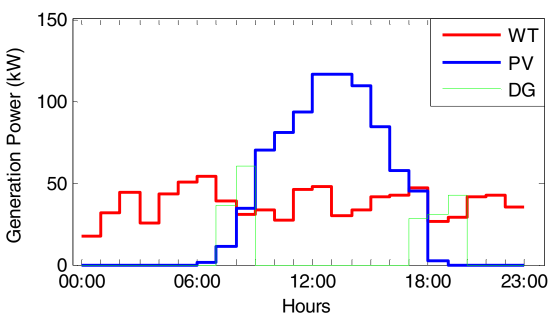
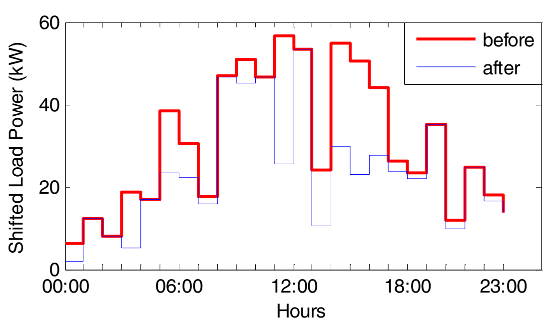


Fig. 6. Charging power of EVs

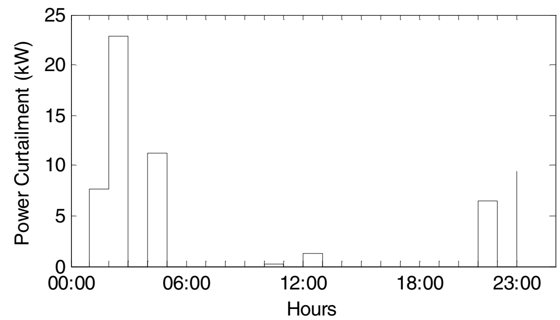
In typical day, the microgrid can rely on distributed generation to satisfy the demands of important load, and even a large amount of surplus in some periods. Thus there is no need to receive energy from electric vehicles, and The EVs are always in charging mode. Fig. 6 shows that under proposed model, most of the electric vehicles were transferred to a lower price period for charging.



(a) Day-ahead generation scheduling



(b) Shifted load power



(c) Power curtailment of renewable energy generation

Fig. 7. Simulation results of case 1

TABLE II. DAY-AHEAD OPTIMAL SCHEDULING OF CASE 1

Hours	Day-ahead Generation Scheduling			Cost	
	Wind turbine (kW)	***Photovoltaic (kW)***	***Diesel generator (kW)***	***EVs (yuan)***	***MG (yuan)***
0:00-1:00	17.40	0	0	0	15.4
1:00-2:00	31.5	0	0	0	17.9
2:00-3:00	44.1	0	0	0	25.1
3:00-4:00	25.3	0	0	0	32.4
4:00-5:00	43.3	0	0	0	24.6
5:00-6:00	50.2	0	0	0	47.0
6:00-7:00	53.8	1.1	0	0	40.7
7:00-8:00	38.5	11.6	36	29.3	51.7
8:00-9:00	30.8	34.7	60	26.2	90
9:00-10:00	33.1	70.0	0	0	81.5
10:00-11:00	27.5	80.7	0	0	80.4
11:00-12:00	45.8	93.3	0	57.6	80.4
12:00-13:00	47.6	116.7	0	30.8	89.9
13:00-14:00	30.0	116.5	0	36.7	89
14:00-15:00	33.1	109.6	0	50.0	71.4
15:00-16:00	41.1	84.7	0	52.4	71.4
16:00-17:00	42.7	57.3	0	40.0	49.4
17:00-18:00	46.6	44.9	28	57	47.5
18:00-19:00	26.2	2.5	31	0	60.8
19:00-20:00	29.0	0	42	0	70.0
20:00-21:00	41.8	0	0	0	26.1
21:00-22:00	42.5	0	0	0	24.2
22:00-23:00	35.5	0	0	0	21.8
23:00-24:00	34.9	0	0	0	19.8

