Research Article

Study on Influencing Factors and Estimation Model of the Water Supply and Drainage Structure Cost in Substation

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This paper made an in-depth analysis of the articulation between a substation's design parameters and water supply and drainage structure quantities and costs, innovatively built a hierarchical structure model of influencing factors of quantities, and eventually extracted the key parameters affecting quantities. Meanwhile, the influence path of the price level change on the water supply and drainage structure costs was also analyzed in this paper. The BP neural network model and linear regression model were employed to estimate the ontology engineering cost and the price difference due to preparation time, so as to realize the purpose of quickly estimating the cost of substation water supply and drainage structure by knowing a few key parameters. Through calculation and stimulated analysis, the error of the model is controlled within ±3%, which provides an effective tool for quickly estimating the cost of substation water supply and drainage structure. Therefore, this model has practical significance and application value.

1. Introduction

The water supply and drainage structure are one of the important components of the substation project. How to quickly and reasonably make accurate predictions and estimates of its cost is an urgent problem for constructors, designers, builders, and other participant units. At present, there is still a lack of an explicit model about the relationships among design parameters, price levels, and the corresponding cost. To calculate the cost of the water supply and drainage structure, it is necessary to first calculate the detailed quantities according to the design plan and then the cost personnel calculate the project cost based on the budget regulations [1] of the power industry. This conventional way to calculate the cost gains low efficiency, though high quality is promised, and is not suitable for the business requirement of rapidly estimating the cost.

The cost of the water supply and drainage structure in the substation is mainly composed of four aspects, which are quantity, price, fee, and quota, and the cost's influencing factors can also be attributed to these four aspects, i.e., quantity, price, fee charging, and quota [2]. Within the year of the adopted samples, the project quotas are subject to the unified version of the quotas, the fee charging is implemented according to the unified budget-making regulations, and the quotas and fee charging standards are relatively fixed. Therefore, the influencing factors for cost changes are mainly attributed to the quantities and the price level. The dimensions of analysis are divided into two aspects: the main quantities, such as the quantities of firefighting, water supply, and drainage, and the water source, and the price level, such as the price of equipment, main materials, labour, and machinery. This paper specializes in the analysis of the impact of changes in major quantities and price levels on the cost of water supply and drainage structure to achieve a rapid and reasonable estimation of the cost.

2. Analysis of the Influence of Design Parameters on Quantities

The water supply and drainage structure in the substation studied in this paper refers to the works of water supply, waste water discharge, and water quality improvement, mainly divided into water supply works and drainage works.

In normal times and unexpected situations such as fire, the water supply and drainage structure are supposed to safely and reliably provide sufficient water based on the users' requirements for water quality and pressure. A thorough analysis of the design parameters that affect the quantities of the water supply and drainage structure in a substation can make the influence of the complex design parameters on the quantities more concise, thus identifying a few key parameters that have a greater impact on the quantities.

2.1. Analysis of the Factors Influencing the Quantities

2.1.1. Quantities of Firefighting and Water Supply System.
The water in the substation is mainly for firefighting and domestic use.

The firefighting water consumption of the main transformer is related to its voltage level and external size. Main transformers with voltage levels of 220 kV and above should adopt a water spray fire extinguishing system. Fire-fighting water spray needs to cover the external surface of the main transformer. The larger the surface area of the main transformer is, the more water the firefighters use. Main transformers with voltage levels of 110 kV and below are not equipped with a water spray fire extinguishing system, and there is no water consumption for their firefighting.

The water consumption of the building's firefighting is directly connected with the building's fire hazard. The higher the fire hazard is, the more water it uses. For substations of the same scale, when the main transformer and power distribution devices are laid out indoors (referred to as "whole-indoor layout"), the fire hazard of buildings is the highest and the water consumption for the building's firefighting is the largest; when the main transformer is laid out outdoors and GIS is laid out indoors (referred to as "semi-indoor layout"), the water consumption for building's firefighting takes the second place; when the main transformer and power distribution devices are laid out outdoors (referred to as "outdoor layout"), the fire hazard of the building is the lowest and the water consumption for firefighting is the smallest [1].

