Research on Investment decision-making scheme of Power Grid Enterprises Considering the Expansion of Incremental Power Distribution Service

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Abstract. After the thorough implementation of the power system reform, the business of incremental power distribution grid (IPDG) investment has gained great attention from the public as a key point that needs to be promoted. The power grid enterprises (PGE), therefore, urgently need to come up with new development strategies to enhance their core competitiveness and to increase the revenue of IPDG investment. According to the current development status of the IPDG and the business objectives of the PGE under the new business format, an investment decision-making scheme for IPDG, including the demand analysis forecasting, investment ability estimation and projects’ scientific assessment, was proposed, and the investment decision management mechanism for IPDG projects was also developed at the meantime, which will provide technical support for the development of PGE’s IPDG business.

1. Introduction

Since the 18th National Congress of the Communist Party of China, the Party Central Committee and the State Council have attached great importance to the reform of the power system. Power companies have focused on energy transformation and industrial upgrading, and have achieved a series of fruitful results at the same time. The investment of IPDG is a key point of the reform of power system. Since various links have been involved in the IPDG market, including planning and construction, operation and profit ability, resulting that the process is complicated, the corresponding implementation plan for PGE has not yet been formed, and further exploration is needed¹⁴. In addition, the investment decision of IPDG projects has characteristics of complex optimised objectives, wide coverage areas and a large number of potential uncertainties. Therefore, in order to adapt to the new situation, proposing an adaptive investment decision-making scheme of IPDG is a practical issue that needs to be solved by PGE². At present, the research on investment decision of power grid projects mainly involves the establishment of power grid investment decision-making model and the algorithm of calculating the optimised target. Literature³ established the power grid investment decision-making model and applied the Backward Induction as the algorithm. The example results included the optimal investment
portfolio strategy, investment scale and investment timing. Literature\(^4\) took minimised cost as the objective function which considered the investment amount, working duration and other factors, and applied genetic algorithm to figure out the results. The current researches on investment decision of power grid projects are mainly carried out from a micro perspective. There is a lack of comprehensive macro investment decision-making schemes which combine with China’s policies and regulations and current status of power grid construction. There is also few investment decision-making schemes for IPDG projects from the perspective of PGE.

Taking the policy, economic and technical factors of power grid distribution investment into account, this paper investigated the investment decision-making method of IPDG, designed the investment decision-making scheme and provided the basis for estimating the enterprises’ investment ability. The provided basis was constrained by debt asset ratio. This paper also refined the project evaluation indicators based on Principal Component Analysis and further developed investment decision management mechanism. The proposed investment decision-making scheme of IPDG and its management mechanism provided a valuable reference for PGE to manage and control the business of IPDG.

2. The Design of Investment Decision-making Scheme for IPDG Projects

The main contents of the investment decision of IPDG projects include the determination of the investment direction, the scale and the selection of the investment plan. The key of the investment decision is to comprehensively consider the power demand and the project information, and to select cost-effective investment plan which is suitable to capital capacity after estimating an enterprise’s investment ability. For enterprises, the correct and reasonable investment decision can help to increase the financial efficiency of funds, and it is also an important guarantee for the smooth cash flow and rapid funds’ turnover\(^5\)\(^6\).

In combination with the current development status of IPDG in China and based on the procedure research of investment decision for PGE’s projects, this paper proposed a unique kind of investment decision-making scheme for IPDG projects. The procedure of the proposed scheme can be seen in Figure 1, and the main steps are shown as follows:

![Figure 1. Flow chart of investment decision-making scheme for incremental distribution network project](image-url)
(1) The analysis and forecast of power demand
Affected by multiple factors such as economic level, functional positioning and current power grid status, the power demand of IPDG projects is very varied from that of traditional power distribution grid projects. Through the comprehensive investigation of the IPDG projects, a database of the IPDG projects was established. The data mining intelligent algorithm was combined to carry out the power demand analysis of the IPDG projects. When formulating the comprehensive forecast scheme of power demand for IPDG, regional location, industrial structure and the local medium-to-long term development plan were required to be considered. At the same time, the scheme should be strictly defined within the scope of national policies and regulations to ensure the qualitative power demand is in line with legal compliance.

(2) The estimation of investment ability for PGE
In the environment of in-depth reform of the power system, the profit structure of PGE has changed from vertically integrated monopoly structure to a multi-ownership mixed market-oriented competitive model, which has a direct and huge impact on the level of resource integration and overall investment ability of PGE. Under this context, it is necessary to accurately estimate and rationally plan the investment ability of the PGE so as to ensure their core competitiveness and return on investment.

