Multi-objective fuzzy optimization model of power system dynamic environment economy based on coordinated dispatching of wind power and electric vehicles

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Abstract. In order to coordinate the impact of the integration of electric vehicles and wind power on the economic dispatch of power systems, a multi-objective dispatch model for the environmental economy of wind farms with PHEVs connected to the grid was constructed. The uncertain factors of wind power generation and load will increase the difficulty of dispatching. The fuzzy theory will be used to realize the fuzzy modelling of the coordinated connection of wind power and electric vehicles. The satisfaction index will be used to transform the multi-objective problems of deterministic environment and economy into single For the objective optimization problem, based on the improvement of the traditional particle swarm optimization algorithm using linear descent search ideas and the particle information sharing method considering boundary constraints, the improved PSO algorithm is used to solve the proposed dynamic environment and economic dispatch model. From the grid operation and vehicle owners from the perspective of demand, the constraints of the system's rotation reserve and the daily travel of the owner are considered. The comparison and analysis of the simulation of algorithms and calculation examples and multiple scheduling schemes in different scenarios verify the rationality of the model and the superiority of the improved PSO algorithm for solving such dynamic scheduling problems.

1. Introduction
Wind power generation and other renewable energy power generation are clean and environmentally friendly. Compared with traditional thermal power units, the dispatching and operation of the power system can obtain longer-term and more objective environmental and economic benefits. On the other hand, due to the constraints of wind speed and other natural factors, the output of wind farms is strongly intermittent and unpredictable. In addition, plug-in hybrid electric vehicles (PHEVs)
technology for low carbon emissions and environmental pollution reduction has been rapidly developed. Its large-scale network access will bring new thinking and challenges to the operation and control of the power grid[1]. Therefore, in consideration of the profitability of clean energy wind power generation and the inevitability of PHEVs to be connected to the grid, this paper will study the collaborative optimization scheduling model of the two.

At present, the research on the economic dispatch of wind power and electric vehicles has made many achievements. The literature [2] considers the opportunity constraint model of fuzzy processing of wind power and load at multiple time scales; literature [3] established a rotation reserve daily plan optimization model with wind power generation system based on the analysis of the random characteristics of wind farm output; however, none of the above considered the impact of electric vehicle network access. Literature [4] has constructed a multi-objective model of dynamic environmental economy containing electric vehicles, but the model does not fully reflect the advantages of PHEVs after network access to energy saving and emission reduction. Most of the optimization problems of coordinated scheduling of the two are still in the preliminary exploration stage. Literature [5] takes into account the wind power output and the uncertainty of electric vehicles, and the single-target stochastic economic dispatch model with the smallest expected value of system power generation cost; Literature [6] studied the multi-objective model of coordinated scheduling of wind power and electric vehicles at the demand response level, which effectively increased the penetration rate of electric vehicles, but did not consider the volatility of wind power and pollution emissions indicators for the development of dynamic economic dispatch of power systems Impact.

Based on the above-mentioned shortcomings of modelling and optimization of wind power and PHEVs collaborative scheduling of power system environmental economic dispatch, this paper fully considers the fuzzy modelling of wind power random output and the impact of multi-objective dispatch model on the environment, and constructs Multi-objective fuzzy optimization model of environmental economic dispatch for automobile collaborative grid connection. In order to better coordinate the conflicting optimization goals of environment and economy in the objective function, fuzzy and singular optimization goals are optimized through the membership function, and innovatively add the evaluation index of wind power active output membership to the satisfaction index of the multi-objective optimization model. In this paper, the improved PSO algorithm is used to solve the dynamic economic scheduling model, and a multi-scenario scheduling scheme is established to verify and analyse the model.

2. Environmental and economic multi-objective optimization model for coordinated grid-connected dispatch of wind power and electric vehicles

2.1. Objective function

1) Fuel cost

The conventional unit fuel cost function of the system can be expressed by the following formula:

\[
\min F_i = \sum_{t=1}^{T_{day}} \sum_{j=1}^{N_g} U^j_i \left\{ \left[ a_i + b_i P_i^j + c_i \left( P_i^j \right)^2 \right] + g_i \sin \left[ h_i \left( P_{i\min} - P_i^j \right) \right] \right\} 
\]

Where: \( T_{day} \) is the number of time periods in the dispatch cycle; \( N_g \) is the total number of conventional units; \( P_i^j \) is the active power output of unit \( i \) at time \( t \); \( U^j_i \) is the start and stop of unit \( i \) at time \( t \); \( a_i, b_i, c_i \) are Fuel cost coefficient; \( g_i, h_i \) are the valve point effect coefficient of unit \( i \).