Fig. 7(a) shows the simulation results of day-ahead optimal scheduling model in typical day, it describes the power of distributed generators in 24 hours. The variation of shiftable loads is given in Fig. 7(b). Fig. 7(c) illustrates EVs charging load were transferred to the period of surplus renewable generation

TABLE III. SYSTEM STATUS UNDER DIFFERENT CHARGING MODELS

Charging Model	Micogrid Generation Cost (yuan)	Charging Cost (yuan)	Abandoned rate of renewable energy power
uncoordinated charging	1736.3	615.9	7.9%
coordinated charging	1623.3	321.5	3.4%

under the coordinated charging/discharging model, which improves the utilization rate of renewable energy to a great extent. The detail data is summarized in TABLE ˜.

It is clear in TABLE ˜ that the cost of both mirogrid and EVs is reduced compared with the uncoordinated charging system.

B. Case 2:

In order to evaluate the weather impact of the scheduling framework, we simulated another scenario. It is assume that in the typical day, the temperature drops sharply because of the bad weather from 13:00 to 14:00 in the afternoon and there are 28.8 kWh impartant load cannot be powered caused by it, which is shown in Fig. 8.

Fig. 9 and Fig. 10 shows that electric vehicles participate in the discharging process to maintain the stable operation of the microgrid during the period when the important load cannot be supplied.

Fig. 11(a) shows the simulation results of day-ahead optimal scheduling model in scenario 2, it describes the power of distributed generators in 24 hours includes wind turbine, photovoltaic and diesel generator. The variation of shiftable loads is given in Fig. 11(b). The detail data is summarized in TABLE ˜ .

