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The optimization of Chinese power grid investment based on transmission and distribution tariff policy: A system dynamics approach☆

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ABSTRACT

Grid investment optimization is an effective method for solving the mismatch between investment demand and the investment capacity of power grids. China is carrying out a new round of power system reform, and the main content is to control the revenue of the power grid enterprise through the transmission and distribution tariff policy. Revenue control may make the investment capacity of the power grid enterprise appear even more insufficient than it is currently. This paper studies the influence of the transmission and distribution tariff policy on the cash flow of the power grid enterprise and establishes an investment optimization decision-making model for the corporation using system dynamics theory. Then, taking a city as an example to undertake an empirical analysis, the paper puts forward suggestions and policy implications for the investment decision of the power grid enterprise after the reform of the electricity market.

1. Introduction

The purpose of power grid investment optimization is to meet investment demand with limited investment capacity. The transmission and distribution tariff policy of power market reform in China requires the power grid enterprise to control its revenue. In this context, the issue of power grid investment optimization is becoming increasingly important. China's electric power industry market has undergone 13 years of reform since 2002. By splitting the State Power Corporation, China initially aimed to “introduce price bidding by separating the operations of power plants and power grids” and completed the transition from a complete monopoly to a relative monopoly (Wang and Chen, 2015). To a certain extent, this improved the efficiency of the Chinese power market, especially on the power generation side (Meng et al., 2016). At the same time, the Chinese government has gradually improved the regulation of the electricity market. However, the power generation side and the sales side have not formed a real market due to the control of the market by the power grid enterprise (Ngan, 2010).

Many countries in the world have carried out reform of their electricity markets and many scholars have conducted in-depth research on transmission and distribution tariff policy reform and regulation. As the electricity market is becoming increasingly open and the association with other industries is becoming more complex, transmission and distribution tariff regulation is mainly concentrated on the expansion of the transmission grid, operating costs and profit levels (Mastropietro et al., 2015). According to the relevant laws and regulatory standards, power grid enterprises are developing transmission and distribution tariff calculation methods in accordance with the principles of cost allocation (Ortega et al., 2008). Moreover, based on changes in the market environment, accounting methods are being adjusted (Stoilov et al., 2011). At the same time, the development of smart grids and renewable energy has given rise to greater requirements for investment and supervision of the power market (Cambini et al., 2016; Kucsera and Rammerstorfer, 2014). To ensure fair competition among power market participants, regulatory authorities generally require the transmission and distribution network to open up to all market participants without discrimination, thus providing fair distribution and distribution services (Lester et al., 1997). In relation to the electricity market in Texas, scholars have conducted in-depth research on the transmission and distribution tariff of electricity, including the price formation mechanism, the process of approval for the original tariff, the price adjustment provisions and the implementation of control methods and so on (Deng, 2007). The study found that transmission and distribution tariff reforms have a more complex impact on power grid enterprises than other measures. To ensure the economic sustainability of the implementation of electricity transmission and distribution tariffs, it is necessary to clarify the transmission mechanism of such tariffs and how operating costs might be recycled (Yang, 2011; K.L. He et al., 2015; Y.X. He et al., 2015). Thus, we need a systematic research method that can reflect the mutual internal influence.

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System dynamics, which originated in 1956, concerns research on and the analysis of information feedback systems. The central idea is that a system must have a structure and the system structure determines the system function. This entails the systematic study of the development and change of things according to the feedback characteristics of a system's internal elements of reciprocal causation (Nabavi et al., 2017). System dynamics was mainly used early on in industrial enterprise management, employing modelling to simulate changes and identify problems (Li et al., 2012). Then, the scope of its application gradually expanded and some scholars have used it to study strategies in electric power industry investment. The Malaysian government introduced a photovoltaic tariff policy to promote the development of photovoltaic power generation. Some scholars have simulated the local electricity market using system dynamics to calculate the investment funds and installed capacity of the future market and study the impact of policy implementation on the photovoltaic power generation industry (Ahmad et al., 2015). Some scholars have proposed an incentive mechanism for wind power investment and have established a model of system dynamics simulation to study the effect of different incentive mechanisms (Alishahi et al., 2012). Due to the instability of wind power, investors will be affected by risk when making decisions. In the Iranian electric power market, an investment incentive mechanism has been introduced to recover investment and operation costs. Some scholars have studied the distribution of power generation capacity in different regions through system dynamics theory, which provides some reference for decision-making departments (Hasani-Marzooni and Hosseini, 2013). The formulation of power grid investment decision making is the result of the influence of various environmental factors and thus it is suitable for the introduction of system dynamics.