2) Pollutant gas emission function

When the conventional unit is in operation, the environmental pollution is mainly manifested in the discharge of SO2, NOX, CO2 and other exhaust gases into the atmosphere, and its emission depends on the output of the unit. Based on the comprehensive consideration of the three gas emissions, it is expressed as follows Secondary function:
In the formula, $\alpha_i$, $\beta_i$, $\gamma_i$ and $\zeta_i$ are the emission coefficient of unit $i$.

2.2. Constraints

1) Power balance constraints

$$\sum_{i=1}^{N_i} U_i^j P_{D}^i + P_{\text{av}}^t = P_{\text{D}}^0 + P_{\text{L}}^t + P_{\text{chr}}^t$$

Among them, $P_{\text{D}}^t$ and $P_{\text{chr}}^t$ are the discharge and charging loads of electric vehicles at time $t$; $P_{\text{av}}^t$ is the average output of wind power system during time $t$; $P_{\text{D}}^0$ and $P_{\text{L}}^t$ are the load demand and transmission network loss at time $t$, respectively. The load value can be obtained by prediction, and the system transmission loss can be expressed as follows.

$$P_{\text{D}}^0 = \sum_{i=1}^{N_i} L_i H_{ij} P_{D}^i + \sum_{i=1}^{N_i} H_{ij} P_{L}^i + H_{00}$$

where: $H_{ij}$ is the $i$ -th row and $j$ -th column component of the network loss coefficient; $H_{ij}$ is the $i$ -th component of the network loss vector $H_i$; $H_{0i}$ is the network loss coefficient.

2) Remaining battery capacity constraints

The remaining electric quantity of the electric vehicle energy storage system at time $t$ is:

$$S_f = S_{f-1} + \xi^c P_{\text{chr}}^f \Delta t - \frac{P_{\text{D}}^t}{S_{D}} \Delta t - L\Delta S$$

where $\xi^c$ and $\xi^D$ are the charge and discharge efficiency coefficients of the energy storage battery; $\Delta t$ is the dispatch period; $\Delta S$ is the power consumption per unit distance; $L$ is the mileage of the electric vehicle during the period $t$.

3) The daily travel demand constraints of car owners

As a means of transportation, electric vehicles must meet the daily driving needs of car owners. Suppose that an electric vehicle completes a charge-discharge cycle within the dispatch period to satisfy:

$$\sum_{i=1}^{T_{\text{dis}}} (L\Delta S) = \sum_{i=1}^{T_{\text{dis}}} \xi^c P_{\text{chr}}^t \Delta t - \sum_{i=1}^{T_{\text{dis}}} \frac{P_{\text{D}}^t}{S_{D}} \Delta t$$

3. Fuzzification of the objective function

The random ambiguity of wind farm output will undoubtedly bring challenges to the economic dispatch of power systems. In this paper, fuzzy decision method based on fuzzy set theory will be introduced to solve the uncertainty caused by wind power generation and load fluctuation. For the multi-objective optimization problem of considering the dynamic economic dispatch of the PHEV grid-connected wind farm power system, the key lies in rationally determining the membership function of the objective function and then implementing the fuzzy processing. This paper considers that the randomness of wind power and load have certain similarity, and their fuzzy variables can all be represented by trapezoidal functions; the membership function of the objective function is selected to be a semi-linear shape.
3.1. Membership function of active output of wind farm

\[ \chi_w (P^w_j) = \begin{cases} 
0 & P^w_j \leq P_{w1}, \quad P^w_j \geq P_{w2} \\
(P^w_j - P_{w1})/(P_{w2} - P_{w1}) & P_{w1} < P^w_j < P_{w2} \\
1 & P_{w2} < P^w_j < P_{w3}
\end{cases} \]  

(7)

In the formula, \(\chi_w (P^w_j)\) is the membership function corresponding to the active output of the wind farm in each period.

3.2. Membership function of economic and environmental objective function

\[ \chi_1 (F_1) = \begin{cases} 
1 & F_1 \leq F_{1N} \\
(F_{1N} + \rho_1 - F_1)/\rho_1 & F_{1N} < F_1 \leq F_{1N} + \rho_1 \\
0 & F_1 > F_{1N} + \rho_1
\end{cases} \]  

\[ \chi_2 (F_2) = \begin{cases} 
1 & F_2 \leq F_{2N} \\
(F_{2N} + \rho_2 - F_2)/\rho_2 & F_{2N} < F_2 \leq F_{2N} + \rho_2 \\
0 & F_2 > F_{2N} + \rho_2
\end{cases} \]  

(8)

(9)

In the formula, \(\chi_1 (F_1)\) and \(\chi_2 (F_2)\) are the membership functions of the economic and environmental objective functions in the dispatch cycle respectively; \(F_{1N}\) and \(F_{2N}\) are the ideal values of the unit's fuel cost and exhaust pollutant emissions, respectively; \(\rho_1\) and \(\rho_2\) are the allowable scaling values of the multi-objective function, respectively.

