Research on Evaluation Method of Coal-to-Electricity Project Considering Load Access Mode

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Abstract. With the aggravation of air pollution, some cities in northern China have carried out the coal-to-electricity project in succession, replacing the traditional coal-fired heating with clean and pollution-free electric energy in winter heating period. In the process of project promotion, the regenerative electric boiler is widely used. In this context, this paper first analyzes the operating characteristics of regenerative electric boilers, and establishes a coal-to-electricity project evaluation model from the perspective of heating energy type conversion and distribution network construction based on optimization models that take into account different start-stop modes. And in the part of simulation examples, the actual data is used to evaluate and analyze the different load access methods, and the results verify the effectiveness of the model proposed in this paper. It can also guide the engineering practice and provide theoretical support for the introduction of DSM in the subsequent engineering.

1. Introduction
Replacing traditional energy with new energy, replacing scarce energy with superior energy, and replacing fossil energy with renewable energy are the top priorities of my country's energy replacement strategy. My country's existing traditional fossil energy resources are dominated by coal, and high-quality fossil energy resources such as oil and natural gas are relatively insufficient [1].

Vigorously promoting alternative technologies for electric energy and improving the level of electrification can solve the contradiction between economic development and environmental protection. The coal-to-electricity conversion project is an important means to adjust the energy structure and transform the way of energy use, and has a positive significance for improving the current power surplus and promoting the development of clean energy [2,3]. The coal-to-electricity conversion refers to the use of electricity to replace coal, the use of centralized heating such as electric boilers or other facilities to provide heating to users[4]. The implementation of the coal-to-electricity project will help increase the proportion of electric energy in the final energy consumption [5].

At present, foreign coal-to-electricity conversion projects are relatively mature. The electric heating technologies and supporting policies of the United States, Japan, and South Korea have become more sophisticated and have been vigorously promoted, making these countries have higher levels of commercial and residential electrification. The application rate of electric heating technology in the United States has reached 50%, while Japan and South Korea have reached 80%. In contrast, my country's electric heating is still in its infancy. The coal-to-electricity conversion project is mainly
concentrated in the northern Beijing-Tianjin-Hebei region, covering 28 cities and 1,972,500 residents. All the northern regions have formulated corresponding supporting policies to promote the smooth implementation of the coal-to-electricity conversion project. This project will bring significant economic benefits. For example, the 74,000 rural bungalow heat storage electric heater project in a certain area of Hebei, after implementation, the price is 0.10 yuan/ (m$^2$.day) lower than that of gas heating.

The implementation of the coal-to-electricity conversion project can have the effect of cutting peaks and filling valleys. Literature [8] analyzed the implementation status of coal-to-electricity projects in Beijing-Tianjin-Hebei area from two aspects of decentralized heating and centralized renovation projects, including heat storage electric heaters and air-source heat pump projects, and concluded that they cut the power grid during low-level operation The obvious conclusion of peak valley filling. On this basis, literature [9] also concluded that the air source heat pump is more suitable for peak shaving in winter due to the heat storage effect of the enclosure structure. Literature [10] analyzed the changes in the rural power grid before and after coal conversion from the perspective of load characteristics, and concluded that the load has increased to a large extent, and the peak-valley period of the load curve also shifted.

In addition to peak-shaving and valley-filling of the grid load, many literatures have studied the investment and economics of coal-to-electricity conversion projects [11, 12]. However, a complete system of economic benefit evaluation index system has not yet been formed. This paper applies the financial evaluation process of the economic benefit of the distribution network to the effectiveness analysis of the coal-to-electricity reform project, as the economic benefit evaluation index of the coal-to-electricity reform.

This paper analyzes the results of coal-to-electricity conversion projects in terms of economic benefits. First, it analyzes the load characteristics of regenerative electric boilers connected to the power grid, and then proposes an evaluation method of economic benefit indicators to select the optimal operation mode of electric heating load.

