Forecasting of power grid investment capability based on grey neural network combination model

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Abstract. Under the market environment, power generation investment has become an investment behavior aimed at maximizing the interests of investors, and the construction of power generation projects presents the characteristics of uncertainty, so it is difficult to balance power supply and demand. In this context, how to make their own optimal investment decisions to reduce risk has become a very important issue for a single power generation company. Therefore, from the point of view of the whole system, this paper focuses on the causal relationship between the variables of the power generation investment system under the market environment, and on the basis of power supply and demand balance, puts forward a power grid investment capacity prediction model based on the grey neural network combination model. In this paper, the investment of power grid in a province of China is taken as the research object, the grey neural network prediction model is constructed, the investment demand and the internal and external influence indexes of the investment capacity of power grid are analyzed, and the investment demand and the investment capacity in the next six years are predicted. The prediction results verify the correctness and effectiveness of the grey neural network model in the investment prediction of power grid.

1 Introduction

Power grid is the foundation of social development, and its importance is obvious. Power grid is of great significance in many aspects, such as support for industrial production, guarantee for residents' life and maintenance of social stability and development. Generally speaking, investment decision-making refers to the analysis, judgment and scheme selection of major problems in economic activities such as investment necessity, investment goal, investment scale, investment direction, investment structure, investment cost and return by using certain scientific theories, methods and means in order to achieve the expected investment goal. Electric power industry is a pillar industry, and is closely related to the national economy. Grid investment system is a very complex dynamic system that many power producers make decisions and managements under the coordination of market supply and demand relationship and electricity price with the goal of maximizing their own interests¹²; The model considers three factors: investment cost, operation cost and power supply shortage; The paper³⁴ studies the probability model of coordinated power generation and transmission planning based on reliability and economy, which can be used in the sequencing of transmission network investment projects and is helpful to promote the research of transmission reliability and ease transmission congestion; A linear programming model of transmission network capacity adequacy is constructed in reference⁵⁶, and the medium-term transmission network
expansion and new construction projects under the condition of power market are evaluated; Literature\cite{7} reviews the previous research literature on transmission network investment and planning methods, and puts forward an analytical framework for the internal relationship between the economics of transmission network investment projects and engineering technical indicators; Literature\cite{8} based on option-game theory, the realization method of power generation and grid investment decision-making in power market environment is studied; The paper\cite{9,10,11} studies the necessity of power grid supervision structure and incentive policy under the market environment, and puts forward that the design of policy mechanism can effectively ensure the adequacy of power grid investment; Literature\cite{12,13} proposes investment decision-making model for evaluating urban power grid projects, which better improves the technical and economic evaluation method of urban power grid planning projects; Ref.\cite{14,15} point out that the enterprise investment benefit evaluation has a history of more than 100 years. According to the content of evaluation system, its development is divided into four stages: cost evaluation stage, financial evaluation stage, value evaluation stage and comprehensive evaluation stage.

In this paper, considering the causal relationship between the variables of power generation investment system under the market environment, based on the balance of power supply and demand, a dynamic model of power generation investment based on grey neural network is proposed. The grey neural network is used to predict the investment demand and investment capacity of power grid. Firstly, the grey neural network prediction model is constructed, and the internal and external influence indicators of the investment demand and the investment capacity of power grid are selected and analyzed. The investment demand and the investment capacity of power grid in the next six years are predicted respectively, which provides a data basis for the coordination and optimization of the investment demand and the investment capacity of power grid.

2 Grey neural network modeling of power grid investment

2.1. Grey model

The model created in a grey system is called a gray model. The model is a differential equation based on the original data sequence. The most representative model in grey modeling is GM model for time series. It directly converts time series data into differential equations, uses system information, and predicts the system output in the absence of system characteristic knowledge\cite{16}.

GM first accumulates the original data sequence so that the accumulated data presents a certain rule, and then fits the curve with typical curves. Set time data sequence:

\[
x(t) = (x_1(t), x_2(t),...,x_n(t))
\]

Accumulating \(x(t)\) to obtain a new data sequence \(x^{(1)}\), the new data sequence item \(t\) is the sum of the first \(t\) items of the original data sequence \(x^{(0)}\) as follow:

\[
x^{(1)}(t) = (x^{(1)}(1), x^{(1)}(2),...,x^{(1)}(n))
\]

According to the new data sequence \(x^{(1)}\), an equation is established, as follow:

\[
\frac{dx^{(1)}}{dt} + ax^{(1)} = u
\]