(3) The comprehensive and scientific assessment of IPDG projects
Removing the restriction on IPDG business is aimed at encouraging the participation of private capital. The government clearly stipulates that PGE should “participate in investment, construction and operation in a way that cooperates with social capital”, indicating that the PGE are required to participate in IPDG pilot projects in the form of mixed ownership. In order to improve the investment decision-making level of PGE in the IPDG market, it is necessary to develop a comprehensive and scientific assessment system for each project, considering the particularity and difference of IPDG projects, and ultimately to conduct the feasibility assessment based on the result of the scientific assessment system.

2.1. The Analysis and Forecast of Power Demand
Under the thorough implementation of the power system reform, the power demand forecast of the IPDG is very different from that of traditional stock power distribution grid. When conducting the forecast, it is necessary to pay much more attention to the following factors:

(1) The impact of distributed generation
The market-oriented competitive mode that mixes with centralised and distributed generations is the current development trend of the IPDG market. On the one hand, when the distributed generation is connected to the grid, the voltage class of the access varies according to the scale. When the access scale is considerable, the load forecast of the regional power grid of the corresponding voltage class is affected. The accuracy of the load forecast is reduced due to the fluctuated and highly-impacted power output. At the same time, the current load forecasting method is based on different voltage classes, so this impact will also affect the load forecast of other voltage classes. On the other hand, when the distributed generation is not connected to the grid, users, depends on their needs, need to randomly switch between the mode of self-generation of the power at the users’ end for self-use and the mode of the utilisation of surplus power in the grid. The power’s flowing direction and the capacity of generated power and that of consumed power are hard to control. It is also difficult to forecast that surplus power capacity utilised in the grid after self-use in the users’ side or the capacity of power generated from the grid when the self-generated power cannot meet the self-use power demand. Therefore, the load forecast will be affected.

(2) The impact of new electricity price mechanism
Before the power reform, the on-grid power price and the power selling price were all implemented by the guidance of the government tariff, so the power price was relatively stable and had not great influence on power demand. After the power reform, the restriction on competitive power price is removed, and new price modes such as time-of-use price and real-time price are available in the market. It thus enables large-scale power users to choose different power generation enterprises based
on their price mechanisms, and to negotiate power selling price. At the same time, individual and small-scale power users can adjust their power consuming habits based on their demand in order to reduce economical cost. Therefore, the new power price mechanism increases its influence on consumed power and also strengthens the complexity of distribution network’s power forecast.

(3) The impact of diversified energy consumption on the demand side

No.9 document issued by the General Office of the CPC Central Committee in 2015 suggested that the application of Demand Response (DR) technologies to the user side should be greatly promoted. As DR technologies are promoted in a large scale, factors that influence electrical load will become diversified and excessive. On the one hand, there will be more diversified energy consumption resources on the demand side, like price incentives, interruptible load, energy storage system, electric vehicle, etc. On the other hand, with the gradual implementation of smart distribution grid, the traditional one-way direction of power flow will be replaced by distributed generation users and interactive electric load. Thus, the demand side resources will participate in the process of demand side management, changing the features of energy consumption greatly and imposing direct impact on the electric load. Then, the demand side forecasting requires further calibrating.

2.2. Estimation of PGE’s Investment Ability

To estimate a company’s investment ability, it must account the company’s total profit and confirm the amount of loans for the coming year and other financial sources in accordance with the annual financial plan[8]. Estimating a PGE’s investment ability can enable the enterprise to better identify the investment scale and the project time, and also serve as theoretical evidence in project financing management and control.

Debt-Asset ratio is suggested to be the constraint for a PGE’s investment ability, whose annual growth should be stipulated to be 1% and the Debt-Asset ratio should not be more than 75%.

Then the grid company’s asset-liability ratio can be expressed as:

\[ T = A / B \]  (1)

\( T \) is the asset-liability ratio, and \( A \) is the total liability for the year, which can be expressed as:

\[ A = I_t + I_m - W_t \]  (2)

Among them, \( I_t \) represents the total debt at the beginning of the year; \( I_m \) represents the maximum loan amount in one year; \( W_t \) represents the loan amount that the enterprise should repay.

\( B \) is the cumulative total assets for the year and can be expressed as:

\[ B = W_t + W_n - I_m \]  (3)

Among them, \( W_t \) represents the total assets of the enterprise at the beginning of the year; \( W_n \) represents the net profit of the grid enterprise for one year.

The maximum loan amount for one year from formula (1) to (3) is:

\[ I_m = \frac{r(W_t+W_n)+W_t-I_t}{1-r} \]  (4)

Therefore, the actual annual investment capacity of grid companies is:

\[ F = S_t + O + I_m \]  (5)

Among them, \( F \) represents the annual actual investment capacity of the grid enterprise; \( S_t \) represents the expected minimum return; \( O \) represents the depreciation loss; \( I_m \) represents the maximum loan amount available to the grid enterprise.

