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SPECIAL SECTION ON KEY ENABLING TECHNOLOGIES FOR PROSUMER ENERGY MANAGEMENT

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A Survey on Investment Demand Assessment Models for Power Grid Infrastructure

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ABSTRACT The investment demand forecast of the power grid is the further deepening of grid supply and demand management. Under the current reform of the power system in China, we are facing new challenges in analyzing and predicting the investment demand of the power grid. Firstly, the influencing factors of power grid investment demand from both internal and external aspects are analyzed in this paper. Then the selection principles of power grid investment demand factors by domestic and foreign scholars are summarized in this paper. Based on the above content, the forecast indicators and selection methods of domestic and foreign scholars on power grid investment demand are summarized in this paper. The common influencing factor mining algorithms are the grey correlation analysis, the core principal component analysis, and their combination methods. Moreover, the research status of domestic and foreign scholars in power grid investment demand, data mining technology, and forecasting technology is investigated. The current situation of power grid investment demand in China and the common forecasting methods are also elaborated. Finally, the key issues that need to be solved in future research on the investment demand of power grid infrastructure are summarized in this paper. This review will help power utilities find problems in power grid infrastructure investment demand and guide the future investment demand calculations of power utilities.

INDEX TERMS Grid infrastructure, power grid investment, demand forecasting, indicator system, power utilities.

I. INTRODUCTION

Due to the high-speed development of society in recent years, coupled with the integration of renewable energy sources, the electricity consumption of the entire society has been continuously increased [1], [2]. As a significant pillar of foundations of the national economic construction, the power grid bears the responsibility for maintaining the stability of the state energy system and making contributions to social development [3], [4]. In China, amounts of money are invested by power utilities to accelerate the construction and transformation of the power grid, making the scale of power grid construction and investment larger [5], [6]. The investment is the chief driving factor for power utilities to realize healthy and stable operation and sustainable development [6]–[10]. The increasing macroeconomic uncertainties and the continuous deepening reform of the electric power system have led to significant variations in the internal and external environment for the development of power utilities. Moreover, power utilities are facing an increasing investment demand, which further increases the difficulty of investment [11]–[14]. Besides, the power grid investment demand forecasting involves various factors, complex influencing factors, multiple calculation indicators, and strong uncertainties. Most of the work focused on the evaluation of the investment, but the researches on investment are uncommon. Therefore, the accurate assessment of power grid infrastructure investment demand is a perennial problem that needs to be solved for the power grid planning department.

Aiming at the research of power grid infrastructure investment demand, the current research status from the aspects of influencing factors, measuring index system, and forecasting methods were summarized in this paper.

The rest of this work is organized as follows: The factors that affect the investment demand of the power grid from both internal and external aspects are analyzed in the second

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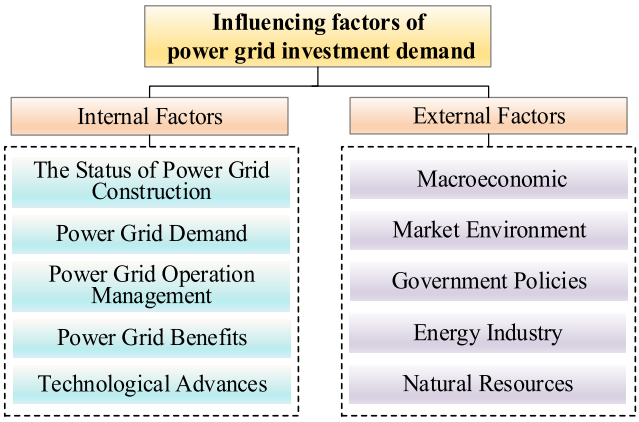

FIGURE 1. The influencing factors of power grid investment demand.

part. The forecasting index of the power grid investment demand is selected and summarized in the third part. The fourth part conducts the in-depth analysis and researches on the existing investment demand methods and summarizes the current research status of power grid investment demand. Finally, the conclusion is given in the fifth part.

II. ANALYSIS OF INFLUENCING FACTORS OF GRID INVESTMENT DEMAND

The investment demand for power grid infrastructure is not merely influenced by internal factors such as the construction, demand, operation, benefits, and technological advances of the industry itself, but also by external factors such as the macroeconomic, market environment, government policies, energy industry [15]. Common influencing factors are shown in Fig. 1.

