A demand-side integrated flexible load regulation optimization strategy for clean energy consumption

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Abstract: In order to absorb large-scale clean energy for power grid, the use of energy storage technology is paid more and more attention. However, most of the current researches are focused on a single kind of energy storage forms, and few are involved in the joint use of multiple energy storage devices. This paper aims at the insufficient application of a single energy storage device and the conflict between multiple energy storage technologies. A demand-side integrated flexible load regulation optimization method is proposed. For the heat storage electric boiler system and the ice storage air conditioning system, the combined algorithm is used to optimize their operation. It is clear that the combined algorithm based on genetic algorithm combined with cold, hot and electrical system has a more significant effect of absorbing clean energy than the single energy storage system. And, the example result proves the correctness and feasibility of the proposed comprehensive demand side response strategy.

1. Introduction

Energy is an important material for people's survival. With the gradual decrease of fossil energy storage in the world, the researchers have paid more and more attention to the development of clean energy [1,2]. While the use of energy storage technology is focus to solve the problem of new energy consumption, the integrated energy system has become an important strategic direction to solve the problem of wind power consumption [3,4].

Nowadays, in order to absorb renewable energy, most researchers [5,6] focus on how to add an energy storage device in the system, but ignore the joint use of a variety of energy storage equipment.

In this paper, the comprehensive demand response project in the integrated energy system is studied. The genetic algorithm is used to combine it with the thermal storage electric boiler and cool storage air conditioning, and then the optimization method of the demand side comprehensive response strategy is proposed.

2. Power effect analysis of regenerative electric boiler

In this paper, it is considered that the regenerative electric boiler mainly uses the abandoned wind power, so it will increase a part of local power load, and its output model is as follows:

$$H_{EBL} = P_{EBL} \cdot \eta_{ah}$$  \hspace{1cm} (1)
where, \(P_{EB,t}\) and \(H_{EB,t}\) are electricity consumption and heating power of electric boiler in time period \(T\), \(\eta_{eb}\) is the conversion efficiency of electric boiler.

The mathematical model of heat storage capacity is

\[
S_{HS,T} = (1 - \mu)S_{HS,T-1}\left(\frac{H_{HS\_in,t}\lambda_{HS\_in,t} - H_{HS\_out,t}}{\lambda_{HS\_out,t}}\right)\Delta t
\]

(2)

where, \(S_{HS,T}\) is the thermal storage capacity of period \(T\), \(\mu\) is the heat loss rate, \(H_{HS\_in,t}\) and \(H_{HS\_out,t}\) are the heat absorbing and releasing power and efficiency in time \(t\) respectively.

It is noticed that the regulating power of regenerative electric boiler is very dependent on the electrode rod, So far, it is not common to have electrode rods that can match the wind power with high randomness and volatility, therefore, the effect of this strategy in real life is not very obvious, and the practicability is not very high.

3. Characteristics of cool storage air conditioning

The calculation formula of average cool storage rate of cool storage air conditioning is as follows:

\[
Q_s = \frac{\int G_q \rho_c \rho_v (T_{w, in} - T_{w, out}) dt}{\int dt}
\]

(3)

The operation mode of ice storage air conditioning during the day, it could be divided into night ice storage period and daytime cooling period. The ice storage period is generally concentrated in the valley section of the power grid. At this time, the user's cooling demand is 0, Recorded as \(L_k\), the air conditioning system stores ice to the ice storage device with hourly ice storage capacity, when the ice storage capacity reaches the rated value of the ice storage equipment, it stops working. The specific formula is shown in formula 4.

\[
\begin{cases}
L_k = \sum L_{t,i} \\
0 \leq L_k \leq L_{k,max}
\end{cases}
\]

(4)

i) Ice storage rate (IPE), the ice storage rate is the ratio of the ice stored in the ice storage tank to the total ice storage capacity. It is defined as:

\[
IPF = \frac{V_1}{V_2} \times 100\%
\]

(5)

ii) Ice melting rate (DE), the ice melting rate refers to the proportion of the ice volume used for melting to the total ice storage, It is defined as:

\[
DE = \frac{Q_1}{Q_2} \times 100\%
\]

(6)

In this paper, the characteristics of air conditioning system are studied, we should pay attention to the limitation of storage capacity, the ability to optimize the load trough is insufficient.

