Multi-domains dispatching method for power system considering energy storage

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Abstract. Reasonably arranging the matching of power sources is an effective mean to improve the capacity of new energy consumption. Using the dispatching characteristics of the transferable load of the energy storage systems can play an important role in the actual dispatch of the power system. From the perspective of flexible scheduling, a multi-domain scheduling method is proposed, which comprehensively considers the influence of factors such as load, wind power output random fluctuations and system adjustment capabilities, and redistributes it into three control domains. That is, the normal control domains with the goal of completely absorbing wind power, anomaly control domain where the energy storage systems needs to be used to absorb wind power, and the emergency control domain where there is no regulation ability and forced to abandon wind. To maximizing clean energy consumption, CPLEX software is used to optimize output and realize multi-domain green economic dispatch. The calculation example shows that this method can effectively improve the absorption capacity of clean energy.

1. Introduction

In recent years, on the energy supply side, the proportion of new energy has increased tremendously. Large-scale new energy grid-connected will affect the main network and threaten the stability and security of the system [1-2]. Wind power is widely distributed and clean. It is developing very rapidly [3]. Wind power has the characteristics of random and indirect uncertainty and anti-peak shaving. To effectively absorb wind power, a large number of studies have been carried out on the operation and design of wind power storage integrated systems at home and abroad, and the use of fuzzy control to optimize the operation of energy storage systemss has appeared [4]. Multivariate forecasting algorithms are used to analyze wind power data technology to reduce the volatility of wind power and improve the system's absorption capacity [5].

Literature [6-7] reduce the error of power output by improving the accuracy of wind power forecasting, but the amount of calculation is large and the reserve capacity allocated for wind power volatility is not easy to determine, and it is easy to have excess or shortage of resources, causing unnecessary waste. Literature [8] uses a multi-objective algorithm to design an operation scheme that can reduce wind power fluctuations. However, this scheme is not economical in scheduling, and the
scheduling scenarios involved are single. Literature [9] proposes an economic dispatch strategy for wind farms and energy storage that takes into account the power market, but the wind power output under this strategy fluctuates too much and does not have the flexibility and speed required for dispatch, which affects the reliability of the power system. Literature [10] analyzed the renewable energy in the system and proposed the concept of flexibility margin, but the proposed method did not consider the specific dispatcher from the actual operation through qualitative analysis of the system principle. Therefore, the design can reasonably allocate adjustment resources in the scheduling of the day and formulate a scheduling plan that can be adjusted quickly and flexibly under different domains, to consume new energy economically, which is currently a topic waiting for research.

Aiming at the above problems, a multi-domain scheduling method is proposed. First, divide the domain for the load changes in the system and the regulation and output capacity of conventional units. Under the relative difference between supply and demand, to solve the above problems, a multi-domain scheduling method is proposed. Firstly, the domain is divided into the load changes in the system and the regulation and output capacity of conventional units. Under the relative difference between supply and demand, according to the adjustment capacity of the corresponding period time, it is divided into normal control domain that can be completely absorbed by adjusting conventional units, and energy storage need to be adjusted. The system suppresses the anomaly control domain of wind power and the emergency control domain where wind abandonment needs to be considered. Then, in different control domains, by directly calling the software CPLEX, it can be reasonably in different domains, and the efficiency of the unit and energy storage allocation in each period can be seen. Reasonably coordinate and match multiple sources, optimize traditional scheduling schemes, enhance the pertinence of each scheduling period, achieve full consumption of new energy as much as possible, and increase the profit of the power grid.

2. Multi-domain economic dispatch

Comprehensive consideration of the situation of wind power generation, the use of the flexible characteristics of the energy storage systems to match with conventional units, to maximize wind power consumption, according to the relative difference between supply and demand, the adjustment of conventional unit output and energy storage. A multi-domain scheduling method is proposed.

