Research on pricing strategy of electricity transmission-distribution based on system dynamics

Liu Jianghua¹, Yalin Chen², Liu Jiaojiao², Dong Ziqi², Zhu Yao²

¹China National Nuclear Power Co. Ltd, 100045, Beijing, P.R. China;
²Nanjing University of Finance and Economics, 210023, Jiangsu, P.R. China

Corresponding author email: chen.yalin@163.com; Telephone: 025-87888085

Abstract: The electricity transmission-distribution is an important link of power system. Pricing transmission-distribution is the key part in the new round electricity market reform in China. The paper investigates the components of cost during transmission and distribution considering the different levels of voltage under government regulation, which forms original pricing model according to the reasonable profit pricing mode. Based on the above model, we apply System Dynamics to simulate the trend of the transmission-distribution price and capacity under the different scenarios classified by return on investment. The result of the simulation shows that the increasing ROI can raise the grid capacity investment, but it can't motivate power grid companies to reduce costs and improve management efficiency.

1. Introduction
In China, the new round reform of electricity market had been symbolled by 'Several opinions on further deepening the Reform of Power system' (shorted as No.9 Documentary) since 2015. The relative supporting documents have pointed out that the price of electricity transmission-distribution will be authorized separately according to "allowable cost and reasonable profits" and voltage levels. After four years of the new round reform, the pricing of transmission-distribution has been regarded as the key for the success of the reform. The optimal pricing system for checking and ratifying the transmission and distribution tariff independently, can promote power grid enterprises to reduce cost and raise efficiency. Littlechild (1983) took the lead in putting forward the price cap regulation method, relevant researches studied the composition and calculation method of transmission and distribution costs, then various pricing procedures under different electricity markets were presented.

Considering the complexity of power system, it is difficult to solve the corresponding pricing model under multiple uncertain factors. This article investigates the trend of transmission-distribution prices by a simulation experimental method. And then, we make some suggestions on the pricing system with the help of scenario simulation.

2. Model for power transmission and distribution pricing
Transmission-distribution costs can be classified into special service cost by function, common transmission service cost, the charge of the ancillary services purchased and transmission-distribution loss. The costs are also divided into controllable cost and non-controllable cost according to whether they are controllable or not. Generally, Operation and Maintenance fee is considered as controllable cost, while depreciation, wage and welfare are non-controllable cost.
At present, five regular pricing modes have been applied to authorize the price of transmission and distribution: (1) the investment rate of return (ROI) method; (2) price-cap method; (3) yardstick competition method; (4) A determination method based on the return on investment (ROI); (5) A regulation method based on price-cap.

On the grounds of reforming trend, authorized pricing will be designed based on the return rate of capital in the future. At each voltage level, through individual voltage class line and the fixed assets ratio of power transformation calculating the allowed revenues sharing, it permits a recovery of the electricity's cost.

\[ A = \sum_{i=1}^{k} (A_i^l + A_i^t) \]  

(1)

Where, \( A \) is the original value of fixed assets; then, by the mean of the following formulae to acquire the cost allocation of each voltage class line and substation part:

\[ \beta_l^i = \frac{A_l^i}{A} \times 100\% \]  

(2)

\[ \beta_t^i = \frac{A_t^i}{A} \times 100\% \]  

(3)

Allowable benefits are allocated among different voltage levels:

\[ C_{i,t} = I \times \beta_t^i \]  

(4)

\[ C_{i,t} = I \times \beta_t^i \]  

(5)

When calculate the total cost of each voltage level, assuming that the highest voltage grade 500KV is '6', and the total cost is represented by \( TC_6 \):

\[
\begin{align*}
TC_6 &= C_6 \times \frac{D_6}{D_{6,\text{total}}} \\
D_{6,\text{total}} &= D_6 + \Sigma S_6
\end{align*}
\]  

(6)

Where, \( D \) and \( S \) mean electricity loads which share among the total expenses below 500KV:

\[
\begin{align*}
TC_i &= C_i \times \frac{D_i}{D_{i,\text{total}}} \\
C_i &= C_{i,t} + C_{i,l} + C_{i,o}, i < 6 \\
C_{i,o} &= \sum_{j=i+1}^{i+n} \left( C_i \times \frac{S_{ji}}{D_{j,\text{total}}} \right) \\
D_{j,\text{total}} &= D_j + \Sigma S_j
\end{align*}
\]  

