An optimized demand-response operation method of regional integrated energy system considering 5G base station energy storage

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Abstract—The scheduling technology of regional integrated energy system is one of the key technologies to realize carbon neutralization by utilizing wind-power. Aiming at the optimal scheduling problem of regional electrothermal integrated energy system considering wind-power utilization and load side energy consumption, this paper proposes an optimized demand-response operation method of regional integrated energy system considering 5G base station energy storage. The regional integrated energy system of load side demand response is constructed based on the comprehensive consideration of technical and economic factors such as wind-power utilization and economic costs and load side peak valley difference. Finally, a two-layer particle swarm optimization method is proposed to solve the model. The experimental results show that the proposed method can effectively achieve wind-power utilization, economic dispatch and reduce the peak valley difference through load side demand response, which can improve the economic efficiency, environmental protection and low-carbon operation of regional integrated energy system.

1. Introduction

With the proposal of the national strategic goal of "dual carbon", the construction and development of energy Internet has faced new technical challenges [1]. How to ensure the safe and stable operation of a high proportion of clean energy power system with the help of advanced technologies such as solar storage technology, demand side response technology and large grid interconnection while promoting clean replacement and electric energy replacement has become one of the keys to achieve carbon peak and carbon neutrality in the power industry [2]. Regional Integrated Energy Systems (RIES) have the technical advantages of multiple Energy forms, absorbing renewable Energy, supporting demand side response and providing multiple demands for multiple loads [3]. RIES coordinates and optimizes the distribution, conversion, storage and consumption of various types of energy, including electricity, heat and gas, to break the original independent operation mode, improve system flexibility, make full use of renewable energy and effectively improve energy efficiency [4].

At present, scholars at home and abroad have carried out a lot of work on regional integrated energy system from two aspects of demand response and optimal scheduling [3][4][5] [6][7][8][9].Therefore, on the basis of comprehensive consideration of wind power consumption, economic and environmental costs, and load side peak-valley differential and other technical and economic factors, this paper
constructs a multi-objective optimization operation model of regional integrated energy system RIES for economic cost optimization and peak-valley differential optimization.

2. Mathematical Description of Integrated Energy System Model

RIES systems may include power systems, thermal systems, renewable energy generation systems, energy storage systems and integrated load users. Typical centralized RIES containing wind power generation system (hereinafter referred to as wind power system) and 5G base station energy storage system are shown in Figure 1.

![Figure 1. Operation architecture of typical centralized RIES with wind-power and energy storage](image)

2.1. Energy supply model of cogeneration unit

The CHP, as the core of RIES “coordinated dispatching, is powered by coal or natural gas (natural gas in this case) to generate both electricity and heat. The energy supply model of unit cogeneration unit in the time period is shown in Formula (1).

\[
\begin{align*}
T_{CHP}(t) &= \eta_T \cdot u_c \cdot M_T(t) \\
P_{CHP}(t) &= \eta_P \cdot u_e \cdot M_P(t)
\end{align*}
\]

Where, \(T_{CHP}(t)\) and \(P_{CHP}(t)\) are thermal power output and electric power of cogeneration unit at the time, \(\eta_T\) and \(\eta_P\) are heating efficiency and power generation efficiency of the unit respectively, \(u_c\) is gas burning energy per unit (kJ/1000Nm3), \(M_T(t)\) and \(M_P(t)\) are gas consumption of cogeneration unit at the time (Nm3). \(T_{CHP}(t)\) and \(P_{CHP}(t)\) can be converted to each other with the help of the ratio of electric output and thermal output of the hot spot cogeneration unit. In the normal mode of "fixed electricity by heat", \(T_{CHP}(t) = \eta_{conversion} \cdot P_{CHP}(t)\).
2.2. Energy storage model
Energy Storage system is an important part of RIES. The energy Storage model consists of Electric Storage (ES) of 5G base station and Thermal Storage (TS). This model uses storage battery and heat storage tank to store heat.

2.2.1. Energy storage model of 5G base station
The dynamic model of 5G base station energy storage device is expressed by the following formula.

\[ E(t) = E(t-1) + \frac{P_c(t)\eta_c}{N} \Delta t \]

Where, \( E(t) \) is the electric quantity stored during the period \( t \), \( P_c(t) \) and \( P_d(t) \) are respectively the charge and discharge power, \( \eta_c \) and \( \eta_d \) are respectively the charge and discharge efficiency of the battery, and \( N \) is the rated capacity of the energy storage battery.

2.2.2. Thermal storage model
The thermal storage TS model (in this paper, the heat storage tank is used as an example) participates in the dynamic heat storage characteristics of RIES, including capacity, output and input characteristics, and thermal conversion efficiency, as shown in Equation (3) [9].

\[ H_{TS}(t) = (1-k_s)H_{TS}(t-1) + [Q_{st}(t)k_{st} - Q_{es}(t)k_{es}]\Delta t \]

Where \( H_{TS}(t) \) is thermal energy storage capacity of time period \( t \); \( k_s \) is the heat loss rate of thermal energy storage, \( Q_{st}(t) \) and \( Q_{es}(t) \) and \( k_{st} \) and \( k_{es} \), are respectively the heat absorption and heat release power efficiency.