2. Economic benefit analysis of coal-to-electricity Project
Replacing existing coal-fired hot water boilers with energy-saving and high-efficiency regenerative electric boilers, using valley electricity with lower electricity prices to store heat at night and heat all day, can achieve more economical and environmentally friendly purposes.

The optimization model arranges the start-stop plan and output of each thermal storage boiler in each period of the cycle. On the premise of meeting the total system load requirements and other constraints, the minimum rate of synchronization with the power grid is achieved. The thermal storage boiler is used as a controllable heating load When selecting its optimal access mode, it is necessary to ensure that the impact on the power grid is minimal. Therefore, the concept of simultaneous load rate is introduced, and the lowest simultaneous rate is taken as the optimization goal. In the implementation of the coal-to-electricity project, adjusting the ratio of heat storage boilers to optimize the load characteristics can be divided into different batch start and stop optimization models. For specific methods, please refer to the reference [13].

The economic benefit analysis of coal-to-electricity reform is mainly evaluated on the basis of the economics of two fuels, coal and electricity, and the economic benefits of investment in distribution networks before and after coal-to-electricity reform.

2.1. Economical comparison of coal and electricity
The comparison between the operating costs of electricity and various types of fuels is mainly based on the current electricity price policy and fuel prices. The cost of electricity replacement technologies and oil and natural gas application technologies under the same conditions are analyzed and compared. The specific quantified parameters are the actual heating value and the daily operating cost at full load.

The actual calorific value refers to the heat actually released by consuming a certain amount of certain energy. Assuming that the actual heating value is $q$. 


\[ q' = q \cdot \eta \]  

(1)

Where \( q \) is the theoretical calorific value of the energy, \( \eta \) is the thermal efficiency.

Full-load daily operating costs refer to the daily costs incurred when coal-fired or electric boilers are operating at full load. Assuming that the daily operating cost at full load is \( C \).

\[ C = P \cdot p \cdot t \]  

(2)

Where \( P \) is the full load during operation, \( p \) is the market price of raw materials during this period, \( t \) is the number of operating hours per day.

2.2. Calculation parameters of economic indicators

The operating costs of the newly added power grid mainly include new maintenance and repair costs and new employee wages and welfare fees. Suppose the operating cost is \( C_M \).

\[ C_M = C_o + W \]  

(3)

Where \( C_o \) is maintenance and repair cost, \( W \) is employee salary and welfare cost. Assuming that the electricity sales revenue is \( R \) and the electricity purchase cost is \( C_B \).

\[ C_s = \frac{Q_N}{1-\Delta P^\%} p_s \]  

(4)

\[ p_B = p - p_t \]  

(5)

\[ R = Q_N p \]  

(6)

Where \( Q_N \) is the amount of electricity sold, \( p \) is the unit price of electricity sales, \( p_B \) is the unit price of electricity purchase (including tax), \( p_t \) is the transmission and distribution price, \( \Delta P^\% \) is the line loss rate.

2.3. Economic evaluation index

After calculating the annual cash inflows and outflows in the planned life of the distribution network, the main financial evaluation indicators are calculated to analyze the profitability and solvency of the project, thereby obtaining financial evaluation results. The main financial evaluation indicators include network-wide investment, internal rate of return and investment payback period.

The financial internal rate of return refers to the discount rate when the total present value of capital injection during the economic life of the project is equal to the total present value of capital outflow and the cumulative net present value is equal to 0. The mathematical model is:

\[ \sum_{t=1}^{n} (CI - CO) \times (1 + FIRR)^{-t} = 0 \]  

(7)

Where \( CI \) is the cash inflow (including sales income and residual value of fixed assets), \( CO \) is the cash outflow (including original investment, operating costs, financial expenses and taxes, etc.), \( (CI-CO) \) is the net in the \( t \) year Cash flow, \( FIRR \) is the financial internal rate of return.