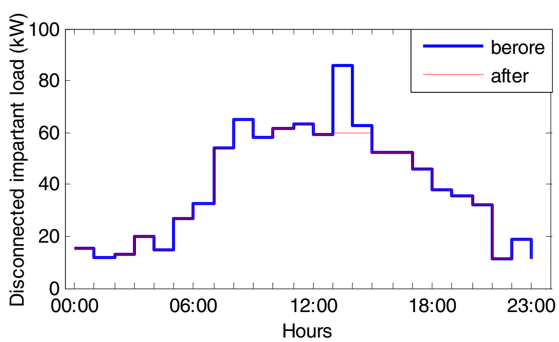


Fig. 8. Power of the important load cannot be supplied

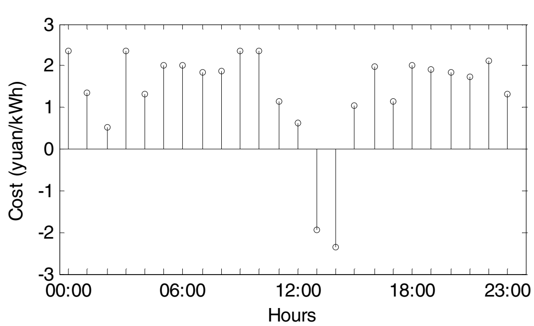


Fig. 9. Charging price in 24h

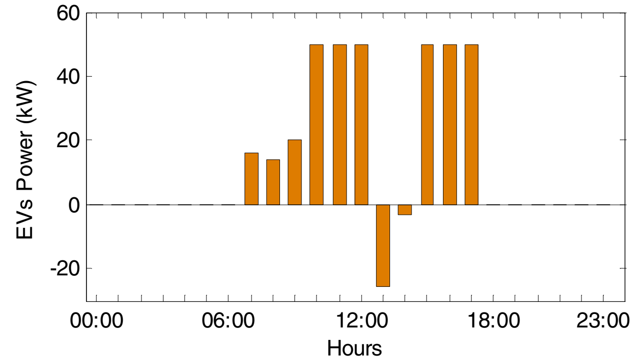
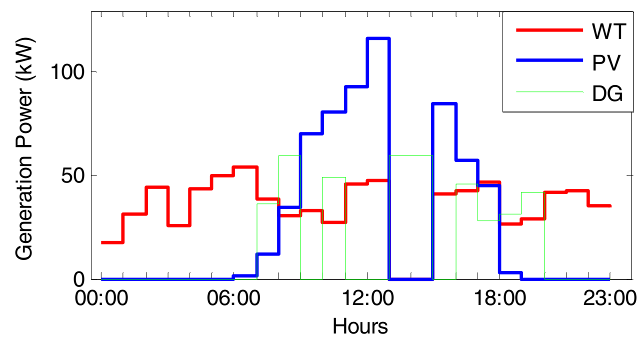
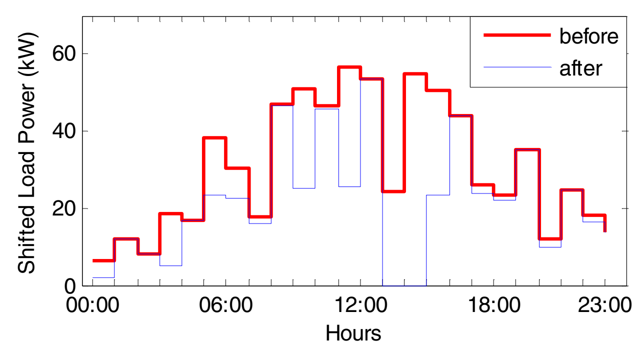


Fig. 10. Charging power of EVs



(a) Day-ahead generation scheduling



(b) Shifted Load Power

Fig. 11. Simulation results of case 2

TABLE IV. DAY-AHEAD OPTIMAL SCHEDULING OF CASE 2

Hours	Day-ahead Generation Scheduling			Cost	
	Wind turbine (kW)	*Photovoltaic (kW)*	*Diesel generator (kW)*	*Evs (yuan)*	*MG (yuan)*
0:00-1:00	17.40	0	0	0	15.4
1:00-2:00	31.5	0	0	0	17.9
2:00-3:00	44.1	0	0	0	25.1
3:00-4:00	25.3	0	0	0	32.4
4:00-5:00	43.3	0	0	0	24.6
5:00-6:00	50.2	0	0	0	47.0

Hours	Day-ahead Generation Scheduling			Cost	
	Wind turbine (kW)	***Photovoltaic (kW)***	***Diesel generator (kW)***	***Evs (yuan)***	***MG (yuan)***
6:00-7:00	53.8	1.1	0	0	40.7
7:00-8:00	38.5	11.6	36	29.3	51.7
8:00-9:00	30.8	34.7	60	26.2	90
9:00-10:00	33.1	70.0	0	47.7	58.9
10:00-11:00	27.5	80.7	49	117.4	23.9
11:00-12:00	45.8	93.3	0	57.6	80.4
12:00-13:00	47.6	116.7	0	30.8	89.9
13:00-14:00	0	0	60	-11.3	112.7
14:00-15:00	00	0	60	-7.5	183
15:00-16:00	41.1	84.7	0	52.4	71.4
16:00-17:00	42.7	57.3	46	98.4	29.5
17:00-18:00	46.6	44.9	28	60.0	44.5
18:00-19:00	26.2	2.5	31	0	60.8
19:00-20:00	29.0	0	42	0	70.0
20:00-21:00	41.8	0	0	0	26.1
21:00-22:00	42.5	0	0	0	24.2
22:00-23:00	35.5	0	0	0	21.8
23:00-24:00	34.9	0	0	0	19.8

The results of case 2 show that if the weather turns bad accidentally and the renewable energy can not generate as predicted, the electric vehicles can also act as the mobile energy storage of the system, which further verifies the flexibility and feasibility of the proposed strategy.

V. CONCLUSIONS

This paper proposes a day-ahead optimal scheduling strategy for microgrid with EVs charging station based on mixed integer linear programming. A price-guided V2MG strategy is explored based on the EVs coordinated charging. The possible contributions of the optimazation strategy are as follows,

- A real-time price-fixing method is explored including charging and discharging price.
- Establish a coordinated charging strategy of EVs charging station, which could reduce charging costs.
- Propose a two-stage day-ahead optimal scheduling technique and the operation cost of the MG is redused.