(7)

\( C_{i,o} \) is cost-sharing for the \( i \)-level voltage; \( S_{ji} \) marks the power supply load from \( j \)-level to \( i \)-level voltage. The T&D price obtained eventually by two-part electricity prices:

\[ P^d_i = \begin{cases} 
(TC_i \times \alpha)/(D_i \times 12), D_i > 0 \\
0 
\end{cases} \]  

(8)

\[ P^q_i = \begin{cases} 
([TC_i \times (1 - \alpha)]/Q_i, Q_i > 0 \\
0 
\end{cases} \]  

(9)

Where, \( P^d_i \) is the capacity price of the \( i \)-level voltage; \( P^q_i \) is the electricity price of the \( i \)-level voltage; \( \alpha \) is the proportion of capacity power cost-sharing. The pricing evolving trend will be simulated under the uncertain load.

3. Power transmission and distribution pricing-power capacity simulation based on system dynamics (SD)

3.1. flow chart of system simulation
System dynamics (SD), created at MIT in the 1950s by Jay Forrester, is designed to help us learn about the structure and dynamics of the complex systems in which we are embedded, design high-leverage policies for sustained improvement, and facilitate successful implementation and change. Drawing on engineering control theory and the modern theory of nonlinear dynamical systems, SD often involves the development of formal models and management flight simulators to capture complex dynamics, and to create an environment for learning and policy design. In recent years a number of researches have attempted to present a broad unified view of system dynamics by discussing electrical, mechanical, hydraulic, and thermal components and graph theoretic procedures for describing their interconnection.

According to the analysis in last section, price of T&D is decided jointly by power load, allowable benefit, allowable cost and tax. Crucial to the efficient assets and O&M (operation and maintenance) cost are power capacity and line length, which are on the decisive role of allowable benefit and allowable cost. Particularly, there are uncertainties in power load, power capacity, line length, tax, allowable benefit, allowable cost and others. If so, the enthusiasm of T&D enterprises to invest in power grid will be interrupted, which could lead to power capacity effects. The interactive, closed-loop graph is shown as figure 1:

![Figure 1. Flow chart of transmission and distribution pricing-power capacity based on SD](image)

3.2. parameter setting and model checking

The power capacity is selected as the state variable, its speed of construction as the rate variable, the allowable cost, allowable income, taxes as the auxiliary variables, the tax rate, depreciation rate and return rate on investment as constants. Wherein, initial linear parameter values are ascertained taking load and line data of 2012-2013 as the reference; depreciation rate 4%, comprehensive tax rate according to VAT 17%, urban maintenance rate 7%, education surcharge 3%, unit capacity cost and unit line cost are converted to 300,000 yuan/megavolt-ampere and 900,000 yuan/km respectively. After the model test and unit test of system dynamics, the deviation between the predicted value and the real value is less than 7%, the simulation model has passed the authenticity test, based on which scenario simulation can be carried out.

3.3. analysis and result of simulation

Taking a certain region as the case study, transmission and distribution lines of 110KV and 220KV, simulation time 2012-2022. Suppose the load has been increasing annually. Two scenarios have been simulated under the ROI set by 5% and 8% respectively. The trends of grid capacity are shown as following:
From figure 2, the gradual growth trends of grid capacity are approximately same under ROI are 5% and 8% respectively; While the ROI is adjusted from 5% to 8%, the investment construction of power capacity will be stimulated. The corresponding simulation results for other variables are shown as the following figures:

Figure 3 shows that a smaller growth in T&D price, tax and allowable cost, but a great growth in reasonable profit while the ROI has been increased from 5% to 8%. The growth of ROI cannot motivate power grid enterprises to improve internal cost control, but can increase revenue.