Normal control domain: It is defined as the difference between the output value and the load value of each unit under the typical daily load curve, and within the adjustment range of the conventional unit, the wind power can be fully absorbed. The thermal power unit can be adjusted in line with the full consumption of wind power. If the energy storage systems has surplus energy the day before, it will be used first for backup in the anomaly phase. Adjustable margin:

\[
\Delta P_{nf} = \sum_{i=1}^{N} \sum_{t=1}^{T} \Delta P_{nf_{i,t}} + \sum_{t=1}^{T} \sum_{i=1}^{N} \Delta P'_{es_{i,t}}
\]

Where, \(\Delta P_{nf}\) expressed as the adjustment size of the normal domain; \(\Delta P_{nf_{i,t}}\) as the adjustment ability of unit i, \(\Delta P'_{es_{i,t}}\) expressed as the remaining capacity of the energy storage systems the previous day.

Anomaly control domain: It is defined as when the wind power output value changes greatly under the typical daily load curve, and there is still a margin after the conventional unit is adjusted, the energy storage systems change is greater than or equal to the range of the wind power margin. When the adjustment resources are not exhausted. The range of scheduling in the system is:

\[
\Delta P_{af} = \sum_{i=1}^{N} \sum_{t=1}^{T} \Delta P_{af_{i,t}}
\]

Where, \(\Delta P_{af}\) as the adjustment size under the anomaly domain, \(\Delta P_{af_{i,t}}\) as the energy storage adjustment capacity under the current domain.
Emergency control domain: It is defined as the period during which wind power changes further increase under a typical daily load curve, and resources cannot be absorbed through adjustments, and a reasonable abandonment of wind must be carried out. Wind curtailment: 

$$\Delta P_{EF} = P_w' - (\Delta P_{AF} + \Delta P_{EF})$$ (3)

Where, $\Delta P_{EF}$ expressed as the amount of wind power that must be abandoned in the emergency domain beyond the regulation capacity; $P_w'$ expressed as the wind power output in the anomaly domain.

Also, to cope with emergencies, in the traditional dispatch scheme, 15% of the maximum power generation load should be reserved for each scheduling period. The current adjustment capacity is divided into each scheduling period in advance, and reserve capacity can be set in the dispatch period of the anomaly domain and the emergency domain, thereby reducing power generation costs.

3. Multi-domain dispatching model considering the largest consumption of new energy

3.1. Objective function

Considering all kinds of regulating resource costs under different domains, the generation cost is calculated according to the constraints under each domain in 96 scheduling periods, as shown in formula (4).

$$\min C_S = \sum_{i=1}^{N} \sum_{j=1}^{T} u_{NF} C_{NF} + \sum_{j=1}^{T} u_{AF} C_{AF} + \sum_{k=1}^{T} u_{EF} C_{EF}$$ (4)

$C_S$ is the total cost, $C_{NF}$, $C_{AF}$, $C_{EF}$ expressed as generation costs under three domains: $u$ represents that in a certain state, As shown in Table 1, when $\Delta P$ changes within $\Delta P_{NF}$, the state quantity of $u_{NF}$ is 1 otherwise 0, $u_{AF}$, $u_{EF}$ are the same, i, j, k is the number of periods under different domains.

|        | $\Delta P_{NF}$ | $\Delta P_{AF}$ | $\Delta P_{EF}$ |
|--------|-----------------|-----------------|-----------------|
| $u_{NF}$ | 1               | 0               | 0               |
| $u_{AF}$ | 0               | 1               | 0               |
| $u_{EF}$ | 0               | 0               | 1               |

In this domain, based on the condition of minimum network loss, all wind power output can be absorbed by adjusting the thermal power unit, and at the same time, the thermal power output can be appropriately reduced under constraint conditions to give priority to the use of energy storage margin to stay in the anomaly domain. Adequately absorb wind power and increase the consumption margin. Formula (5) is the output cost of each unit in the normal domain.

$$\min C_{NF} = \sum_{i=1}^{N} \sum_{j=1}^{T} (\alpha_i^j \cdot P_{i,j} + \beta_i^j \cdot P_{i,j} \cdot \gamma_i) + \sum_{i=1}^{N} \sum_{j=1}^{T} P_{i,j} \cdot c_i$$ (5)

$C_{NF}$ is the cost of power generation in the normal domain; $\alpha_i^j$, $\beta_i^j$, $\gamma_i$ is the cost coefficient of thermal power unit output; $c_i$ is set as the adjustment cost coefficient of the energy storage systems.