The investment payback period refers to the time required to offset the entire investment with the net income of the project, including from the year when the project starts construction to the year when the cumulative net cash flow appears to be a positive year. It is an auxiliary decision indicator that takes into account the financial benefits and risks of the project. Assuming that the investment payback period is \( P_t \), the mathematical model is expressed as:
\begin{equation}
\sum_{i=1}^{n} (CI - CO)_i = 0 \tag{8}
\end{equation}

Assuming that the benchmark payback period is \( P_C \), when \( P_t < P_C \), the project can recover the investment within the required time, which is feasible; when \( P_t > P_C \), the project is not feasible.

3. Simulation examples

3.1. Parameters and scenarios

Under normal circumstances, during heating, coal-fired boilers are converted into full-power operating conditions on average about 7 to 8 hours per day. The heating period is considered as 150 days. During the heating period, the coal consumption of one coal-fired boiler is 144 t. The basic data of coal-fired boilers and electric boilers are shown in Table 1. One coal-fired boiler replaces 700 kW of electrical energy. The grid voltage level is 10 kV, and the load valley period is from 21:00 to 7:00 the next day. This example analyzes and compares three types of thermal storage boiler load optimization modes and the load characteristics of the power grid under different modes, and calculates their economic benefits.

| Boiler                  | Calorific value | Thermal efficiency/% | Original price | Coal-to-electricity price |
|------------------------|-----------------|----------------------|----------------|---------------------------|
| Coal-fired boiler      | 7000            | 65                   | 0.65           | 0.65                      |
| Electric boiler        | 860             | 95                   | 0.832          | 0.44                      |

The main parameters of economic evaluation include the following four points:

1. Increase sales of electricity

Taking a province as an example, from 2016 to 2020, the predicted new electricity sales of “coal to electricity” project is shown in Table 2. Among them, the annual electricity sales increase is based on 2015 electricity.

| Year | Increase sales/108kWh |
|------|-----------------------|
| 2016 | 21                    |
| 2017 | 33                    |
| 2018 | 36                    |
| 2019 | 42                    |
| 2020 | 46                    |

2. The registered capital is 20% of construction investment (dynamic investment) and 80% of financing. The financing method is temporarily based on a loan to a domestic bank. The annual interest rate of the loan is 6.15%. The interest is calculated quarterly. The principal repayment method (unfixed) is adopted. The loan repayment period (including the grace period of 3 years) is 15 years; the ratio of working capital loans is 80%. The annual interest rate of loans is 5.6%.

3. Operating cost

The operating cost of the newly added power grid mainly includes the new maintenance and repair costs and the new employee wages and welfare fees. The parameters are calculated as follows: welfare fees and insurance coefficients 50%, material costs 1.0%, maintenance and repair costs 1.5%. The insurance premium rate is 0.1%, other expenses are 2.5%, and the above expense percentages are calculated based on the total salary; the line loss rate is 6.5%, the operating period is 25 years, and the project's target internal rate of return on investment is 7%.

4. Other instructions

The fixed asset formation rate is 100%, and the fixed depreciation adopts the average life method. See Table 3 for details.
Table 3. Other instruction data

| Parameter                        | Numerical value |
|----------------------------------|-----------------|
| Depreciation period/year         | 15              |
| Residual rate/\%                 | 5               |
| VAT rate/\%                      | 17              |
| Urban construction and maintenance fee tax rate/\% | 7               |
| Educational surcharge tax rate/\% | 3               |
| Local education surcharge tax rate/\% | 2               |
| Income tax rate/\%               | 25              |
| Statutory provident fund withdrawal ratio/\% | 10          |

The electricity purchase price (including tax) is calculated in combination with the transmission and distribution price of the power grid and the sales electricity price standard. According to statistics, the sales price of electricity in this province in 2015 was 450 yuan / kWh, and the price of power transmission and distribution in the power grid was 232 yuan / kWh. The purchase price (including tax) was 218 yuan / kWh.