The amount of domestic water used in a substation is directly related to the number of personnel on duty. The higher the voltage level is, the more personnel are on duty, and the higher the domestic water consumption is.

The diameter of firefighting and water supply pipelines is positively related to water consumption; the length of pipelines is positively related to the floor area of the substation; the floor area of the substation is associated with the substation's prospective scale and layout; and the length of the firefighting pipeline of the main transformer is positively related to the current scale of the main transformer in this period.

2.1.2. Quantities of Water Source.
The quantities of the water source are highly correlated with the substation's water consumption, geographical location, and geological conditions [3]. The water yield of the water source should satisfy the need for production water supply in the substation.

According to the substation's groundwater condition and its distance from the location of municipal water, a comprehensive judgment is made to choose the plan of digging a deep well or introducing tap water from outside.

2.1.3. Equipment of Water Supply and Drainage Structure.
Equipment of the water supply and drainage engineering refers to pneumatic water supply installation, deep well fire pump set, submersible sewage pump, and other equipment related to water supply and drainage structure, which is generally set up according to the prospective scale of the whole substation and is positively related to the water consumption of the prospective scale of the whole station.

2.1.4. Water Pump House and Firefighting Pool.
The water pump house and firefighting pool, designed according to the prospective scale of the whole substation, are positively related to the water consumption of the prospective scale of the whole substation. The more amount of water it uses, the larger the building volume of the water pump house and the firefighting pool is, and the larger the quantities are.

2.1.5. Quantities of Drainage System.
The drainage system is divided into the indoor drainage system, an in-station drainage system, and an outside-station drainage system.

The length of in-station drainage pipes is positively related to the floor area of the substation. The rain inlets are arranged on both sides of the road. After being collected by rain inlets, the rainwater is discharged to the rainwater inspection wells at the lowest part of the substation through drainage pipes and continues to be discharged to the outside of the substation. The diameter of the drainage pipes is positively related to the drainage volume, which is positively correlated with the local hydrometeorological rainstorm intensity as well as the water consumption of the substation.

The diameter of the sewage drainage pipes is positively related to water consumption. Oil-immersed electrical equipment is equipped with the accident oil pool and oil drainage pipeline. The diameter of the oil drainage pipeline is positively related to the accidental oil discharge amount, and the length of the oil drainage pipeline is positively correlated with the scale of oil-immersed equipment, such as the main transformer, and their distance from the accident oil pool.

The indoor drainage system is positively related to the water consumption of the building, and its quantities are small. The quantities of the outside-station drainage system are associated with the geographical location of the substation. The farther the suitable drainage point is from the substation and the worse the construction conditions outside the station are, the larger the quantities are.