3.3. Satisfaction index

According to the maximum-minimum rule of fuzzy set theory [7], this paper sets the minimum value of all the above-mentioned membership functions to \(\lambda\), and its value can be used to express the satisfaction of the decision maker, namely:

\[ \lambda = \min \{\chi_w, \chi_1, \chi_2\} \]  

(10)

Among them, \(\chi_w = \min \{\chi_w (P^w_j)\}\).

Through (16), the original model multi-objective optimization problem is transformed into \(\lambda\) single-objective nonlinear optimization model that maximizes the satisfaction index \(q\) that satisfies the constraints:

\[ \begin{align*}
\max & \quad \lambda \\
\text{s.t.} & \quad F_1 + \lambda \rho_1 \leq F_{1N} + \rho_1 \\
& \quad F_2 + \lambda \rho_2 \leq F_{2N} + \rho_2 \\
& \quad 0 \leq \lambda \leq 1
\end{align*} \]  

(11)

4. Example calculation and analysis

4.1. Test system related data

This article takes the classic 10-machine system as the simulation object, and the scheduling period is 24h. For the data of conventional unit and load data of each period, please refer to [7]. Suppose that the wind farm contains 100 asynchronous wind turbines of the same model operating in parallel. The rated active output is 160MW. The average output power curve of each period predicted by the wind farm in the dispatch period is shown in figure 1. The corresponding minimum output power \(P_{w \text{min}}\) is
40MW, and the maximum output power is 142MW; the parameters $\omega_1$, $\omega_2$, $\omega_3$, and $\omega_4$ of the active power output of the wind farm at each time period are 0.6, 0.9, 1.1, and 1.4, respectively.

3) Electric vehicle data
Suppose there are 5000 electric vehicles connected to the network to participate in the optimal scheduling, the unit battery capacity of PHEV is 24, the charging and discharging efficiency of the battery is 85%, the power consumption per 100 kilometres is 15. In addition, consider the rotation reserve of the system to take 10% of the load value in each period.

4.2. Model verification
In order to verify the effectiveness and feasibility of the optimization model proposed in this paper, the following scenarios are studied respectively.

Scene1: Considering wind power output, vehicles without PHEVs are connected to the grid;
Scene2: Considering wind power output, PHEVs are only connected to the grid as a load to participate in dispatching;
Scene3: Considering wind power output, the intelligent charging and discharging mode of electric vehicles is connected to the grid to participate in dispatching.

The above three scenarios are solved using the improved PSO algorithm proposed in this paper. Table 1 lists the optimal solutions in different scenarios, and figure 2 shows the corresponding load curve.

Table 1. The optimal solution of different scenes.

| Scenes | Objective function | Fuel cost / $ | Pollution emissions / lb |
|--------|--------------------|---------------|--------------------------|
| 1      | Optimal solution   | 2324251       | 263231.9                 |
| 2      | Optimal solution   | 2418517       | 270482.4                 |
| 3      | Optimal solution   | 2376801       | 266091.9                 |

Comparing the above solution and the load curve, the peak load of the original load is larger when there is no peak and valley filling of the electric vehicle during the valley period. When operating in
Scene1 mode, due to the reverse peaking characteristics of wind power output, the peak-to-valley load difference will be exacerbated after grid connection, resulting in a heavier burden on conventional units. In scene2 mode, although the power load is not released to the grid during the peak period, the power load will not be released to the grid during the peak period. When operating in Scene3 mode proposed in this paper, wind farms are connected to the grid to generate electricity. Electric vehicles are charged through the effective two-way energy exchange during the late night when the wind is rich in load valleys and discharged to the grid during peak and heavy load periods of the grid. The coordinated discharge into the network makes the effect of peak clipping and valley filling the most obvious.

5. Conclusion
The fuzzy optimal dispatch model built in this paper that considers the environmental economic goals of wind farm power systems with electric vehicles connected to the grid has the following characteristics:

(1) The fuzzy multi-objective dynamic scheduling model of wind power generation system considering PHEVs connection to the grid was established, and the dynamic model was simulated and calculated with a classic 10-machine system. The stochastic uncertainty of wind power has an adverse effect on system scheduling. Model verification in different scenarios further illustrates the rationality of the model considered in this paper.

(2) In view of the uncertainty of wind power output and load fluctuations, the fuzzy membership function of the maximum and minimum theory is introduced, and the maximum satisfaction index method is adopted to convert the considered multi-objective optimization problem into a single-objective optimization problem and use the improved PSO algorithm for solving, the model takes into account both environmental and economic benefits, making it more practical.

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