The simulation results show that the strategy can also improve the utilization rate of renewable energy, and maximize the benefits of both microgrid and EV shokeholders. When EVs are seen as mobile energy storages, the reliability caused by the fluctuation of renewable energy generation has been solved.

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REFERENCES

[1] Basu, M. "Dynamic economic emission dispatch using nondominated sorting genetic algorithm-II." International Journal of Electrical Power & Energy Systems 30.2 (2008): 140-149.

[2] Xu, Yinliang, Wei Zhang, and Wenxin Liu. "Distributed dynamic programming-based approach for economic dispatch in smart grids." IEEE Transactions on Industrial Informatics11.1 (2015): 166-175.

[3] Chen G, Li C, Dong Z. Parallel and distributed computation for dynamical economic dispatch[J]. IEEE Transactions on Smart Grid, 2017, 8(2): 1026-1027.

[4] Luna A C, Diaz N L, Graells M, et al. Mixed-integer-linear-programming-based energy management system for hybrid PV-wind-battery microgrids: Modeling, design, and experimental verification[J]. IEEE Transactions on Power Electronics, 2017, 32(4): 2769-2783.

[5] Lambert T, Gilman P, Lilienthal P. Micropower system modeling with HOMER[J]. Integration of alternative sources of energy, 2005: 379-418.

[6] Xiaoming Sun, Wei Wang, Li Su. Design of orderly Charging Control Strategy for Electric Vehicles Based on TOU price [J]. Automation of Electric Power Systems, 2013, 37(1): 191-195.

[7] Xingyong Zhao, Shuai Wang, Xinhua Wu. Microgrid coordinated control strategy with distributed generations and electric vehicles [J]. Power System Technology, 2016, 40(12): 3732-3740.

[8] Liu Z, Chen Y, Zhuo R, et al. Energy storage capacity optimization for autonomy microgrid considering CHP and EV scheduling[J]. Applied Energy, 2018, 210: 1113-1125.

[9] Guo Y, Xiong J, Xu S, et al. Two-stage economic operation of microgrid-like electric vehicle parking deck[J]. IEEE Transactions on Smart Grid, 2016, 7(3): 1703-1712.

[10] Wang D, Guan X, Wu J, et al. Integrated energy exchange scheduling for multimicrogrid system with electric vehicles[J]. IEEE Transactions on Smart Grid, 2016, 7(4): 1762-1774.

[11] Chekired D A, Khoukhi L, Mouftah H T. Decentralized cloud-SDN architecture in smart grid: A dynamic pricing model[J]. IEEE Transactions on Industrial Informatics, 2018, 14(3): 1220-1231.

[12] Wang T, O'Neill D, Kamath H. Dynamic control and optimization of distributed energy resources in a microgrid[J]. IEEE transactions on smart grid, 2015, 6(6): 2884-2894.

[13] Zhang M, Chen J. The energy management and optimized operation of electric vehicles based on microgrid[J]. IEEE Transactions on Power Delivery, 2014, 29(3): 1427-1435.

[14] Li G, Wu D, Hu J, et al. HELOS: Heterogeneous load scheduling for electric vehicle-integrated microgrids[J]. IEEE Transactions on Vehicular Technology, 2017, 66(7): 5785-5796.

[15] Mohsenian-Rad A , Wong V W S , Jatskevich J , et al. Autonomous Demand-Side Management Based on Game-Theoretic Energy Consumption Scheduling for the Future Smart Grid[J]. IEEE Transactions on Smart Grid, 2010, 1(3):320-331.

[16] Katiraei F , Iravani M R . Power Management Strategies for a Microgrid With Multiple Distributed Generation Units[J]. IEEE Transactions on Power Systems, 2006, 21(4):1821-1831.

[17] Frédéric Colas, Lu D , Lazarov V , et al. Energy management and power planning of a microgrid with a PV-based active generator for Smart Grid Applications[J]. IEEE Transactions on Industrial Electronics, 2011, 58(10):4583-4592.