In the anomaly domain, if only adjusting thermal power units to consume wind power during this period cannot meet the dispatch economy, the energy storage systems needs to be used to absorb wind power. The output cost at this time is as shown in formula (6).

$$\min C_{AF} = \sum_{i=1}^{N} \sum_{j=1}^{T} (\alpha_i^j \cdot P_{i,j} + \beta_i^j \cdot P_{i,j} + \gamma_i) + \sum_{i=1}^{N} \sum_{j=1}^{T} P_{i,j} \cdot c_i$$ (6)

$C_{AF}$ is the cost of power generation in the anomaly domain.
When wind power increases further, the adjustment resources cannot be used to stabilize the wind power generation. The wind power can only be abandoned reasonably under the premise of economically optimal, and the output cost in the anomaly domain is the formula (7).

\[
\min C_{t} = \sum_{i=1}^{n} \left( \alpha P_{t,\text{max}} + \beta P_{t,\text{min}} + \gamma \right) + \sum_{i=1}^{n} P_{i,j} \cdot h_{i}
\]

(7)

\(P_{i,j}\) is the output of the abandoned wind power, and \(h_{i}\) is the penalty cost coefficient of the abandonment.

3.2. Model constraints

Supply and demand balance, line power flow constraints should be considered in the control under different domains, as shown in formulas (8) to (11).

\[
\sum_{j=1}^{N} P_{i,j} + P_{i,\text{dc}} + P_{i,\text{inj}} = \sum_{j=1}^{T} P_{i,j} + P_{\text{loss},i,j} + P_{\text{wind},i,j}
\]

(8)

\[
P_{n} - P_{i,n} = V \sum_{i=1}^{N} V_{i} (G_{in} \cos \theta_{in} + B_{in} \sin \theta_{in})
\]

(9)

\[
Q_{n} - Q_{i,n} = V \sum_{i=1}^{N} V_{i} (G_{in} \sin \theta_{in} - B_{in} \cos \theta_{in})
\]

\[
I_{L,i} \leq I_{L,i,\text{max}}
\]

(10)

\[
\sum_{j=1}^{N} P_{\text{out},i,j} + \sum_{j=1}^{N} P_{i,n} - \sum_{j=1}^{N} P_{i,j} \geq 0
\]

(11)

\(P_{n}\) and \(Q_{n}\) are the active power and reactive power injected into the grid by the power supply at node \(m\) respectively, \(P_{i,n}\) and \(Q_{i,n}\) are the active load and reactive power at node \(m\) respectively; \(V\) is the voltage amplitude of each node; \(\theta_{in}\) is node \(m\) and The phase angle difference between node \(n\), \(G_{in}\) and \(B_{in}\) are the electrical conductance and electrical susceptance on branch \(i,n\) respectively, \(I_{L,i}\) and \(I_{L,i,\text{max}}\) are the actual current and the maximum current flowing through the \(i\) branch respectively.

4. Example analysis

4.1. General solution ideas

Optimal scheduling of multiple power sources is a very complex nonlinear problem. When the system scale is large, it is very difficult to directly optimize the solution. To reduce the problem search space and improve computational efficiency. In this paper, the multi-domain control theory is proposed. Firstly, the adjustable margin of various scheduling domains is calculated according to the adjustment ability of various adjustment resources. According to the predicted daily load curve and wind power prediction curve, 96 time periods are divided into domains. By using commercial software CPLEX to absorb new energy as much as possible, the power generation cost under different operation modes is calculated and the power grid economy is improved Income. In this paper, the multi-domain scheduling scheme and the conventional scheduling scheme are compared and analyzed based on the unit output cost and wind rejection rate.

4.2. Numerical simulation model

This paper uses the dispatching scheme of a dominal power grid system in Liaoning Province as an example to verify the validity and feasibility of this model and method. The system includes a wind power cluster with an installed capacity of 0.35 GW and a thermal power unit with a total installed capacity of 0.6 GW, with a 0.12 GW·h energy storage systems. The minimum storage capacity is 15 MW·h, the initial storage capacity is 20 MW·h, the rated charge/discharge power is 40 MW, the charge/discharge efficiency is 0.92.
4.3. Example analysis

Three schemes are proposed for comparison and analysis of the results. They are the dispatching scheme of the non-energy storage systems, the dispatching scheme of the energy storage systems, and the multi-domain dispatch scheme.

