System Dynamic Modelling of Comprehensive Carrying Capacity for Power Grid Development Planning

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Abstract. In the face of the changing demand of economic and social development and the policy of power system reform, the carrying capacity of power grid development should be calculated to guide the future planning. Based on the causality of the factors in China’s Power Grid Planning, a System dynamics model is constructed to quantitatively carry the capacity of power grid development dynamically. A series of indicators were also considered in the model, including the power transmission and distribution pricing policy, power load demand, power grid operation benefit and cost, etc. An example of a regional power grid in China is given to verify the validity and feasibility of the proposed model.

Keywords: System Dynamic Model, Carrying Capacity, Electric Grid Development Planning, Electric Consumption.

1. Introduction
China’s economic development has entered a new normal stage. The growth rate has changed from high speed to medium high speed, and the development mode has changed from scale-speed type to quality-efficiency type. The economic structural adjustment has changed from increasing capacity mainly to adjusting stock and optimizing and increasing. The impetus of development has shifted from relying mainly on the input of factors to being driven by innovation. In the meantime, the growth rate of electricity consumption slows down, the overall supply and demand of electricity is loose, the local supply is surplus, and the electricity demand market has entered a 'new normal' stage.

The reform of electric power system has been deepened and the market competition pattern has gradually taken shape. The distribution business has been gradually liberalized, and the market entities have been continuously diversified. The transmission and distribution price has been approved according to the method of “permitted cost plus reasonable income”, which breaks the company’s traditional profit model. Investments that cannot be considered effective assets will be tightly controlled. In order to meet the challenge of the new normal of economic development and energy consumption, and power market reform to power grid development, the carrying capacity of electric grid development should be quantified to avoid excessive and inefficient Investment.

There are some researchers on carrying capacity and development potential for electric grid. Chakraborty et al [1] carries out a study of vehicle-to-grid operation of rechargeable electric vehicles to describe the characteristics of the effective carrying capacity provided by these vehicles. Then they [2]...
proposed an efficient and practical algorithm for optimizing the V2G operations. Leveraged the framework and actual hourly load data from New York City to calculate the effective load carrying capacity (ELCC) contributed by PEVs. Brown[3] proposed a method for determining carrying capacity for economic investments based on an emergy evaluation of the environmental resources of a region. He used Emergy as a unit of resource use and work potential to quantitatively evaluate intensity of development. ZHANG et al [4] believed that the fundamental way to solve the problem of renewable energy was to scientifically plan renewable energy based on the carrying capacity of the power system. Two key indexes, namely the capacity coefficient of renewable energy and the capacity coefficient of renewable energy, were proposed to reflect the actual carrying capacity of renewable energy in power system. Cochran et al.[5] cleared the challenges to integrating increasing amounts of variable renewable energy, summarized emerging practices in power system planning and operation that can facilitate electric power grid integration, and proposes the concept of economic carrying capacity, which can provide a framework to assessing actions to adapt to higher penetration rates of renewable energy.

The above literatures have measured the carrying capacity from different angles and proposed the importance of measuring carrying capacity for the sustainable development of electric vehicles and energy and electric power. These research results only considered the security status and technical needs of the system operation in the calculation of carrying capacity. However, the development planning of electric power electric grid is a complicated decision-making process that is influenced by policies, economic and social development, and market demand. There be some dynamic uncertainties to impact on the decision-making process.

Therefore, this study analyzed the influence of power market demand and power system reform policy on the power grid system operation and constructed the carrying capacity model of power grid development planning. System dynamics (SD), developed by Professor Jay W. Forrester in the late 1950s, is based on the cybernetics and servo-mechanisms and introduced to simulated the impact of power market demand and power system reform policy on the electric power grid development under different decision scenarios and calculate the carrying capacity of power grid development.

2. System dynamics approach

System dynamics approach is defined by a series of the causal relation and the concept of feedback. The decision behavior can be showed by logic, mathematical language, and models. According to this theory, the initial information system can be obtained through practical observation, the information of the system can be improved by reasonable path optimization. The intervention of computer technology can help analysts predict the future behavior of the system. Therefore, System dynamics theory is mainly used to analyze the problems of large complex systems involving multiple factors and feedback relations[6]. Behavior in a system can be thought of as fluid motion, and the structure of the system can be described in the form of causality and flow diagrams. The concepts of subsystem, system variable and feedback loop must be defined before causality and system flow diagram are constructed.

According to System dynamics theory, the behavior of continuous system dynamic change contains the structure of internal causality, so causality diagram is often used to describe the causal relationship among the variables. There are usually positive and negative causal relationships in the system, which are expressed by causal loop. If the increase or decrease of a variable in the system leads to the increase or decrease of the corresponding variable, the causality will be a positive causal loop. If an increase or decrease in a variable in the system causes a decrease or increase in the corresponding variable, the cause-and-effect relationship is a negative causal loop, as shown in figure 1.

![Positive causal loop and negative causal loop diagrams](image-url)
Based on causal loop, a flow chart method which can reflect the feedback relationship between system variables and the behavior control law is proposed. A variety of simple symbols and arrows can be used to reflect causal logic relationships between variables of different properties in a system. The variable types included in the flow charts are state variable, rate variable, auxiliary variable and constant.

3. Modeling for carrying capacity of electric grid Planning

3.1. Overall model structure

The study was according to China’s State Grid considerations of the overall situation of the power system operation, the economic and social development, the market demand and the power system reform policy. In order to define the model boundaries of the carrying capacity. These variables including power generation resources distribution and power supply and demand balance were taken as external factors and remained relatively constant in the system simulation phase. Based on the characteristic of the power system operation, the system dynamics model can be divided to the grid demand subsystem and the grid operation subsystem.