The reform of electricity transmission and distribution tariffs requires that power grid enterprises control their income, so under the new revenue model they may have insufficient investment capacity. In the case of such limited capacity, investment optimization research is especially necessary. Grid system reliability is an important indicator of grid investment and construction. Some scholars have established system dynamics models, using the reliability index as a constraint to simulate the recovery of the system after its failure. Moreover, they use the prediction function of system dynamics modelling to support power grid investment decision making (Koziolek et al., 2016). Other scholars consider system dynamics a research method for constructing a dynamic feedback model for grid investment and investment efficiency indicators, undertaking investment decision making with investment benefit as a constraint (K.L. He et al., 2015; Y.X. He et al., 2015; Liu et al., 2015).

The above research on the investment optimization of power grid enterprises is not related to China's current transmission and distribution tariff policy, so this research is forward looking and innovative. Its innovativeness lies mainly in the following points:

(1) Considering the main contents of China's electric power market-oriented reform, the paper focuses on the impact of transmission and distribution tariff policy on the revenue pattern of power grid enterprises. The paper also analyses corporate cash flow, so as to study changes in business investment capacity.
(2) This paper conducts quantitative research on the factors affecting the power market reform and establishes a system dynamics model to undertake auxiliary research concerning the optimization of the power grid investment decision.
(3) This paper conducts an empirical analysis using the data of City A to provide policy advice and technical support for the market-oriented reform and grid investment decision making.

In this paper, Section 2 describes China's new round of market-oriented electricity reform trends. Section 3 describes the construction of the system dynamic investment optimization model. Section 4 carries out empirical analysis using the data of City A. Section 5 contains the sensitivity analysis of the system dynamics model. The final section presents the conclusions and policy implications.

2. The trend of electricity marketization reform

2.1. Main contents of electric power marketization reform in China

On 15 March 2015, the Chinese government issued “Some Opinions about the Further Deepening of the Reform of the Electric Power System” and put forward related opinions on deepening the reform of the power system, which officially opened a new round of electric power reform.

The goal of electric power marketization reform is to break two monopolies, namely the trade monopoly in the integration of power generation, transmission and distribution and the regional monopoly of “only one power company in each province”. Another goal of reform is to implement three separations: the first is to “introduce price bidding by separating the operations of power plants and power grids”; the second is to “separate secondary lines of business from the core business of power grids”; the third is to “introduce competition in the power supply market by separating the operations of transmission and distribution”. Thus, the aim is to form a number of independent power generation companies, transmission companies and distribution companies in China. Other ancillary industries and subsidiaries of power grid enterprises are to be reorganized with power generation enterprises or transferred to local governments. The ultimate goal is to establish a market system with fair competition and open, ordered and healthy development.

2.2. The verification and control method of the transmission and distribution tariff

At present, the transmission and distribution tariffs are formulated according to five voltage grades – 500 kV, 220 kV, 110 kV, 10 kV and less than 1 kV – under China's reform scheme. Power grid enterprises set independent transmission and distribution tariffs according to the assets, costs, transmission capacity and line loss rate of the different voltage levels in the power grid enterprise (NDRC of PRC, 2016). Thus, we estimate the following equation:

$$p_i = \frac{y_i}{q_i} \tag{1}$$

where p_i represents the transmission and distribution tariff at a certain voltage, y_i represents the total permitted revenue at a certain voltage and q_i represents the quantity of electrical transmission at a certain voltage.

Transmission and distribution tariff regulation includes total revenue regulation and tariff-level regulation. The assessment of total revenue is based on effective assets, which refers to the assets necessary for the transmission and distribution services provided by the power grid enterprises, excluding auxiliary businesses, which should be separate from power grid enterprises. The tariff level shall be determined on the basis of the reasonable costs of transmission and distribution for each voltage class.

2.3. Effect of transmission and distribution tariff reform on the revenue stream of power grid enterprises

Before the electric power reform, the income of power grid enterprises depended primarily on the income from sales of electricity, with a single structure of income cash flow. Due to the integration of power transmission, distribution and sales and strong industry monopoly characteristics, power grid enterprises faced a weak market risk.

Since the electric power reform, the income of power grid enterprises has been divided into two parts: income from the sale of power and income from transmission and distribution. Electricity users are