A. EXTERNAL FACTORS OF POWER GRID INVESTMENT DEMAND

As shown in Fig. 2, macroeconomic factors are considered as the most relevant factors which can reflect regional income, economic level, and direct impact on the investment of grid enterprises [16]. With the rapid development of the national economy, the growth momentum will be stronger and power grid investment is positively correlated with the growth in electricity demand generated by economic growth [17]. Generally, economic development, economic structure, economic driving factors, and economic operations are considered as macroeconomic factors [18].

Generally, the economic structure refers to the proportion of different economic components and industrial sectors in the national economy; The economic development, in terms of society and economy, refers to the scale, speed, and level of economic growth which is accompanied by changes in economic structure and output distribution; The economic incentives are associated with the fixed-assets investment, exports, and national consumption; Economic operations are related to the stable operation of the economy, such as the Li Keqiang index, price index, Purchasing Managers' index[19].

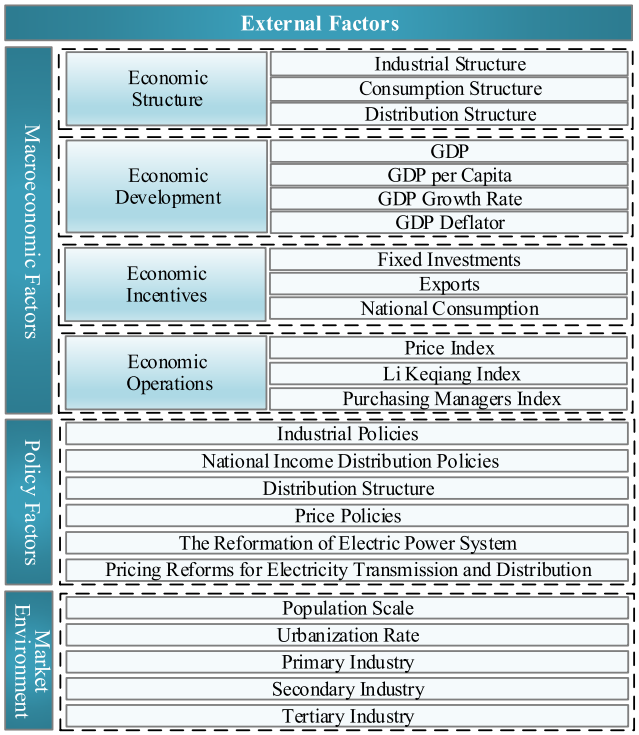

FIGURE 2. External factors influencing investment demand.

Government Policy factors refer to strategies formulated and implemented by the government, such as industrial policies, national income distribution policies, distribution structure, price policies, pricing reforms, the reformation of the electric power system, and pricing reforms which may have an effect on the power grid investment under the social environment conditions and political culture factors, legal provisions and industrial policies [20].

The market environment is closely associated with marketing activities. Based on a population scale, urbanization rate, and the three times industrial structure, the power grid conducts the marketing analysis and the revenue analysis [21].

B. INTERNAL FACTORS OF POWER GRID INVESTMENT DEMAND

As shown in Fig. 3, the status of the power grid construction directly reflects the intensity of the power grid infrastructure. The capital construction, renovation, and reformation investment, investment in real estate development, power load, the balance of electric power and energy and transmission route selection are considered as factors concluded influencing power grid construction [22].

Along with the continual development of the power grid construction, the investment demand for power grid infrastructure will also increase. Besides, the substation capacity and line length are the standards of power grid construction according to State Grid Corporation of China (SG) [23]. The structure and development of the regional power grid must meet the local power demand. Moreover, the construction level of the power grid can be improved with the