The solution of the equation is established, as follow:

\[
x^{(1)} = (x^{(0)}(0) - \frac{u}{a})e^{-at} + \frac{u}{a}
\]

\(x^{(1)}\) is an estimate of the \(x^{(1)}\) sequence, and the predicted value \(x^{(0)}\) of \(x^{(0)}\) is obtained by cumulatively subtracting \(x^{(1)}\), as follows
\[ x_i^{(t)} = x_i^{(t-1)} - x_{i-1}^{(t)} \quad t=2, 3, \]  

2.2 Grey neural network

Grey problem is to predict the development and change of the behavior characteristic value of the grey uncertain system. The original sequence \( x_i^{(0)} (t = 0,1,2,\ldots, N-1) \) of the uncertain system characteristic shows exponential growth after one-time accumulation, so it can be fitted and predicted by a continuous function or differential equation. For convenience, the symbol is redefined, the original sequence \( x_i^{(0)} \) is represented by \( x(t) \), the sequence \( x_i^{(1)} \) generated by one-time accumulation is represented by \( y(t) \), and the prediction result \( x_i^{(*)} \) is represented by \( z(t) \).

The differential equation of the grey neural network model with \( n \) parameters is as follows:

\[
\frac{dy_1}{dt} + ay_1 = b_1 y_2 + b_2 y_3 + \ldots + b_{n-1} y_n
\]  

(6)

\( y_1, y_2, y_3, \ldots, y_n \) are the system input parameter, \( y_1 \) is the system output parameter. \( a, b_1, b_2, b_3, \ldots, b_{n-1} \) is coefficient of differential equation.

The time response of formula (6) is as follows:

\[
z(t) = (y_1(0) - \frac{b_1}{a} y_2(t) - \frac{b_2}{a} y_3(t) - \ldots - \frac{b_{n-1}}{a} y_n(t))e^{-at} + \frac{b_1}{a} y_2(t) + \frac{b_2}{a} y_3(t) + \ldots + \frac{b_{n-1}}{a} y_n(t)
\]  

(7)

Assuming that:

\[
z(t) = (y_1(0) - d) \frac{e^{-at}}{1+e^{-at}} + d \frac{1}{1+e^{-at}} - (1+e^{-at}) = (y_1(0) - d)(\frac{1}{1+e^{-at}}) + d \frac{1}{1+e^{-at}} - (1+e^{-at})
\]  

(8)

In the figure 1, \( t \) is the input parameter sequence; \( y_2(t), \ldots, y_n(t) \) are the network input parameter; \( W_{21}, W_{22}, \ldots, W_{2n}, W_{31}, W_{32}, \ldots, W_{3n} \) are the network weight value; \( y_1 \) is the network prediction value; \( LA, LB, LC, LD \) represent the four layers of gray neural network respectively.
Assuming that: 
\[ \frac{2b_1}{a} = u, \quad \frac{2b_2}{a} = u, \quad \ldots, \quad \frac{2b_{n-1}}{a} = u_{n-1} \]
the network initial weight is as follows:
\[ W_{11} = a, W_{21} = -y_1(0), W_{22} = u_1, W_{23} = u_2, \ldots, W_{2n} = u_{n-1} \]
\[ W_{31} = W_{32} = \ldots = W_{3n} = 1 + e^{-at} \]
The threshold for the output nodes in the LD layer is as follows:
\[ \theta = (1 + e^{-at})(d - y_1(0)) \] (9)

3. Forecasting of power grid investment based on Grey Neural Network
This paper selects Chinese Province in 2010-2016 power grid investment data as the basis of the grey neural network prediction. The main voltage levels of the power grid in this province include 500KV and 220KV.

3.1 Selection of forecast index

3.1.1 External factor index
The external factors mainly choose the population factor and the per capita GDP as the research object. Population growth is an important factor in determining the ability of electricity to invest. When the population grows in the market, there is a positive correlation between the per capita GDP and the demand for electricity.