3. Energy Optimization Modeling for Integrated Energy Systems
The constraint conditions and optimization objective function of the model are introduced in turn.

3.1. The constraint
RIES constraints are mainly equipment involved in scheduling optimization and user-side DR load constraints.

3.1.1. CHP constraints on cogeneration units
CHP constraints of CHP units include upper and lower limits of output and climbing rate constraints, as shown in Equations (4) [3].

\[ P_{C_{CHP}}^{\text{min}} \leq P_{C_{CHP}}(t) \leq P_{C_{CHP}}^{\text{max}} \quad Q_{C_{CHP}}^{\text{min}} \leq Q_{C_{CHP}}(t) \leq Q_{C_{CHP}}^{\text{max}} \]

Where \( P_{C}(t) \) is the generation power of the unit during the period \( t \); \( P_{C_{CHP}}^{\text{min}} \), \( P_{C_{CHP}}^{\text{max}} \), \( Q_{C_{CHP}}^{\text{min}} \) and \( Q_{C_{CHP}}^{\text{max}} \) are respectively the maximum output power and minimum power of generation and heating of CHP.

3.1.2. Energy storage constraint of 5G base station
Electric energy storage ES of 5G base station are shown in Equation (5).

\[ S_{ES}^{\text{min}} \leq SOC(t) \leq S_{ES}^{\text{max}} \]

Where, \( S_{ES}^{\text{min}} \) and \( S_{ES}^{\text{max}} \) are respectively the upper and lower limits of the charged state of the electric energy storage ES, and \( SOC(t) \) is the value of the charged state of the electric energy storage ES in the current period \( t \).

For other constraints, please refer to [3][4][5][6][7][8][9].
3.2. The objective function

RIES system economic cost is calculated according to Equation (6).

\[
C_{\text{run}}(t) = C_{\text{CHP}}(t) + C_{\text{WT}}(t) + C_{\text{ES}}(t) + C_{\text{TS}}(t)
\]

(6)

Where \( C_{\text{run}} \) is the operating cost of RIES, including DR compensation cost, \( C_{\text{WT}}(t) \), \( C_{\text{ES}}(t) \), \( C_{\text{TS}}(t) \) and \( C_{\text{EB}}(t) \) and are respectively WT wind turbine abandon cost, ES charge and discharge cost of electric energy storage, HS operating cost of thermal energy storage and EB operating cost of electric boiler. For specific calculation, please refer to reference [9].

RIES system technical cost is calculated according to Equation (7).

\[
\delta_{\text{L}}^{\text{DR}}(t) = \frac{1}{\Delta t} \sum_{\Delta t} [P_{\text{EL}}(t) - \bar{P}_{\text{EL}}(t)]^2
\]

(7)

Where \( \Delta t \) is the scheduling time in unit time period, and \( \bar{P}_{\text{EL}}(t) \) is the mathematical expectation within the time period \( t \).

4. The Example Analysis

In order to verify the effectiveness of the model proposed in this paper, an urban area in northern China was selected, and the regional power supply and heating was provided jointly by CHP, WT, ES, TS and EB. The other parameters of the model are set as follows: The average gas cost of CHP is 3.6 yuan/Nm3 (commercial), the heating efficiency \( \eta_T \) is 0.8924, the power generation efficiency \( \eta_P \) is 0.3539, and the electric heating ratio \( \eta_{\text{conversion}} \) is 1. Unit wind power cost is calculated according to [9]. The technical and economic parameters of operation and maintenance of RIES equipment [9] are set in Table 1.

| Unit type          | \( P_N \) / MW | \( P_N \) / kW h | \( P_{\text{min}} \) / MW | \( P_{\text{max}} \) / MW | \( k_i \) / yuan (kW h) combating |
|-------------------|----------------|-----------------|--------------------------|--------------------------|-------------------------------|
| Cogeneration system | 200            | —               | 100                      | 200                      | 0.0946                        |
| TW                | 40             | —               | 0                        | 2                        | 0.0296                        |
| EB                | 10             | —               | 0                        | 10                       | 0.0500                        |
| ES                | —              | 200 \times 96   | 0.024                    | 0.078                    | 0.0832                        |
| TS                | —              | 4 \times 5000   | 1.5                      | 4                        | 0.0450                        |

In experimental case 1, only CHP, TW and heat load were involved in dispatching. On the basis of case 1, thermal energy storage, electric energy storage, electric boiler and DR electric load are added into case 2 to participate in scheduling. Figure 2 shows the comparison of wind power consumption results between case 1 and case 2. Case 1 wind power consumption rate is 47.68%; In case 2, the wind power consumption rate was increased to 90.43%, which greatly improved and reduced the waste of wind power resources.
Figure 2. Wind power utilization comparison.

Figure 3. Power load balance and SOC curve of ES in Case 2.