2.2. Hierarchical Structure Model of the Factors Influencing the Quantities.
The factors influencing the quantities of a substation's water supply and drainage structure have an obvious hierarchy. According to the successive logical relationship between the design parameters and the forming
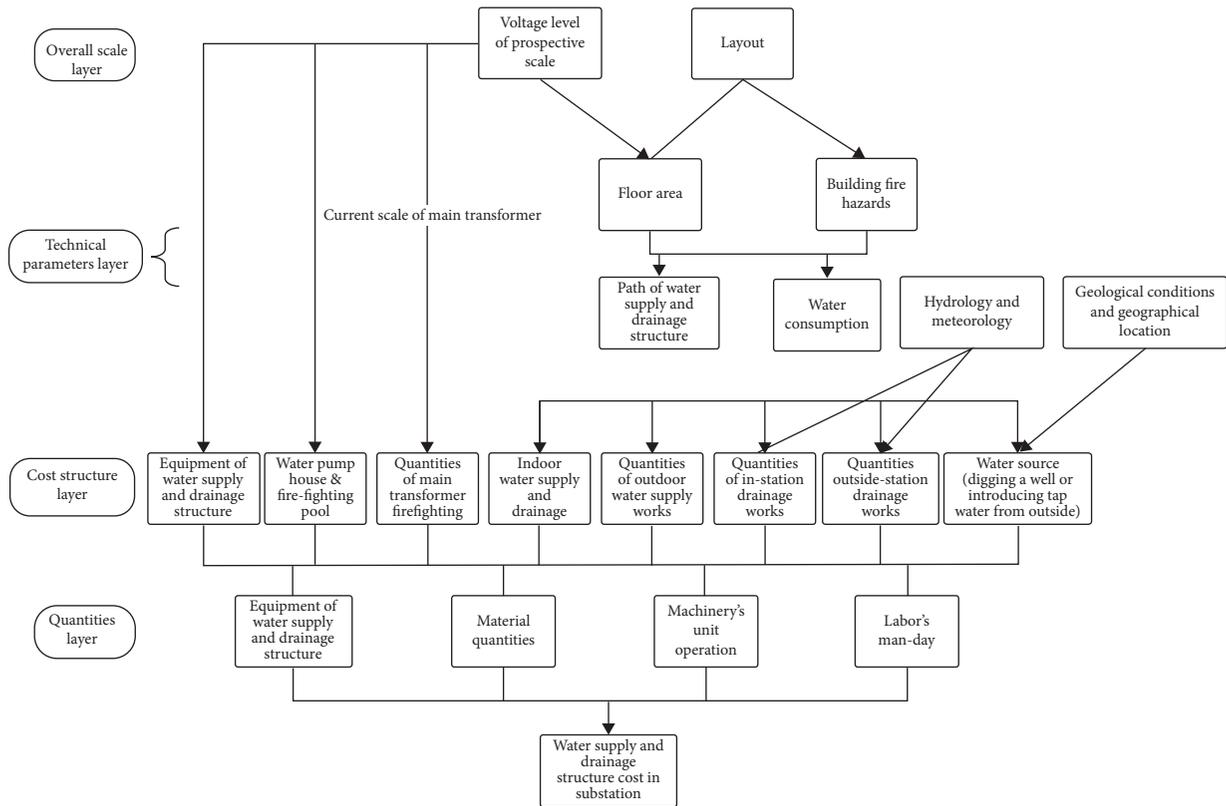
FIGURE 1: hierarchical structure of the factors influencing quantities.

process of quantities [4], the influencing factors are summarized into four layers: the overall scale layer, the technical parameters layer, the cost structure layer, and the quantities layer. Each layer has a clear logical relationship and lucid functional route, as shown in Figure 1.

Except for the water source and outside-station drainage, which are related to the substation's geological conditions and geographical location, for the quantities of in-station water supply and drainage structure, only the diameter of the substation drainage pipeline is related to the hydrology and meteorology, and the other quantities are eventually determined by four design parameters, namely the voltage level, the prospective scale, the layout, and the current scale of the main transformer. Through the statistics of the sample data of a province in the past five years, these four design parameters can determine 98% of the quantities of water supply and drainage structures except for the water source and outside-station drainage [3].

3. Analysis of the Impact of Price Level on Project Cost

The cost of the water supply and drainage structure in the substation is composed of the ontology engineering cost and the price difference due to preparation time. The ontology engineering cost is affected by quantities determined by the design parameters; the price difference due to preparation time, based on the ontology engineering cost, is affected by the price level [5].

3.1. Price Level of Equipment. The total price of equipment for water supply and drainage structures is affected by changes in its price level. However, there are few types of equipment for water supply and drainage structures in substations, and the price level of equipment is relatively stable [6]. Therefore, the total price of the equipment is greatly affected by the quantities and less affected by the changes in the equipment's unit price.