**Internal factor index**

(1) Electricity sale income
\[ S = E_p \times S_p \] (10)
Where: 
- \( S \) — Electricity sale income, yuan
- \( E_p \) — Electricity sale unit price, yuan/kWh
- \( S_p \) — Electricity sales, MWH

As shown above, the sales revenue is a product of the sale of electricity and electricity. The following table is a comparative analysis of investment capacity and electricity sales revenue in 2016-2011.

| Year | Investment capacity (yuan) | Annual growth rate of investment capacity | Electricity sale income (yuan) | Annual growth rate of electricity sales |
|------|---------------------------|------------------------------------------|-----------------------------|----------------------------------------|
| 2011 | 3836300                   | —                                       | 20748932.25                 | —                                      |
| 2012 | 3689500                   | -3.83%                                  | 19987515.77                 | -3.72%                                 |
| 2013 | 3928800                   | 6.49%                                   | 21283812.51                 | 6.04%                                  |
| 2014 | 4106800                   | 4.53%                                   | 22248265.72                 | 5.12%                                  |
| 2015 | 4976100                   | 21.17%                                  | 26957810.29                 | 21.10%                                 |
| 2016 | 5241400                   | 5.33%                                   | 28394745.49                 | 5.29%                                  |

From the above table, we can see that the total investment capacity of the province is 3 million 836 thousand and 300 yuan, 3 million 689 thousand and 500 yuan, 3 million 928 thousand and 800 yuan, 4 million 106 thousand and 800 yuan, 4 million 976 thousand and 100 yuan and 5 million 241 thousand and 400 yuan respectively in 2011, 2012, 2013, 2014, 2015 and 2016. The annual growth rate of total
investment capacity in 2012, 2013, 2014, 2015 and 2016 were -3.83%, 26.18%, 4.24%, 3.27%, 9.43%, 39.57%, respectively. It can be seen that the total investment capacity is increasing year by year beside 2012.

(2) Cost of electricity sale

The cost of electricity sale is made up of materials, wages, repairs and other expenses. The following table shows the cost of electricity sale in 2011-2016 years, the total investment capacity of power grid construction in 2011-2016 years, and the annual growth rate of the cost of electricity sale and investment.

| Year | Investment capacity (yuan) | Annual growth rate of investment capacity | Cost of electricity sale (yuan) | Annual growth rate of cost of electricity sale |
|------|---------------------------|------------------------------------------|--------------------------------|-----------------------------------------------|
| 2011 | 3836300                   | ——                                      | 16912594.46                    | ——                                           |
| 2012 | 3689500                   | -3.83%                                  | 16208029.36                    | -4.17%                                       |
| 2013 | 3928800                   | 6.49%                                   | 17355043.28                    | 7.08%                                        |
| 2014 | 4106800                   | 4.53%                                   | 18241468.51                    | 5.11%                                        |
| 2015 | 4976100                   | 21.17%                                  | 22981680.4                     | 25.99%                                       |
| 2016 | 5241400                   | 5.33%                                   | 23153372.39                    | 0.75%                                        |

Note: data comes from the network

From the above table, we can see that the total investment capacity of the province is 3 million 836 thousand and 300 yuan, 3 million 689 thousand and 500 yuan, 3 million 928 thousand and 800 yuan, 4 million 106 thousand and 800 yuan, 4 million 976 thousand and 100 yuan and 5 million 241 thousand and 400 yuan respectively in 2011, 2012, 2013, 2014, 2015 and 2016. For example, the growth rate in 2016 was only 0.75%. That is that the two are connected, but not strong. Therefore, the grey neural network can be used to predict the investment demand of the future power grid.

(3) The sales of Electricity in a province

The electricity sales is power enterprise sold to users (including wholesale households) and the non electric power production department, basic construction department, maintenance department and production department (such as canteen, dormitory). The following table shows electricity sales of one province in 2011-2016 years, total investment capacity of power grid construction, and the annual growth rate of electricity sales and investment capacity of the annual growth rate.

| Year | Investment capacity (yuan) | Annual growth rate of investment capacity | Electricity sales (MWH) | Annual growth rate of electricity sale |
|------|---------------------------|------------------------------------------|------------------------|--------------------------------------|
| 2011 | 3836300                   | ——                                      | 3635.3                 | ——                                   |
| 2012 | 3689500                   | -3.83%                                  | 3798.6                 | 4.49%                                |
| 2013 | 3928800                   | 6.49%                                   | 4050.7                 | 6.64%                                |
| 2014 | 4106800                   | 4.53%                                   | 4243.8                 | 4.77%                                |
| 2015 | 4976100                   | 21.17%                                  | 5117.9                 | 20.60%                               |
| 2016 | 5241400                   | 5.33%                                   | 5380.7                 | 5.13%                                |

Note: data comes from the network

From the above table, we can see that the total investment capacity of the province is 3 million 836 thousand and 300 yuan, 3 million 689 thousand and 500 yuan, 3 million 928 thousand and 800 yuan, 4
million 106 thousand and 800 yuan, 4 million 976 thousand and 100 yuan and 5 million 241 thousand and 400 yuan respectively in 2011, 2012, 2013, 2014, 2015 and 2016. That is that the two are related, but not strong. Therefore, the grey neural network can be used to predict the investment demand of the future power grid.