3.2. The power grid demand subsystem

In the grid demand subsystem, some indicators were considered to reflect the power grid planning and development needs. The indicators can impact on the affect the grid structure of the grid size, capacity, and power supply reliability, including the power consumption and peak load demand of the whole society and the electricity price, electricity purchase cost, the transmission and distribution cost and total operating profit. The subsystem. The main variables in the subsystem is shown in the table 1.

| Indicator                        | type             | Indicator                          | type             |
|----------------------------------|------------------|------------------------------------|------------------|
| Market trading load              | Instrumental variables | Power consumption of secondary industry | Instrumental variables |
| Power consumption of tertiary industry | Instrumental variables | Electricity sales revenue of primary industry | Instrumental variables |
| Residential electricity consumption | Instrumental variables | Residential electricity price | Instrumental variables |
| General industrial and commercial electricity price | Instrumental variables | Guaranteed total load of power supply | Instrumental variables |
| Revenue from transmission and distribution services | Instrumental variables | Changes in other operating income | Rate variable |
| Total grid assets                | State variables  | Changes in operating costs         | Rate variable   |
| Other costs                      | State variables  | Changes in other costs             | Rate variable   |
| Other operating income           | State variables  | Retained profits                   | Rate variable   |
| Operating costs                  | State variables  | Decrease in assets                 | Rate variable   |

Figure 1 showed the flow diagram of causality relationships between variables. The equations for the main variables in the power demand subsystem are as follows.

1) Guaranteed total load of power supply= Residential electricity consumption+ Electricity consumption of primary industry + Non market trading load

2) Revenue from guaranteed power supply= Electricity sales income of residents+ Electricity sales revenue of primary industry+ Electricity sales revenue of secondary and tertiary industries

3) Market trading load= Power consumption of tertiary industry × 0.1 + Power consumption of secondary industry × 0.4

4) Non market trading load= Power consumption of tertiary industry × 0.9 + Power consumption of secondary industry × 0.6
(5) Net income from guaranteed power supply = Revenue from guaranteed power supply - Guaranteed power transmission and distribution cost - Electricity purchase cost

Figure 2. The flow of power grid demand subsystem

3.3. The power grid operation subsystem

Based on the principle of electricity transmission and distribution, the grid operation subsystem was conducted. Some indicators about the power grid operation and carrying capacity were considered into the subsystem, including transmission distribution price, new depreciation, permitted rate of return, permitted net benefits and so on. The main variables in the grid operation subsystem is shown in the Table 2.

Table 2. Main variables of power grid operation subsystem

| Indicator                                      | type               | Indicator                                      | type               |
|-----------------------------------------------|--------------------|-----------------------------------------------|--------------------|
| transmission distribution price                | Instrumental variables | New operation and maintenance cost             | Instrumental variables |
| comprehensive carrying capacity               | Instrumental variables | New depreciation                              | Instrumental variables |
| New effective assets with accrual income       | Instrumental variables | permitted return                               | Instrumental variables |
| income tax                                     | Instrumental variables | Total effective assets with income              | State variables     |
| Changes in effective assets                   | Rate variable       | Permitted cost                                 | State variables     |
| Permitted cost changes                        | Rate variable       |                                              |                    |

Figure 2 showed the flow diagram of causality relationships between variables in the power grid operation subsystem. The equations for the main variables in the power operation subsystem are as follows.

1) Transmission distribution price = Permitted net benefits/Electricity consumption of the whole society + price adjustment

2) New effective assets with accrual income = comprehensive carrying capacity × Conversion rate

3) Comprehensive carrying capacity = Proportion of investment × Total grid assets

4) Permitted net benefits = permitted return - permitted cost + Tax within price
4. Results and simulation

China updated its pricing policy for electricity transmission and distribution in 2020. At the same time, the growth rate of economic development is slowing down, and the adjustment of industrial structure also affects the carrying capacity of power grid development. Based on the latest policy and economic and social development environment, this paper selects a regional power grid in China as a case for simulation analysis. VENSIM Version 6.1 software is used to simulate the carrying capacity of power grid development in the region in the next five cycles.

In the simulation, the initial value of power grid assets is 3.8 million yuan. The value of electricity consumption of primary industry, secondary industry, tertiary industry and residents adopts table functions. The output results of the model are shown in the following figures.

![Image of the flow of power grid operation subsystem](image-url)

**Figure 3.** The flow of power grid operation subsystem

![Graph of Transmission Distribution Price](image-url)

**Figure 4.** Simulation of Transmission Distribution Price

The simulation results of transmission and distribution price (Figure 3) show that under the stable load increase and the policy of transmission and distribution price, the price will increase in the next five cycles. The transmission and distribution price in the first cycle is 1837 Yuan/10,000 kWh, and in the fifth cycle is 3257 Yuan/10,000 kWh.
The simulation results of total operating profit (Figure 4) show that under the stable load increase and the policy of transmission and distribution price, the total operating profit will increase in the next five cycles. This profit will significantly affect the carrying capacity of power grid development and the sustainable development of power grid system. The total operating profit for the power grid development in the first cycle is 3.63 million yuan, and in the fifth cycle is 4.39 million yuan.

The simulation results of comprehensive carrying capacity (Figure 5) show that under the stable load increase and the policy, the comprehensive carrying capacity will increase in the next five cycles. The comprehensive carrying capacity for the power grid development in the first cycle is 2.8 million yuan, and in the fifth cycle is 10.1 million yuan.

5. Conclusion
The study proposed a load carrying capacity simulation model of power grid development based on the System dynamics model. A series of factors, such as power load, power supply and transmission capacity, grid structure, power grid operation benefit and cost, are included in the model. Based on China’s current policy environment and economic development level, an example is given to illustrate the validity and practicability of the model. The carrying capacity of the regional power grid development was calculated.

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