3.2. Price Level of Materials. Quantities of water supply and drainage structures can eventually be classified into various types of construction materials. The price level of materials directly affects the price difference due to preparation time in the project cost, and the material price difference is the main content of the price difference due to preparation time.

3.3. Price Level of Labor's Man-Day. The China Electric Power Project Cost Administration will regularly measure the impact of changes in labor and machinery costs on the base price of quotas and issue documents in the form of adjusting the price level of quotas as the basis for the price difference due to preparation time in the project budgeting period.

Take the price level of Beijing in 2022 as an example. According to the regulation on the adjustment of quotas' price level issued by the China Electric Power Project Cost Administration in January 2002, the labor cost of a substation construction project in Beijing is adjusted by 10.25% on the basis of the budget price of quotas and included in the

price difference of labor's man-day, while in Shandong province, it is adjusted by 9.46% and included in the price difference of labor's man-day.

3.4. Price Level of Machinery's Unit Operation.

The market price of the main machinery's unit operation for the construction project is regularly released by the China Electric Power Project Cost Administration, and the theoretical calculation method of the mechanical price difference is the same as the material price differences.

4. Estimation Model of Cost of Substation Water Supply and Drainage Structure

4.1. Construction of Ontology Engineering Cost Estimation Model

4.1.1. Network Structure's Construction and Selection.

The construction of an estimation model of the water supply and drainage structure cost in the substation is based on the actual project data from the past three years, and its main influencing factors [7] are explored. Each influencing factor is taken as the input variable xi of the model. By establishing a nonlinear mathematical model between the model and the cost, the output variable y1, ontology engineering cost, is obtained.

The model is constructed by selecting the three-layer BP neural network as the predictive model. The main factors affecting the ontology engineering cost can be obtained by analyzing the historical data, and then the number of input-layer nodes is measured. The main factors that have an impact on the cost of the substation's water supply and drainage structure are voltage level (x_1), prospective scale (x_2), the current scale of the main transformer (x_3), and layout (x_4). Therefore, the number of input-layer nodes is determined to be four. The ontology engineering cost (y_1) is regarded as the output node, and its number of it is set to one. Usually, the number of nodes in the implicit layer between the input layer and the output layer is set as 10, 15, 20, and 25. According to the setting principles of nodes in the implicit layer of the BP neural network model, the more input and output units there are, the more hidden nodes exist. At the same time, the approximate process should be guaranteed to be complex and complete. There are many input units and nodes involved in this study, and their results are required to be normalized into one output unit after iterative prediction. Therefore, the number of nodes in the implicit layer is set to 25, which means the structure of the BP neural network model is 4-25-1. The model structure is shown in Figure 2.

4.1.2. Data Processing and Algorithm Training.

Since the above-mentioned influencing factors of ontology engineering cost are represented by text-structure data, they need to be preprocessed to be converted into algebraic form to participate in the input of the BP neural network. The model chooses to process the data conversion of different
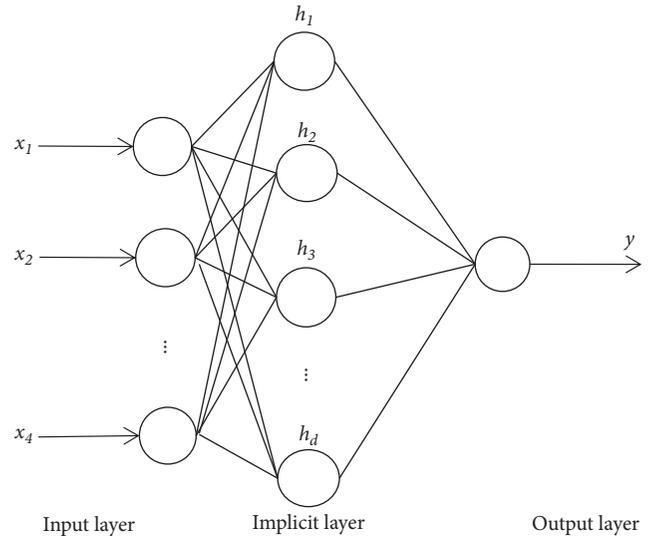