(4) Electricity price

The electricity sales is power enterprise sold to users (including wholesale households) and the non electric power production department, basic construction department, maintenance department and production department (such as canteen, dormitory). The following table shows the electricity sales in 2011-2016 years, total investment capacity of power grid construction in 2011-2016 years, and the annual growth rate of electricity sales and investment capacity.

| Year | Investment capacity (yuan) | Annual growth rate of investment capacity | Electricity price (yuan/KWH) | Annual rate of electricity growth |
|------|-----------------------------|------------------------------------------|-------------------------------|----------------------------------|
| 2011 | 3836300                     | ——                                       | 0.6                          | ——                              |
| 2012 | 3689500                     | -3.83%                                   | 0.61                         | 1.67%                           |
| 2013 | 3928800                     | 6.49%                                    | 0.62                         | 1.64%                           |
| 2014 | 4106800                     | 4.53%                                    | 0.63                         | 1.61%                           |
| 2015 | 4976100                     | 21.17%                                   | 0.62                         | -1.59%                          |
| 2016 | 5241400                     | 5.33%                                    | 0.63                         | 1.61%                           |

It can be seen that the total investment capacity is increasing year by year except for 2012. It grew rapidly in 2015, but grew slowly in 2013, 2014 and 2016, and the growth trend of electricity price was not the same as the growth trend of investment capacity.

3.2 Analysis of prediction results of grey neural network

The process of forecasting the investment demand of power grid based on Grey Neural Network is as follows. Grey neural network constructs grey neural network structure according to the dimension of input / output data. In the forecast of investment demand of power grid, the input data is 6 dimension and the output is 1 dimension. First, the training data is used to train the grey neural network so that the network has the ability to predict. The grey neural network predicts the investment capacity and investment demand by network, and determines the network performance according to the prediction error.

![Figure 2. the prediction of the grey neural network](image-url)
Table 5. Comparison of grey neural network forecast value and actual value

| Year | Value of grey neural network prediction | Actual value | Relative error |
|------|----------------------------------------|--------------|----------------|
| 2011 | 190.6976641 | 203.3294 | -6.21% |
| 2012 | 280.8906712 | 256.559 | 9.48% |
| 2013 | 287.4998081 | 267.433797 | 7.50% |
| 2014 | 248.3657652 | 276.183009 | -10.07% |
| 2015 | 323.0146324 | 302.228738 | 6.88% |
| 2016 | 379.3491673 | 421.810367 | -10.07% |

It can be seen from the above table that the prediction error of the grey neural network is in the range of +10%, and the error of the prediction results is better and the average error is 8.37%.

The results of using grey neural network to predict the investment demand of power grid and power grid investment are as follows.

Table 6. Forecast value of investment demand and investment capacity of power grid (yuan)

| Year | Forecast value of total investment demand | Forecast value of total investment capacity |
|------|-------------------------------------------|---------------------------------------------|
| 2017 | 4444542.132 | 5611014.98 |
| 2018 | 4749672.68  | 6009627.58 |
| 2019 | 5080362.305 | 6420714.375 |
| 2020 | 5433912.445 | 6869851.024 |
| 2021 | 5817609.723 | 7341162.747 |
| 2022 | 6222709.696 | 7845546.605 |

The forecast value of investment demand and investment capacity for 2017-2022 years can be obtained from the above table. Among them, after the prediction, the investment capacity of the power grid is greater than the investment demand of the power grid.

4. Conclusion
As an important infrastructure of national economy and social development, the power grid plays a very important role in supporting industrial production, ensuring residents' life and maintaining social stability and development. In the selection of the index of power grid investment capacity, two indexes of population and per capita GDP are selected from the external factors. From the perspective of power grid investment, we analyzed the impact and relationship between power grid investment capability and electricity sales income, cost of electricity sale, electricity sale and electricity price in recent five years, and explained the reason why grey neural network was selected as a prediction model of power grid investment demand. A grey neural network prediction model of power grid investment demand and investment capacity is built. It forecasts the investment data of grid investment demand and power grid investment capacity in the next six years, and lays the foundation for the coordination and optimization of the next grid investment demand and investment capacity.

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