2.3. Comprehensive and Scientific Project Evaluation

PGE’s project investments are featured in a large amount of finance, long payback period, low financial liquidity and many other variables. Among them, the electric equipment, the location for power transmission and distribution and human recourses call for sustainable money input. The project
operation goes through a long project cycle, including planning, reconnaissance, designing, construction, testing and adjustment. The project investment of PGE is targeted and attached to the locations. Thus, it is difficult to mobilise asset promptly, let alone transfer freely. Moreover, the profits of PGE have been suppressed by the generation and retailing sides. Against the backdrop of the power system reform in China, the profit structure is further adjusted, shifting from the profiting in spread to cost-reasonable profit. Therefore, PGE are required to pinpoint their evaluation on market environment of the IPDG for the targeted areas. They also need to evaluate the investment projects scientifically from multi perspectives such as economics and feasibility.

The feasibility analysis of pilot projects can be set up as a starting point. Project reviews and sorting-first approach are thus to be established. The paper adopted Principle Component Analysis (PCA) for project sorting. Based on this result and the opening up of IPDG, the investment decision-making scheme is established. Detailed procedures are as follows:

The first step is the comprehensive evaluation of a whole project. Before the construction project is about to be implemented, the PGE should have a clear idea of the whole environment in the pilot regions from the perspectives of politics, economy, society and technologies. Politically, PGE must grasp the reform of power system, the regional development plan and other relevant industrial policies and plans. Economically, the economic development status, planning, industrial structure allocation and energy consumption in the region should be surveyed. Socially, the status quo of relevant public utilities, infrastructure and their usage in the region should be grasped. Technologically, the application status and development planning of electricity, energy and technologies in this region should be identified.

The second step is the evaluation of prioritised projects. First of all, based on the first step, we can use market potential, strategic development, economic effect and investment risks of IPDG projects to build up a multi-layer evaluation system for IPDG projects, shown as Figure 2.

The third step is to determine the indicator weight by PCA. PCA is a multi-variable statistical analysis that aims to build up covariance matrix, reducing dimensions, compression and extraction of statistics. It is applied to comprehensive analysis tailored to complicated system with multi variables, indices and features.

a) The characteristic parameter normalization processing, the normalized parameter Y of the characteristic parameter X is calculated according to the formula (6), and for the qualitative index, the index is quantified by the expert scoring method.

\[
\begin{align*}
Y(i,j) &= \frac{X(i,j) - \bar{X}_j}{\bar{X}_{j-s}} \\
\bar{X}_j &= \frac{\sum_{i=1}^{m} X(i,j)}{m} \\
\bar{X}_{j-s} &= \sqrt{\frac{\sum_{i=1}^{m} (X(i,j) - \bar{X}_j)^2}{m}}
\end{align*}
\]

(6)

Where X is an m×n-order matrix, m is the number of samples of the incremental power distribution project, and n is the number of characteristic parameters. \(X(i,j)\) is the i-th row and j-th column characteristic parameter, \(\bar{X}_j\) is the j-th column average value of the matrix X, and \(\bar{X}_{j-s}\) is the j-th column standard deviation of the matrix X.

b) The covariance calculation calculates the characteristic parameter covariance matrix Z of the sample X according to the formula (7).

\[
\begin{align*}
Z &= (P^T \cdot P)/(n - 1) \\
P(i,j) &= Y(i,j) - \bar{Y}_j
\end{align*}
\]

(7)

Where T represents the transpose of the matrix and \(\bar{Y}_j\) is the average of the j-th column of the matrix Y.
The eigenvalues of the covariance matrix $Z$ are obtained, and the feature parameters are sorted according to the eigenvalues, and the contribution rate $\theta_k=\lambda_k/\sum_{l=1}^{n}\lambda_l$ is used as the index weight. Where $\lambda_k$ represents the $k$th eigenvalue.

Figure 2 Distribution network investment project evaluation index system

The last step is to order all project investment plans by TOPSIS. TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution) refers to an analysis method which calculates the geometric distance between each alternative and the positive ideal alternative and the negative ideal alternative to determine the ranking of the evaluated subject. If the evaluated alternative is close to the positive ideal alternative and far away from negative ideal alternative, the evaluated alternative is better; vice versa.

TOPSIS is used in comprehensive evaluation, because it does not have strict requirements in terms of the allocation of statistics, the sample size and the number of indicators. Therefore, it not only applies to a small sample, but also to large systemic statistics with multi-items and -indices. It also can be used for both horizontal and vertical comparison. With great flexibility in applications, simplicity in mathematical computation and objective quantification, it has been used extensively in performance evaluation and economic effect evaluation.