4. Conclusion
Pricing of transmission and distribution is the difficult part in new phase of electricity market reform. This paper investigates the components of transmission and distribution cost, and establishes a model under ROI method with various voltage levels; then applies System Dynamics to simulate trends of the grid capacity and price of T&D under various ROI. The simulation results indicate that ROI pricing motivates to increased investment in developing power system, yet it could be unfavourable to keeping costs or helping improve the efficiency of grid companies. Our work provides a reference for regulators to choose the pricing methods of power transmission and distribution. In the subsequent research, other methods will be analysed and compared.

Acknowledgement
This study was supported by the Humanities and Social Sciences Fund of the Ministry of Education ‘The coal-based industrial policy under water resources constraints: mechanism, modeling and simulation’ (No. 18YJCZH016).
References
[1] General Office of the Central Committee of the Communist Party of China. Available at: http://news.ncepu.edu.cn/xxyd/lxzx/52826.htm. Accessed May 31, 2015
[2] National Development and Reform Commission, National Energy Bureau: http://www.nea.gov.cn/2015-11/30/c_134867851.htm. Accessed Dec. 26, 2015
[3] Wang Dongfa, Lanfei, Jin Shaojun 2019. Cost management problems and Countermeasures of power grid enterprises under the background of transmission and distribution price reform J. Business Accounting, (08) pp 79
[4] Wang, Y., Wang, G., Zuo, Y., Fan, L., & Wei, J. 2017. Comprehensive evaluation of power grid enterprises’ credit rating under the reform of transmission and distribution price J. Advances in Materials, Machinery, Electronics (2017)
[5] Liu, S., Ye, Z., Fan, X., Yao, J., & Wu, Y. 2017. Influence of pricing parameters on transmission and distribution price and its regulation model J. Automation of Electric Power Systems, (24)
[6] Li, C. R., Wang, Y. J., He, H. Y., & He, Y. X. 2010. Research on conduction mechanism of cross-regional and cross-provincial transmission price C. China International Conference on Electricity Distribution (2010)
[7] Tang Yuezhong 2004. Transmission pricing and supervision under the condition stoic market J. Power System Automation. (13)
[8] Zhao Willu, Liu Wei, Li Chunjie 2005. Determination of the level of return on investment in power transmission and distribution price control J. Grid Technology. (21)
[9] Tang Xiaohua, Tang Key 2002. Incomplete information and incentive regulation reform of the network industry system J. Engineering Theory and Practice (7)
[10] LIUSiqiang, Ze, Y. E., Fan, X., Yao, J., Yongfei 2017. Influence of pricing parameters on transmission and distribution price and its regulation model J. Automation of Electric Power Systems, (24)
[11] Zhao Huiru,Ji Jianxun,Zeng Ming,etc 2003.Study on the price control model of transmission and distribution J. China Motor Engineering News (10)
[12] Promise, Yan Hanrong, Wen Fulian, A.K. David 2003. Performance-based control model and its applications J. Power system automation
[13] Dadkhah, A., Vahidi, B 2018. On the network economic, technical and reliability characteristics improvement through demand-response implementation considering consumers’ behaviour J. Iet Generation Transmission & Distribution (2)
[14] Huang Jianbai, Huang Xiangyu, Yu Yu, etc 2006.The establishment of the peak and valley price model and the simulation model based on system dynamics J. Power system automation.
[15] Wang Wei, Zhang Particle, etc 2008. A study of simulation models for macro-layer grid planning based on system dynamics J. China Motor Engineering News
[16] Yongwei, Q. I., Chunhui, Y., Yingcai, Z., Wenyu, L. I., & Caixia, F. 2017. Research on investment allocation model and investment capability measurement model adapting to reform of transmission and distribution price J. Power & Energy (6)
[17] Zeng, M., Quan, S., Tian, K., & Li, N. 2008. Performance-Based Regulation Transition Model of Electricity Transmission and Distribution Price in China C. International Conference on Risk Management & Engineering Management (2018)
[18] Hung-pochao 2006.The critical need for integrated market design and risk management research J. Energy (6)
[19] Karnopp, D. C., Margolis, D. L., & Rosenberg, R. C. 2007. System dynamics: a unified approach J. IEEE Transactions on Systems Man & Cybernetics (10)
[20] Sterman, J. D. 2002. Business dynamics: systems thinking and modeling for a complex world J. Journal of the Operational Research Society, (4), pp472