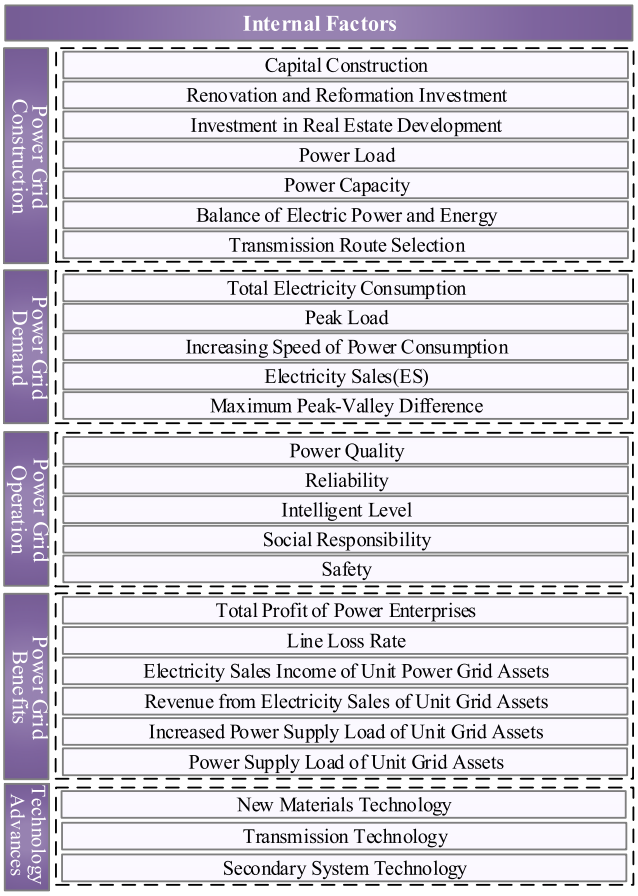

FIGURE 3. Internal factors influencing investment demand.

increment of power grid investment demand. Generally, the total electricity consumption (TEC), peak load, increasing speed of electricity consumption, electricity sales, and maximum peak-valley difference are considered as the factors of power grid demand [24]. The operation management of the power grid is referred to as the implementation of intensive management functions for personnel, property, power planning, power construction, power operation, power maintenance, and power marketing, such as power quality reliability, intelligent level, social responsibility, and safety.

As a comprehensive manifestation for the benefits of corporate operations and power grid, the benefits of power grid reflect the overall situation of grid enterprise development. Owing to the optimization of the grid structure, expanding grid capacity, strengthening power grid supply capacity, and improving operation and maintenance level, the investment income and operating efficiency are effectively increased. Thus, there is a close relationship between the improvement of grid efficiency and the increase in grid construction investment. In [25], the total electricity consumption (TEC), line loss rate, unit electricity sales revenue, increased power supply load, and so on are selected as influencing factors of power grid benefits for power grid demand investment. Furthermore, advanced technology consisted of new materials technology, transmission technology, and secondary system technology is considered as a significant factor affecting power grid investment [20].

TABLE 1. The indicator system of investment demand for power grid infrastructure.

First Level Indicators	Second Level Indicators
Social Economy	• Gross domestic product (GDP) • Population • Urbanization rate • Consumer price index (CPI) • Fixed-asset investment
Electricity Demand	• Total electricity consumption • Power supply • Electricity sales • Peak load
Power Grid Scale	• Installed capacity of power supply • Power transmission line length of different voltage classes • Transformer capacity of different voltage classes
Power Grid Benefit	• Line loss rate • Total profit of power utilities • Electricity sales income

III. FORECASTING INDEX OF POWER GRID INVESTMENT DEMAND

A. SELECTION PRINCIPLE OF PREDICTORS

The indicator system of investment demand assessment models for power grid infrastructure is investigated from influencing factors, which are comprehensive and quantifiable data materials. Significantly, the excellent indicator system, as the solid foundation of investment demand assessment for power grid infrastructure, is established. Moreover, each dimension can be further divided into secondary indicators, which are the gross domestic product (GDP), population, urbanization rate, CPI, fixed-asset investment, electricity sales, total electricity consumption, power supply, peak load, maximum peak-valley difference, line loss rate, profit rate, etc. GDP, population scale, urbanization rate, fixed-asset investment, and CPI were considered in social-economic indicators to predict power gird investment demand in China [26]. Besides, the number of employments, dwelling counts, and GDP per capita was also selected as social-economic indicators. In reference [27], GDP, population-scale, urbanization rate, the total electricity consumption, grid power supply, grid sales, and the installed capacity were selected as key factors to forecast the investment demand of the power grid. Finally, a comprehensive indicator system of investment demand assessment models for power grid infrastructure is summarized in TABLE 1.

B. SELECTION METHODS OF PREDICTORS

Many factors influencing the demand for power grid investment have different importance. Therefore, in addition to the determination of the influencing factors, it is also necessary to identify the key influencing factors. Generally, the first step of investment demand assessment for power grid infrastructure is to analyze and select the influencing factors. Then, different

methods are adopted to obtain the effective input vector of the power grid investment demand prediction model. Correlation analysis, regression analysis, and grey correlation analysis are commonly used to select the influencing factors of power grid investment.

The correlation analysis method was presented in the literature [28]. The study used correlation analysis to find the seven indicators that have the greatest impact on the power grid investment. They were GDP, grid power supply, population, installed power supply capacity, grid electricity sales, the electricity consumption of the whole society, and urbanization rate. The correlations were all above 88%.