Before using TOPSIS, a reasonable branching criterion must be set up, that is, setting up the positive ideal alternative $(x_{i1}^+, x_{i2}^+, \ldots, x_{im}^+)$ and the negative ideal alternative $(x_{i1}^-, x_{i2}^-, \ldots, x_{im}^-)$. For an evaluated alternative $(x_{i1}, x_{i2}, \ldots, x_{im})$, the weighted distance between the two alternatives is:

$$y_i = \sum_{j=1}^{m} w_j f(x_{ij}, x_{j}^*) \cdot i = 1, 2, \ldots, n$$  \hspace{1cm} (8)

Where $w_j$ is the weight coefficient, $f(x_{ij}, x_{j}^*)$ is a certain distance between the component $x_{ij}$ and $x_{j}^*$, and the Euclidean distance is usually taken as a composite function.

Set $(x_{i1}^+, x_{i2}^+, \ldots, x_{im}^+)$ is a positive ideal system, $(x_{i1}^-, x_{i2}^-, \ldots, x_{im}^-)$ is a negative ideal system, then the Euclidean distance of the evaluated object $(x_{i1}, x_{i2}, \ldots, x_{im})$ and the positive ideal point $y_i^+$ is:

$$y_i^+ = \sqrt{\sum_{j=1}^{m} w_j (x_{ij} - u_{j}^+)^2} \cdot i = 1, 2, \ldots, n$$  \hspace{1cm} (9)
Evaluated object \( (x_{i1}, x_{i2}, ..., x_{im}) \) and the Euclidean distance of the negative ideal point \( y_i^- \) is:

\[
y_i^- = \sqrt{\sum_{j=1}^{m} w_j (x_{ij} - u_j^-)^2}, i=1,2,...,n
\]

The system uses the queued indication value to comprehensively evaluate the system. The calculation formula of the specific queue indication value \( C_i \) is as follows:

\[
C_i = \frac{y_i^-}{y_i^- + y_1^+}
\]

### 3. The Design of Management Mechanism of Projects’ Investment Decision-making

A project’s complete investment process is featured in wide scope, long period and multiple uncertain factors. An investment decision can be made after comprehensively considering the power demand, project scale and the company’s investment ability. It is extremely difficult to ensure a project is developed orderly and punctually. Therefore, PGE shall develop suitable investment management mechanism regarding the IPDG projects to ultimately achieve a full-scale and full-process control for the projects’ investment.

PGE failed to make timely adjustments to their investment decisions based on a series of new changes of IPDG, and this means that firstly, the new distribution subject has increased the difficulty of the overall planning and methodical construction of the distribution grid. Secondly, the current planning scheme is lack of adaptability. Thirdly, the process of each step of investment management and control is lengthy and approval procedures are complicated as well. Fourthly, there is few theoretical basis and method support for investment decision-making. And lastly, the investment evaluation mechanism is still flawed\(^2\). Therefore, this paper is aimed to further improve the investment decision-making control mechanism of PGE’s IPDG projects, which is served as a guarantee for the steady progress of project investment. The key points of this mechanism are:

1. The integration of market data. The key is to collect the data of the target distribution grid area, and form a detailed market survey report or regional market database for those projects that can meet the requirements of the IPDG market;

2. The control of funds involved in the distribution investment. The key is to identify projects’ overall cash flow based on the forecasted revenue and expenditure of the distribution grid projects. An expected cash flow plan can be formed by selecting corresponding financial indicators and calculating the optimal investment scale of IPDG.

3. The optimal decision of distribution grid projects. The key is to generate projects’ rationality analysis and investment assessment reports so as to ensure projects’ importance, economics and rationality. The optimal investment decision-making scheme is made up by project evaluation sequence.

4. Initiating the investment for distribution grid projects. The key is to rationally strive for the operation and ownership rights of corresponding assets. Negotiating with different investment entities to achieve a balanced profit and interests and to urge the promotion of the investment.

### 4. Conclusion

Based on the status analysis of IPDG projects and operation goals of PGE, sitting in the opening up of IPDG business, this paper puts forward a decision-making scheme for investing IPDG projects and explains every specific implementation method and technical roadmap in different phases. The decision scheme takes into account the electrical load demand forecast that is affected by many factors, such as the introduction of distributed generation, reform of electricity price-setting mechanisms and user interactive services. In addition, this paper adopted PCA and TOPSIS techniques to order projects and developed an all-around and reasonable project evaluation system. Meanwhile, this paper explored the sources of estimating the investment ability of PGE and analysed the key points in decision-making and management in order to further improve this mechanism. Overall, the findings of
this paper can serve as a reference and technical support for increasing the investment efficiency and promoting the sustainable development of PGE.

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