The dispatch scheme of the non-energy storage systems: Taking a local dispatching plan as an example, Figure 1 shows the actual wind power output and load value, and Figure 2 shows the output curve of each unit on that day. It can be seen that there are two curtailment areas in the traditional dispatching plan, usually from 22:00 to about 6:00 the next day, when the load value is relatively low, the wind power cannot be used as a conventional unit to supply power. At this time, wind power will be forced to restrict wind power, or even to shut down the thermal power unit to save the adjustment cost.

![Flow chart of the overall idea of multi-domain scheduling.](image)

The dispatch scheme of the energy storage systems: Figure 3 shows the dispatch plan after taking into account the energy storage systems. It can be seen that the energy storage systems has two-way nature, which can further increase the absorption capacity of wind power and reduce the wind power curtailment rate to a certain extent. Overall regulation, it is obvious that the energy storage systems is used frequently, and the utilization efficiency is only 52%, and after the dotted line, the energy storage capacity is full and can no longer be used. If the output of the thermal power unit is adjusted, the cost will be greatly increased. In this method alone, the power generation cost of the thermal power unit is 1.22 million yuan. Although the power generation cost of the thermal power unit is effectively reduced, the energy storage adjustment cost has increased by 0.38 million yuan, so the role of energy storage in this method is not fully utilized.

The multi-domain dispatch scheme: Aiming at the foregoing two dispatching schemes, experiments are carried out with the same system scenario using a multi-domain dispatching scheme. As shown in Figure 4, the division of different domains and the output curves of each unit in different domains are
given. The dotted line in the figure is the boundary between the domains. The NF area is the normal domain, the AF area is the anomaly domain, the EF area is the emergency domain, and the shaded area is the air curtailment volume. In the normal domain, the thermal power unit can adjust wind power generation under economic constraints, and the factor is in the daytime. The wind power in this area is relatively weak and there is no need to adjust the energy storage systems. At the same time, it is between 15:15 and 17:45. Hour, and from 23:15 to early morning, the energy storage systems can be allowed to empty the remaining reserves and leave it in the anomaly area to fully absorb wind power. In the anomaly domain, the cost of adjusting thermal power units is increased by calculation at this time, and some units need to be shut down. Therefore, to save costs, wind power can be fully absorbed through the energy storage systems. At the same time, in the emergency domain, the regulation resources in this domain are exhausted, and only wind power can be restricted. The power generation cost, wind abandonment rate, and wind abandonment penalty calculated by this method are compared with the previous two methods as shown in Table 2.

Table 2. Comparison of the results of the three methods.

|                  | Generation cost/million yuan | Wind curtailment rate/% | Wind abandonment penalty/million yuan |
|------------------|------------------------------|-------------------------|--------------------------------------|
| non-energy storage | 1.57                         | 15                      | 0.51                                 |
| energy storage    | 1.60                         | 11                      | 0.37                                 |
| multi-domain dispatch | 1.37                       | 5                       | 0.17                                 |

It can be seen from the table that the multi-domain dispatch scheme reduces the wind abandonment rate from 15% to 5% in comparison with the dispatch plan without energy storage, which greatly improves the absorption capacity of wind power. The pertinence of peak demand and supply is more obvious so that the coordination between thermal power units and energy storage systemss can better solve the problem of wind power consumption. Further, increase the allocation of resources between domains, and the percentage of curtailed wind power decreased by up to 72%, effectively improving the efficiency of wind power utilization.

![Figure 2. No storage system operation diagram.](image-url)
5. Conclusions
In this paper, a multi-source multi-domain dispatching method based on regulating resources is proposed and applied to the preparation of a pre-generation plan for a power grid in a certain part of China. The multi-domain division is based on the example analysis. To ensure wind power absorption and meet the needs of power grid flexibility, improve the utilization of wind power for the power grid dispatching department gate provides an efficient dispatching scheme to absorb wind power.

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