The regression analysis method based on panel co-integration theory was used in the literature [4]. Firstly, the data affecting investment demand have checked the stability by using the unit root test in the study. Then, according to the results of the test, a targeted co-integration test method was used in this study. Finally, based on the data that passed the co-integration test, the research conducted regression analysis on key factors to obtain the final demand forecast indicators. Similarly, regression analysis has also been used in the literature [27].

Grey relational analysis was used in the literature [26]. After a preliminary selection of influencing factors, an influencing factor system was constructed from four aspects. Grey relational analysis was used to rank the matter of influencing factors. Five important indicators were chosen as input variables of the investment demand forecasting model. Similarly, the gray correlation analysis method was adopted in the literature [20].

IV. PREDICTION-MODELS OF POWER GRID INVESTMENT DEMAND

A. RESEARCH ON INVESTMENT DEMAND FORECAST

In recent years, scholars at home and abroad had used a variety of forecasting models in various fields to conduct investment demand forecasting research and achieved considerable success.

Research on the energy demand prediction of road traffic was presented in [29]. They detailed analyzed the relationship between economy, transportation, population, and energy subsystems in Liaoning Province with the system dynamics theory. Then a dynamic model was established and conducted a scenario simulation in Liaoning Province. A multiple linear regression model and an optimal fitting model was established in [30], which effectively predict higher education investment demand. After the scientific selection of variables and data preprocessing, the model had been gradually regressed and solved. Based on statistical testing and error analysis and comparison, an effective forecast of higher education investment demand was realized in the model.

The weighting method to predict the investment of the proposed project was used in [31]. In the decision-making stage of a construction project, the typical completed project data and planned project data were used to construct a comparative data sequence and a parent data sequence. Through gray correlation analysis, three projects with the largest correlation with the proposed project were selected. Then the weighting method to predict the investment of the proposed project was applied in this paper. The chaotic prediction model was established to accurately predict project investment in [32]. Based on the chaos theory and the autocorrelation method, the model was instituted. G-P algorithm, Lyapunov index calculation, and other methods are used in this model to achieve accurate prediction of project investment.

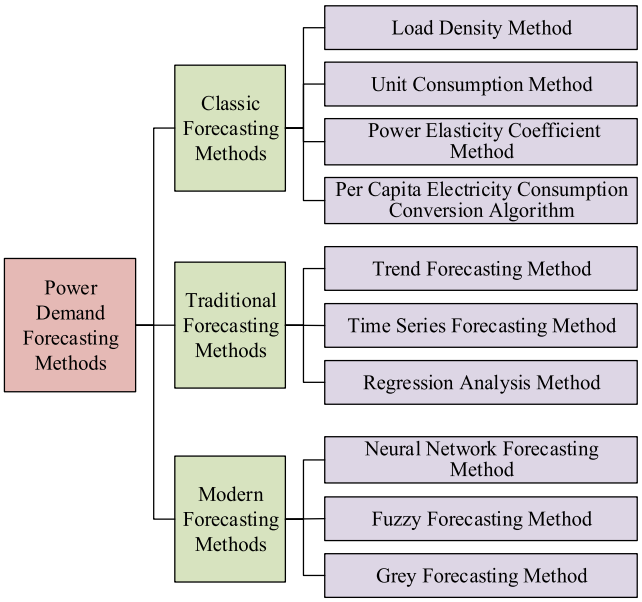

FIGURE 4. Power demand forecasting method.

B. POWER DEMAND FORECASTING METHODS

Power demand is an important index for forecasting power grid investment demand. It is important for rationally arranging investment for power grid construction and reducing capital costs [33]–[36]. The methods of power demand forecasting can be divided into three classes including classic predicting methods, traditional predicting methods, and modern predicting methods, as shown in Fig. 4.

Many factors affect the long-term power demand as shown in [37]. The reason for the uncertainty of forecast results is the complexity of influencing factors. The dynamic artificial neural network model was used in this paper to predict the medium and long-term power demand, which overcame this shortcoming. Besides, the accuracy of the prediction results in this paper was improved, and the prediction error was effectively reduced. Economic development was considered to be the most important factor influencing medium and long-term power demand [38]. The results of this study were more obvious in developing countries. A neural network model that selected 12 economic indicators to predict Iran's medium and long-term power demand was established in this paper. Good results were achieved in this model. The particle swarm optimization was used to estimate the parameters of the power

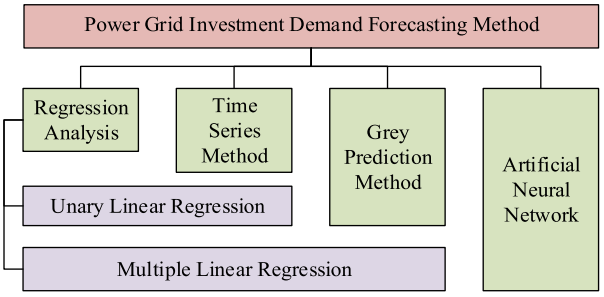

FIGURE 5. Power grid investment demand forecasting method.

demand model in [39]. The error of the forecast results had been effectively reduced in this model. The linear model and the quadratic model was combined with this method to predict the long-term electricity demand in Egypt and Kuwait.