4. Joint optimization model of regenerative electric boiler and cool storage air conditioning

This paper takes thermal storage electric boiler system and ice storage air conditioning system as cold and hot electricity as examples, based on the analysis of regenerative electric boiler system and ice storage air conditioning system in section 2 and 3 respectively, the genetic algorithm is used to optimize the algorithm, it is clear that the combined cooling, heating and electrical system based on genetic algorithm has a more significant effect on clean energy consumption than a single energy
storage system, it proves the correctness and feasibility of the integrated demand side response strategy proposed in this paper.

4.1 Objective function
In this paper MATA LB GA algorithm is used to explore the combined absorption effect of thermal storage electric boiler and cool storage air conditioning, the objective function is to minimize the abandoned air volume, and a joint optimal scheduling model is established.

\[
\min F = \sum_{t=0}^{T} P_{y,t} - P_{s,t}
\]  \hspace{1cm} (7)

4.2 Constraints

4.2.1. Energy balance constraint
Power balance constraints include electric power balance, thermal power balance and cold power balance could be shown as:

\[
\sum P_{H,t} + \sum P_{R,t} + \sum P_{F,t} = P_{kl,t} + P_{gl,t} + P_{FH,t}
\]  \hspace{1cm} (8)

\[
\sum Q_{R,t} + Q_{gl,t} + Q_{kt, out} = Q_{FH,t} + Q_{x, in}
\]  \hspace{1cm} (9)

\[
H_{kl,t} = H_{FH,t}
\]  \hspace{1cm} (10)

4.2.2. Equipment status constraints
The heat storage capacity of heat storage tank should be within its limit value:

\[
Q_{min} \leq Q_{x, in} \leq Q_{max}
\]  \hspace{1cm} (11)

The ice storage capacity of ice storage tank should also be within its limit:

\[
W_{min} \leq W_{x} \leq W_{max}
\]  \hspace{1cm} (12)

4.2.3. Power constraint of electric boiler

\[
0 \leq P_{gl,t} \leq P_{gl, max}
\]  \hspace{1cm} (13)

4.2.4. Power constraint of cool storage air conditioning
Power consumption for ice storage:

\[
P_{ch, max} \leq P_{kt,t} \leq 0
\]  \hspace{1cm} (14)

During virtual discharge:

\[
0 \leq P_{kt,t} \leq P_{sf, max}
\]  \hspace{1cm} (15)

4.3 Genetic algorithm
Genetic algorithm is a main branch of evolutionary computing, compared with the traditional calculation method, genetic method can search multiple peaks in parallel, because the genetic algorithm only uses the objective function and fitness function, it solves the problem that the traditional algorithm cannot carry out because the function cannot be derived, it has more extensive practicability. The standard form of an optimization problem is shown in equation (16).
\[
\begin{align*}
\min f &= f(x) \\
st. &g_i(x) \leq 0 \quad i = 1, 2, \ldots, p \\
&h_j(x) = 0 \quad j = 1, 2, \ldots, q
\end{align*}
\]

5. Example analysis
The MATLAB simulation software is used, and the genetic algorithm is used to solve the model. The simulation parameters of each unit, regenerative electric boiler system and cool storage air conditioning system in the dispatching model are shown in table 1, 2 and 3.

### Table 1 Parameters of thermal and motor units

| Parameter                                      | Value         |
|------------------------------------------------|---------------|
| Minimum operating power of thermal power unit | 100MW         |
| Maximum operating power of thermal power unit | 280MW         |
| Minimum operating power of thermal power unit | 55MW          |
| Maximum operating power of thermal power unit | 280MW         |
| Thermoelectric ratio                          | 100%          |

### Table 2 Parameters of regenerative electric boiler

| Parameter                        | Value         |
|----------------------------------|---------------|
| Rated operating power           | 30MW          |
| Heating efficiency              | 100%          |
| Heat storage capacity           | 100MWh        |
| Maximum thermal storage power   | 40MW          |
| Maximum exothermic power        | 40MW          |
| Initial heat storage            | 0MWh          |
| Heat storage efficiency         | 100%          |
| Self- heat release rate         | 0%            |