FIGURE 2: A network structure diagram of the model.

influencing factors' internal elements. The specific preprocessing principles are as follows:

  (i) Numbers 1, 2, and 3, respectively, represent the voltage levels of 110 kV, 220 kV, and 500 kV, and the weighted average of their proportion of the cost in the substation project is processed;

  (ii) Numbers 1–20, respectively, represent the combinations of the number of main transformer groups of the prospective scale and the circuit number of the high-voltage-side outgoing line. The statistical data shows that the corresponding cost of the prospective scale of different combinations meets the law of normal distribution.

  (iii) Numbers 1, 2, and 3, respectively, represent the number of main transformer groups of the current construction scale, and the weighted average of the current scale of main transformers of different groups is processed.

  (iv) Numbers 1, 2, and 3, respectively, represent the layout modes, where the indoor mode is regarded as the base as a reference item, and the semi-indoor and outdoor modes are, respectively, determined by the scale factor.

The model algorithm training is mainly divided into two processes: forward propagation and backward propagation. Between them, the forward propagation process is mainly used to calculate the final actual output after entering data and passing them through the input layer, implicit layer, and output layer, respectively. The backward propagation process represents the deviation between the actual output and the desired output in the output layer and reversely adjusts the parameters of each layer according to the deviation value, which can finally control the deviation within an acceptable range.

(1) Forward propagation process. In this model, the nodes of the input layer, implicit layer, and output layer are respectively set as n, d, and m, and the vector sets are expressed as $x \in R_n$, $x = (x_1, x_2, x_3, x_4)$, $h \in R_d$, $h = (h_1, h_2, \ldots, h_d)$, and

$y \in R_m$, $y = y_1$. The node calculation formulas and data transfer functions of the implicit layer and output layer are shown in the following equation:

$$h_j = f\left(\sum_{i=1}^{n} W_{ij}x_i - b_i\right), \tag{1}$$

$$F_k = f\left(\sum_{j=1}^{d} W_{jk}h_j - b_k\right), \tag{2}$$

$$f(x) = \frac{1 - \exp(-x)}{1 + \exp(-x)}. \tag{3}$$

In the formulas of equations (1)–(3), W_{ij} and b_j are the weights and thresholds between the implicit layer and the input layer, respectively; W_{jk} and b_k are the weights and thresholds between the implicit layer and the output layer, respectively.

The calculation function of the output nodes' error is shown in the following equation:

$$e = \frac{1}{2}\sum_{k}^{m}(t_k - F_k)^2 = \frac{1}{2}\sum_{k}^{m}\left\{t_k - f\left[\sum_{j=1}^{d}W_{jk}f\left(\sum_{i=1}^{n}W_{ij}x_i - b_j\right) - b_k\right]\right\}^2. \tag{4}$$

In the formula (4), F_k and t_k are the actual output values and desired output values, respectively.

The calculation function of total error is shown as follows:

$$E = \sum_{I=1}^{P} e_i < \theta. \tag{5}$$

In the formula (5), p is the number of samples, and θ is the acceptable deviation.

(2) Backward propagation process. In order to better test the deviation between the actual output and the desired output, it is necessary to iterate the output weights and thresholds repeatedly and finally obtain the correction results of both. The deviation calculation formula and the calculation formula for the correction of weights and thresholds in each layer are shown as follows:

$$\delta_, = (t_k - F_k)F_k(1 - F_k), \tag{6}$$

$$W_{jk}(n_0 + 1) = W_{jk}(n_0) + \mu\sum_{p_i=1}^{p}\delta_k, \tag{7}$$

$$b_k(n_0 + 1) = b_k(n_0) + \mu\sum_{p_i=1}^{p}\delta_k, \tag{8}$$

$$\delta_j = h_j(1 - h_j)\sum_{k=1}^{m}\delta_k W_{jk}. \tag{9}$$

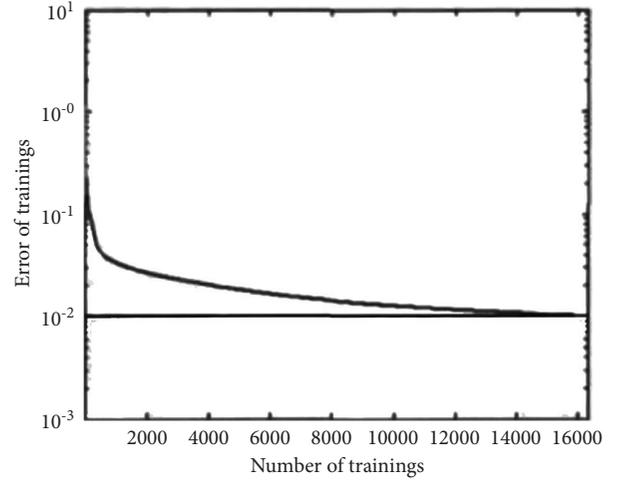In the formulas (6)–(9), n_0 is the number of iterations.

Figure 3: Algorithm training curve.

4.1.3. Algorithm Training and Deviation Analysis. Based on the above models to train the data, the correction algorithm satisfies the gradient descent with the momentum algorithm, which can optimize the learning rate of the BP neural network. Referring to the relationship among the numbers of nodes in each layer, the maximum number of cycles of algorithm training is set to 20,000, the initial learning rate of training is set to 0.03, and the deviation value is set to 0.02. The optimal learning rate is finally obtained after 15,792 times. Figure 3 shows the curve of the algorithm training obtained by MATLAB simulation.

The BP neural network is tested, and the estimation result of ontology engineering cost is obtained by denormalization of the 5 sets of predicted data. It can be seen from Table 1 that the deviation between the estimated value and the actual value is less than 8%, which is in line with the error range in the comparison and selection process in the decision-making stage. Therefore, the estimation model of ontology engineering cost of the substation's water supply and drainage structure based on the BP neural network is feasible (see Table 1).

4.2. Estimation Model Construction of Price Difference Due to Preparation Time

4.2.1. Regression Model Construction of Price. There are about 360 kinds of materials used in the water supply and drainage structure engineering, of which three types of materials, namely, concrete, steel, and pipe, account for about 85% of the total material cost. Concrete materials include concrete, medium sand, gravel, cement, bricks, etc.; steel materials include reinforcing bars, iron pieces, steel pipe, section steel, channel steel, angle steel, etc. [8]; pipe materials include reinforced concrete pipe and UPVC pipe of various pipe diameters, etc. The concrete materials account for about 28% of the material cost, the steel materials account for about 49%, and the pipe materials account for about 8%.

TABLE 1: Results and analysis of denormalization processing.

	Input layer			Output layer	Actual value	Error %
Voltage level	Prospective scale	Current scale of main transformer	Layout	Cost of ontology		
0.38	0.26	0.31	0.16	590	608	−0.03
0.29	0.17	0.22	0.09	470	457	0.03
0.41	0.3	0.27	0.21	709	695	0.02
0.35	0.21	0.29	0.14	557	546	0.02
0.39	0.27	0.34	0.18	638	644	−0.01

By analyzing the material information prices from 2018 to 2022, there is a regression relationship among the prices of materials of the same kind. The three types of materials are represented by the most used material, and other materials of the same kind establish a regression relationship with it. Concrete C30 is chosen as the representative of concrete materials, a round steel bar Φ12 is chosen as the representative of steel materials, and reinforced concrete pipe DN300 is chosen as the representative of pipe materials. Based on this, the calculation formula of the price difference due to preparation time y_2 is listed as follows:

$$\text{Material price difference} = \sum_{i=1}^{n} \left(p_i^1 - p_i^0 \right) q_i. \qquad (10)$$