Datasets from 43 non-EU countries and 26 EU countries were used to analyze the relationship between electricity demand and economic growth [40]. In different countries, the causal relationship was dissimilar between economic growth and electricity demand. There was a positive correlation in developed countries in the European Union and a negative correlation in non-developed countries. The annual power demand forecasting was decomposed into hourly forecasting in [41]. The singular value decomposition technique was used in this paper to predict medium and long-term power demand. The power demand of Jordan was predicted in this paper, and the error was reduced to less than 5%.

C. POWER GRID INVESTMENT DEMAND FORECAST METHODS

At present, scholars at home and abroad do not have much research on power grid investment prediction, and most of them use artificial intelligence and statistical methods for prediction, such as references [42]–[47]. The commonly used methods for forecasting power grid investment demand are shown in Fig. 5.

A power grid investment demand prediction model based on the grey system theory was proposed in [48]. The correlation coefficient method was used in this research to analyze the factors that affect the power grid investment demand. A power grid investment demand forecasting model was established, which was based on the gray correlation analysis theory. For the predictions on the power grid investment, the grey relational analysis method was used in [49] to screen out the main influencing factors. A combined forecasting method was proposed that combined differential evolution algorithm, SVM (support vector machine), and GWO (gray wolf optimization) predict power grid investment. The performance of the model had been analyzed in the example. The results showed that the combined model had stronger generalization and robustness, and the prediction accuracy had also been greatly improved, comparing with the traditional single neural network model.

A prediction model based on BPNN for power grid infrastructure project investment was established in [50]. The principal component analysis was first used to filter and reduce the dimensions of the data. Then the principal component data of the original indicators were obtained as the input of this model. The accuracy and effectiveness of model prediction were greatly enhanced. Finally, the effectiveness of the model was verified through case analysis and application. For the power grid demand forecasting problem, the combined forecasting method was used by some researchers to solve it. Based on studying a series of forecasting methods, there were limitations between a single forecasting method and a combined forecasting method [51]. The problem was that there was a non-independent covariance between the demand side. Therefore, a method was proposed to minimize the prediction error of the target demand group in this paper. The proportion of covariance errors was reduced through the secondary planning of portfolio management, and the accuracy of the power grid investment forecast results was improved.

The characteristic sequence of power grid investment demand was complex, nonlinear, and non-stationary. Firstly, the EMD method was used to deal with the original data in [52]. Then, the power grid investment data sequence was decomposed into two different sub-sequences. Finally, GA-SVM and RBFNN models were used to predict the two sub-sequences. By summarizing the prediction results of the two sub-sequences, the final power grid investment prediction result was obtained. The construction time and space of each power grid are not exactly the same, so the development path and development mode of each power grid is not exactly the same. The differences in power grid development patterns in different regions are firstly analyzed in [53]. Based on the differences in development paths and forms of different units, a determinate relationship was established in the study. The differences between the corresponding investment and development path of the power grid are revealed.

V. CONCLUSION

Investment in grid infrastructure makes up about 80% of investment in power utilities. The characteristics of investment demand presented by each voltage grade are constantly changing. Therefore, the investment demand needs to be predicted according to different voltage levels. This paper is of decisive significance for power utilities to determine the optimal investment strategy and optimize the power network planning and operation strategy. At present, the measurement of the investment demand of each voltage grade of the power grid lacks accurate quantitative data as support. It mainly relies on the prediction of the electricity price and the analysis of the influencing factors of the power grid investment. The calculated results are not objective due to various subjective factors such as the level of knowledge and the personal preference of experts. Future researches on classifying the investment demand of the power grid according to the voltage level are required to solve these problems. It is suggested that future studies should be based on load growth analysis to estimate investment demand for each voltage class layer

by layer, so as to determine the investment scale for power companies and improve their investment profits.

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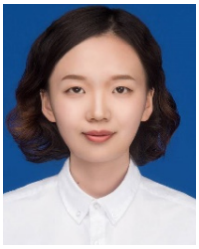

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