Taking this province as an example, it is assumed that a regenerative electric boiler is used to replace one coal-fired boiler. According to Table 1, the maximum heat storage time T is calculated to be 8h. It shows that the regenerative electric boiler can store heat for 8 hours and release heat for 24 hours to meet the original heating demand. On this basis, in order to optimize the different modes of regenerative electric boilers, and compare the load characteristics of the power grid and the economic benefits of coal-to-electricity conversion under different modes, the following three types of regenerative electric boilers are connected according to the proportion of controllable heating load. Pattern analysis.

Mode 1: The load of the regenerative electric boiler is not controlled, and it starts and stops at 21:00-5:00 at the same time, which is high at the same time as the load of the power grid.

Mode 2: Partially controllable boiler load is controlled, and it is turned on in batches at 21:00 and 22:00, and the rate decreases at the same time as the grid load.

Mode 3: The load demand side management of heat storage electric boiler is time-sharing control, and it is opened in batches at 21:00, 22:00 and 23:00.

When the regenerative electric boiler operates in optimization mode 1, that is, all regenerative electric boilers are turned on at 21:00 and turned off at 5:00 at the same time. Due to the high rate of regenerative electric boilers, the load will suddenly rise to the maximum at 21:00, The load mutation effect is obvious.

When the regenerative electric boiler is operated in mode 1, that is, all regenerative electric boilers are operating at 21:00, the load of the regenerative electric boiler on peak shift and valley filling of the original power grid is only 0.15 times the maximum load of the original power grid, and the optimization effect is low.

When the regenerative electric boiler is operated in the optimized mode 2, the controllable boiler load is controlled, and the regenerative electric boiler is turned on in batches at 21:00, 22:00, and the control load rises to the maximum within 2 h, that is, 22:00 The regenerative electric boiler is fully operational. It can be seen from Table 5 that the ratio of the load at 22:00 to the daily maximum load is 0.75, and the load of the regenerative electric boiler to shift the peak and fill the valley of the original grid is 0.25 of the maximum load of the original grid.

When the regenerative electric boiler operates in the optimized mode 3, that is, the demand-side management method is used to control the load of the controllable boiler, the regenerative electric boiler is turned on in batches at 21:00, 22:00, 23:00, and the control load is within 3 h It rises to the maximum value, that is, all the regenerative electric boilers are running at 23:00, and the simultaneous rate with the grid load is optimal. However, the ratio of the load at 23:00 to the daily maximum load is 0.6, and the load of the regenerative electric boiler to shift the peak and valley of the original grid is 0.4 of the maximum load of the original grid.

If the power company uses demand-side management methods to guide users to start the regenerative electric boilers in batches at 21:00 and 22:00, and the regenerative electric boilers will be fully
operational at 22:00, that is, in mode 2, the regenerative electric boiler will move to the original power grid. The optimized load of peak filling is 0.25 times the maximum load of the original power grid, which is 0.1 times higher than the total operation of the regenerative electric boilers at 21:00.

If the user is guided to start the regenerative electric boilers in batches at 21:00, 22:00, and 23:00, and all the regenerative electric boilers will run at 23:00, that is, in operation mode 3, the regenerative electric boiler will shift the peak and fill the valley of the original grid. The optimization effect is 0.4 times the maximum load of the original power grid, which is 0.25 times higher than the full load of the regenerative electric boiler at 21:00, and 0.15 times higher than the full load of the regenerative electric boiler at 22:00. Therefore, the program that guides users to start in batches at 21:00, 22:00, and 23:00, and the full operation of the regenerative electric boilers at 23:00 is the optimal program for shifting peaks and filling valleys of the power grid and improving resource utilization.