In the formula (10), p_i^1 is the local current market price of the ith construction material, p_i^0 is the budget price of the quota of the ith construction material, and q_i is the quantity of the ith construction material.

$$y_2 = \sum_{i=1}^{n} \left(c_i - 1 \right) q_i p_i^0 + m y_1 + n y_1. \qquad (11)$$

In the formula (11), c_i is the proportional coefficient of market price p_i^1 and budget price of the quota p_i^0 of each material; qi is the quantities of each material; p_i^0 is the budget price of the quota of each material; m is the price difference coefficient of labor cost based on the ontology engineering cost; and n is the price difference coefficient of machinery one-shift cost based on the ontology engineering cost. q_i can be obtained by decomposing the ontology engineering cost y_1. The price difference of construction machinery is generally smaller, less than 1%, and it is consistent with the changing trend of the unit price of machinery for one-shift installation. Therefore, m and n are implemented in accordance with the coefficients of labor cost and installation machinery cost of the documents issued by the China Electric Power Project Cost Administration.

4.2.2. Calculation of Regression Coefficient.

The market prices of materials originate from the official cost information websites that release the prices each month from 2017 to 2021, and a one-dimensional linear regression model

of the prices among similar materials is constructed [9]. Because of the large variety of materials included, only representative material regression coefficients are listed in this paper.

The calculation results of the regression coefficient of concrete materials' unit prices with the unit price of concrete C30 as the independent variable are shown in Table 2.

The calculation results of the regression coefficient of steel materials' unit prices with the unit price of round steel bar Φ12 as the independent variable are shown in Table 3.

The calculation results of the regression coefficient of the unit prices of pipe materials with the unit price of reinforced concrete pipe DN300 as the independent variable are shown in Table 4. It can be seen from the data in Table 4 that the simulation calculation results of the regression coefficient fluctuate greatly, which is due to the objective differences in the influence of materials and pipes' diameter on the simulation of the regression coefficient. Generally speaking, in the case of the same material, the larger the pipe's diameter is, the greater the regression coefficient is; in the case of a similar diameter of pipes, the regression coefficient of UPVC material is higher than that of reinforced concrete.

4.3. Simulation of Hydraulic Cost Estimation Model.

The test of the regression model is based on the comparison and analysis of the actual data of substation projects from 110 kV to 500 kV in previous years, and the project features cover the construction scale of common substations, so as to verify the accuracy of the BP neural network, regression model, and project cost estimation results. The simulation results of the substation water supply and drainage structure cost estimation model are shown in Table 5. After the induction and analysis of the existing data samples, the statistical mode is distributed under the voltage level of 200 kV, so more data of 220 kV are selected in the simulation link, and the experimental results can better test the prediction effect and accuracy of the model built in this study.

Figure 4 shows the radar plot of the error between estimated values and actual values. From the relative error between the estimated values and actual values, it can be seen

TABLE 2: Regression coefficients of concrete materials' unit prices.

| Independent variable | Dependent variable | | | |
Concrete C30	Concrete C25	Medium sand	Cement 32.5	Gravel 40
1	0.961	0.285	0.802	0.287

TABLE 3: Regression coefficients of steel materials' unit prices.

| Independent variable | Dependent variable | | | |
Round steel bar Φ12	Galvanized steel pipe DN200	Galvanized steel pipe DN100	Sheet steel	Round steel bar Φ8
1	1.342	1.421	1.086	1.055

TABLE 4: Regression coefficients of unit prices of pipe materials.

| Independent variable | Dependent variable | | | |
Reinforced concrete pipe DN300	Reinforced concrete pipe DN500	Reinforced concrete pipe DN800	UPVC DN75	UPVC DN200
1	1.728	3.492	0.594	2.255

TABLE 5: Simulation results of a substation water supply and drainage structure cost estimation model.