### Table 3 System parameters of cold storage air conditioning unit

| Parameter                        | Value         |
|----------------------------------|---------------|
| Ice storage tank capacity        | 100MWh        |
| Maximum ice making power        | 90MW          |
| Maximum cooling power           | 90MW          |
| Initial ice production          | 0MWh          |
| Ice making efficiency           | 100%          |
| Cooling release efficiency      | 100%          |
| Self cooling rate               | 0%            |

![Figure 1 Wind curtailment of the original system](image1)

![Figure 2 The case which only including the waste air consumption of regenerative electric boiler system](image2)
There are four cases to analyse the capability comparison of joint optimization algorithm for clean energy consumption: (i) There is neither regenerative electric boiler system nor cold storage air conditioning system; (ii) It only includes the air consumption and abandonment of regenerative electric boiler system; (iii) It only includes the air consumption and abandonment of cool storage air conditioning system; (iv) The combined system of regenerative electric boiler and cool storage air conditioning system is used to absorb the abandoned air. The analysis results are shown in Figure. 1, 2, 3 and 4.

As could be seen from figure 4, in the daytime, the combined system takes almost all the wind, and at night, although there are still a lot of abandoned wind that cannot be eliminated, however, the air consumption rate has been greatly increased compared with that before the combination, it has increased from 230 MW to 350 MW, an increase of nearly 120 MW. This is due to the strong volatility of wind power, and the wind power output is small in the daytime, so the system can achieve the goal of absorbing and abandoning wind. However, at night, the wind power output is too large. Even if the combined system is added to absorb the abandoned wind, the amount of abandoned wind that can be absorbed is only a part of the wind power output at night, so there are still a lot of abandoned wind that cannot be eliminated at night.

The wind power consumption effect of the four conditions is compared, the specific consumption comparison is shown in table 4.

| Different situations                  | Wind power consumption (MW) | Abandon wind (MW) | Wind abandonment rate (%) |
|---------------------------------------|-----------------------------|-------------------|---------------------------|
| No boiler, no air conditioning        | 188.8309                    | 775.1691          | 80.41                     |
| Boiler without air conditioning       | 612                         | 352               | 36.51                     |
| No boiler, air conditioning           | 439.7747                    | 524.2253          | 54.38                     |
| There are boilers and air conditioners| 720.5002                    | 243.4998          | 25.26                     |
In this paper, the joint algorithm of genetic algorithm is used to optimize the absorption system. The problem is divided into four cases: the original system without regenerative electric boiler system and ice storage air conditioning system, the optimization system only including the thermal storage electric boiler system, the optimization system only including the ice storage air conditioning system and the joint optimization system. After calculation and analysis, it is found that the combined system consumes 108.5002mw and 280.7256mw more than the single boiler system and the single air conditioning system respectively, and reduces the abandoned air volume by 11.26% and 29.12%. It is proved that the system combined with cold, heat and electricity has more significant effect of absorbing clean energy and higher flexibility than single energy storage system. It proves the correctness and feasibility of the integrated demand side response strategy proposed in this paper.

6. Conclusion
In this paper, a comprehensive demand side response strategy considering clean energy consumption is proposed in combination with hot and cold electricity, which is flexible and feasible. The thermal storage electric boiler and air conditioning system are taken as examples to analyse the combination of various energy storage methods. Then, the optimization effect of the algorithm is calculated and analysed. Finally, the following conclusions are drawn as follows:

(i) The selection of adaptive function has a direct impact on the results of genetic algorithm.
(ii) After modelling, analysis and operation, it could be found that the combined system of thermal storage electric boiler system and cold storage air conditioning system has better effect and higher flexibility than the original system and the single energy storage system.
(iii) It could be concluded from the specific data, compared with the original system, the combined system reduces the wind abandonment rate by 55.12%, which proves the feasibility of the joint strategy proposed in this paper.

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