3.2. Economic benefit analysis of coal-to-electricity project

Electric heating technology in this province promotes traditional projects such as electric boilers, heat pumps, heating cables, etc. The main type of transformation is electric boilers, which are designed to run at 8 hours per day. Based on the basic data in Table 1, the operating costs of electric boilers and fuel boilers are calculated. The comparison is shown in Table 4.

| Parameter                  | Coal-fired boiler | Electric boiler |
|----------------------------|-------------------|-----------------|
| Actual calorific value     | 3250              | 817             |
| Daily operating expenses at full load/(yuan/d) | 915.2 | 4659.2 |
| Coal-to-electricity price  | 915.2             | 2464            |

It can be seen from Table 4 that the daily operating cost of electric boilers is higher than the daily operating cost of coal-fired boilers by 3744 yuan / d at market electricity prices. The daily operation cost of electric boilers is 1548.8 yuan / d higher than that of coal-fired boilers during the coal-to-electricity valley period.

In summary, regardless of the market electricity price or the electricity price during the coal-to-electricity valley period, the daily operating cost of coal-fired boilers is lower than that of electric boilers, and the economic benefits of coal-fired boilers are higher than those of electric boilers.

According to the investment of coal-to-electricity power grid construction when the regenerative power boiler is operated at different time periods, the internal rate of return on the project investment is set at 7% during 2016-2020. The main economic indicators are shown in Table 5.

| Index                              | Mode 1       | Mode 2       | Mode 3       |
|------------------------------------|--------------|--------------|--------------|
| Static investment/ 10^4yuan        | 731,420      | 443,420      | 323,420      |
| Dynamic investment/10^4yuan        | 805,953      | 482,010      | 345,011      |
| Discount years/a                    | 15           | 15           | 15           |
| Project operation period/a          | 25           | 25           | 25           |
| Long-term loan interest rate/%      | 6.15         | 6.15         | 6.15         |
| Loan repayment period/a             | 15           | 15           | 15           |
| Payback period/a                    | 12.17        | 9.00         | 7.38         |
| Investment internal Rate of Return% | 9.34         | 16.14        | 20.32        |
| Project principal internal rate of return% | 13.17 | 20.93 | 25.41 |

It can be seen from Table 5 that when the regenerative electric boiler is operated in mode 1, the static investment is 7.314 billion yuan, and the investment recovery period (after tax) is 12.17a, which is within the prescribed repayment period of 15a, and the internal rate of return is 9.34%. When the regenerative electric boiler is operated in mode 2 and mode 3, the investment is 4.4342 billion yuan and 3.234 billion yuan respectively, and the payback period is 9a and 7.38a, respectively. Model 3 has the
shortest payback period and the largest internal rate of return. Therefore, according to the above economic evaluation indicators, the thermal storage boiler adopts the operating mode three times, and the economic benefits reach the best.

If the power grid company's “13th Five-Year Plan” period achieves a successful coal-to-electricity reform plan, the end of 2020 can achieve the following construction results as shown in Table 6.

Table 6. Expected results of coal-to-electricity project

| Index                          | Numerical value |
|-------------------------------|-----------------|
| Reduce direct burning coal/104t | 158.45          |
| Reduction of sulfur dioxide/104t | 135             |
| Reduce NOx/104t                | 1.1             |
| Emission reduction dust/104t   | 0.96            |
| CO2 emission reduction/104t    | 411.98          |
| Increase power consumption/108kWh | 88.15          |
| Improve electrification level  | 2               |
| Increase wind power installed capacity/104kW | 4500 |

4. Conclusion
This paper proposes to select the optimal access mode for the storage of heat storage boilers from two aspects: the impact on the power grid and the economic benefit evaluation system; taking the coal-to-electricity conversion project in a province as an example, from the perspective of load simultaneous rate, load characteristics and economic benefits It is concluded that the mode of starting the thermal storage boilers in batches is the most reasonable heating load access mode for the coal-to-electricity conversion project. It is pointed out that adopting the thermal storage boilers heating mode in batches can achieve the most ideal power grid optimization and economic benefits. Effect. It provides a reference for the further promotion and implementation of the “coal-to-electricity” project in the future.

The coal-to-electricity project that adopts demand-side management methods can achieve better results in both load characteristics optimization and economic benefits. Each region can carry out the specific implementation of the coal-to-electricity project based on the batch management load optimization model proposed in this article.

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