		Voltage level	500 kV		220 kV		110 kV
Design parameters	Prospective scale	Main transformer (group)	4	3	4	3	3
		High-voltage-side outgoing line (line)	8	3	12	6	2
	Current scale of main transformer (group)		1	2	2	2	2
	Layout		Outdoor	Full-indoor	Full-indoor	Semi-indoor	Semi-indoor
Actual data	Ontology engineering cost (CNY 10,000)		618.14	551.46	669.63	461.57	189.69
	Price difference due to preparation time	Project area	Dezhou, Shandong province	Beijing	Beijing	Beijing	Linyi, Shandong province
		Price-adoption time	July 2021	January 2021	July 2021	December 2021	January 2021
		Price difference due to preparation time (CNY 10,000)	87.03	83.23	120.79	88.31	23.28
	Total cost of water supply and drainage structure (CNY 10,000)		705.17	634.69	790.42	549.88	212.97
Estimated data	Ontology engineering cost (CNY 10,000)		629.19	556.51	656.50	466.62	191.71
	Price difference due to preparation time (CNY 10,000)		91.08	87.29	119.77	92.37	24.29
	Total cost of water supply and drainage structure (CNY 10,000)		720.77	643.80	776.27	558.99	216.00
	Error of total cost		2.14%	1.44%	−1.79%	1.66%	1.42%

visually that the error of the cost estimation model is controlled within ±3%, and the model passes the test. It demonstrates that the reasonable estimation of the water supply and drainage structure costs in the substation can be completed based on the key design parameters and the main market price level.
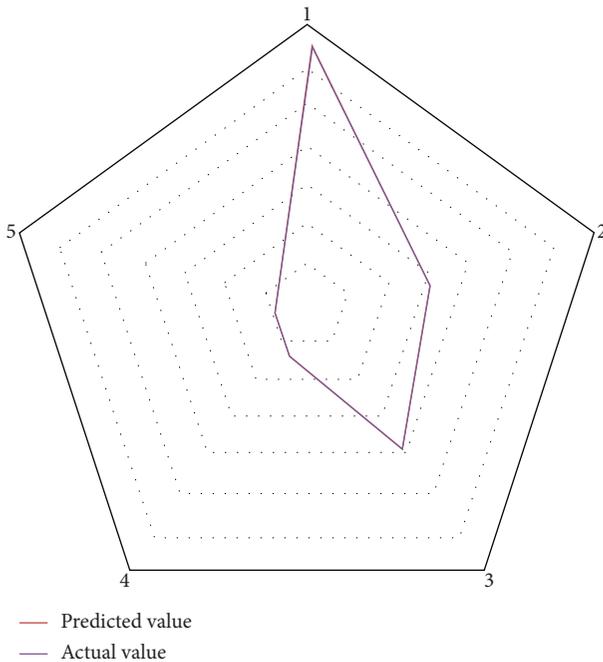
Figure 4: Radar plot of the error between estimated values and actual values.

5. Conclusion

By analyzing the influence of design parameters on quantities in the substation project, this study has built a BP neural network model based on the four design parameters: the voltage level, the prospective scale, the current scale of the main transformer, and the layout, achieving a reasonable estimation of ontology engineering cost. An estimation model of price difference due to preparation time considering market price changes is also built, and the regression method is applied to measure the regression coefficient of the price of materials of the same kind, achieving a reasonable estimation of the price difference due to preparation time. Through calculation and stimulated analysis, the model passes the test, and the error is controlled within ±3%. The cost estimation results are in line with the actual cost requirements, and this model solves the practical problem of rapidly estimating water supply and drainage structure costs for the participant units. On the basis of the cost model of the water supply and drainage structure, the next step of the study is to focus on the further exploration of the potential of design parameters in the rapid estimation of project cost, realizing more efficient practice and application of the cost model.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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