Figure 4. Power load balance and SOC curve of ES in Case 2.

Figure 3 shows that fan output is vigorous during 18:00-24:00. At 00:00-06:00 and 13:00-18:00, the electric energy storage output, electric boiler output and DR output cooperate with each other to improve
the electric load in the changing period and provide space for wind power consumption. Figure 4 shows that from 15:00 to 17:00, thermal energy storage increases to meet the thermal load, reducing fuel cost, absorbing a certain amount of wind power, and greatly reducing fuel cost and wind abandoning cost.

Table 2. Economic cost comparison

|                  | case 1 (Ten thousand yuan) | case 2 (Ten thousand yuan) |
|------------------|-----------------------------|-----------------------------|
| The total cost   | 80.4193                     | 72.0350                     |
| CFU              | 51.7899                     | 43.5208                     |
| CWT              | 6.8904                      | 3.2317                      |
| CTS              | /                           | 0.0070                      |
| CES              | /                           | 0.4173                      |
| CME              | 26.7390                     | 24.8582                     |

The economic expenditure pairs of case 1 and case 2 are shown in Table 2. In case 1, only CHP, TW and thermal load participate in scheduling, and the overall total cost is relatively high. On the basis of example 1, thermal energy storage, 5G base station electrical energy storage, electric boiler and DR electrical load are added to the scheduling in example 2. Through DR electrical load dispatching, the wind power is greatly absorbed, the waste of wind power resources is reduced, and the cost of abandoning wind is greatly reduced.

5. Conclusion
This paper takes the optimization operation of regional integrated energy system that supports the carbon-neutral regional 5G base station energy storage to participate in the demand response as the entry point. The proposed method can effectively realize wind power consumption and economic dispatching, so as to improve the economic efficiency, environmental protection and low-carbon operation of regional integrated energy system. The next step is to further study the optimization operation mechanism and scheduling of regional integrated energy system of 5G base station energy storage and distribution grid.

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References
[1] Ma Zhao. "Dual carbon" target forces the construction of new power system to accelerate [N]. China Energy News,2021-03-22(004).
[2] Qu B, LIU C, LI D Z, et al. Research on energy substitution development strategy under the goal of "carbon neutral" [J]. Power Demand Side Management, 2021,23(02):1-3+9.
[3] Zici Wang, Bingyin Lei, Lingyi Yang, Yuqing Su, Weizhe Sun. Multi-objective bi-level optimal scheduling of regional integrated energy system considering combined demand response of electric heating [J]. Journal of electric power system and its automation: 1-10 [2021-04-10]. HTTP: // https://doi.org/10.19635/j.cnki.csu-epsa.000750.
[4] Li Zilin, LIU Ronghui. Operation optimization of regional integrated energy system with energy storage considering demand side response [J]. Modern electric power,2019,36(06):61-67.
[5] Bai Hongkun, Zhang Peng, Yin Shuo, Yang Meng, Yang Qinchen. Journal of Henan Polytechnic University (Natural Science Edition), 2021,40(02):127-134.
[6] Cao Huiqiu. Day-Ahead Economic Dispatch of Wind Integrated Power System Considering Demand Response[D]. Wuhan : Wuhan University, 2018.
[7] Wang Yali, Liu Hong, ZhaoJuan, et al. Distribution network economic dispatch based on network reconfiguration and power-heat combined demand response[J]. Electric Power Construction,
2019, 40(4): 90-97.

[8] Fang Shaofeng, Zhou Renjun, Xu Fulu, et al. Optimal operation of integrated energy system for park micro-grid considering comprehensive demand response of power and thermal loads[J]. Proceedings of the CSU-EPSA, 2020,32(1):50-57.

[9] Liu Hong, Chen Xingyi, Li Jifeng, Xu Ke. Electric power automation equipment, 2017,37(6):193-200.

[10] Jing Weizhe, Liu Yang, Xiang Yue, et al. Power construction,2017,38(12):68-76.

[11] Lu Jun, PENG Wenhao, Zhu Yanping, et al. Power grid technology,2017,41(07):2370-2377.

[12] Zhengmao, ZHANG Feng,LIANG Jun,et al. Optimization on microgrid with combined heat and power system[J].Proceedings of the CSEE, 2015, 35(14): 3569-3576.

[13] Lu Jun, Zhu Yanping, PENG Wenhao, et al. Automation of electric power systems,2017,41(17):113-120.

[14] Zhenbo Wei, Xiaolin Ren, Yuhan Huang. Multi-objective optimal scheduling of regional integrated energy system considering comprehensive demand side response [J]. Electric power construction,2020,41(07):92-99.

[15] Naveed A. K.,Guftaar A. S.S., Ahmed B. A. etc. Modeling and operation optimization of RE integrated microgrids considering economic, energy, and environmental aspects[J].International Journal of Energy Research. 2019,43(13),pp:6721-39.

[16] Hu Xiaotong, Liu Tianqi, He Chuan, et al. Proceedings of the csee,2016,36(10):2674-2681.