Framework for exploratory modeling of power system evolution

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Abstract: One of the challenges power system evolution research facing is deep uncertainties, which could not be described by Knightian uncertainty. This paper reviews three types of research methods involving power system evolutionary research, one is power system planning modeling, the other is complex network theory, and the third is exploratory modeling, of which exploratory modeling could handle with deep uncertainties. This paper combines the first and the third method, and proposes an exploratory modeling framework of power system evolution, which embeds the power planning model as the core to reflect the operating characteristics of the power system in the framework.

1. Review on power system evolution research methods
Carrying out evolutionary research on the power system can not only provide advance judgment for power system strategic planning, but also provide auxiliary decision-making for power system operation strategies, which has important theoretical and practical value. At present, the power system is undergoing unprecedented changes. First, external driving factors such as fossil energy depletion and climate change, replacing internal driving factors such as technological innovation, have become the main driving force for this round of energy and power transformation. The resulting system changes are often abrupt, not a continuous gradual change pattern[1][2]. The second is the challenge from deep uncertainty[3], including multiple values such as differences in the attitude of the governors on climate change, technological advances in power systems, and morphological changes that can not be described by Knightian uncertainty, as well as the uncertainty of scenarios / decision consequences / decision plans. All these uncertainties make the risk-based analysis method difficult to apply because the underlying premise is not satisfied in a deeply uncertain environment. Therefore, the study of the evolution of power systems needs to fully consider these situations.

Roughly speaking, there are currently three types of research methods involving evolutionary research, one is power system planning modeling, the other is complex network theory, and the third is exploratory modeling.

The essence of the power system planning model is to solve a class of optimization problems with constraints, and to seek the most economical or multi-objective planning solution that takes into account economics and reliability. Since 1993, the IEA (International Energy Agency) has provided medium to long-term energy projections using the World Energy Model (WEM) – in which power generation and heat plant module chooses power generation technology with least long-run marginal cost [4]. The Regional Energy Deployment System (ReEDS) is NREL(National Renewable Energy
Laboratory’s flagship capacity planning model for the North American electricity system, which relies on system-wide least cost optimization to estimate the type and location of future generation and transmission capacity [5]. There are still shortcomings in discovering the evolution mechanism of the power system and coping with unpredictability in the future.

The method of power grid evolution based on complex network theory regards the power grid as a living body, and uses the ideas of evolution of biological body to simulate the mechanism of expansion of power generation and power grid [6]. This method has studied the evolution rules of power grids in accordance with models such as small-world networks, scale-free networks, regular networks, random networks, and local world evolution models, and revealed the evolution characteristics of three generations of power grids in China [7]. These attempts were carried out under the premise that the power grid belongs to an ideal network model. When faced with large-scale proportion of renewable energy and energy storage, it still needs to embed optimization models in order to meet the operating constraints of power system such as power balance and peak shaving [8]. In addition, the rules formulated by the method for the evolution of the power grid are relatively fixed and cannot take into account the deep uncertainty of the power system evolution.

Exploratory modeling is the use of massive computer experiments to study various parametric, structural, and methodological uncertainties[9]. Based on the massive scenarios generated after exploratory modeling, using scenario discovery techniques, it is possible to explore different evolution paths of energy and power systems under deep uncertainty, and thus determine favorable conditions to meet future goals to assist policy decisions [10]. This method of exploratory modeling incorporating scenario discovery technology, also known as robust decision making in the field of decision making, is used to weigh the vulnerabilities and sensitivities of alternatives in detail. The World Bank research report [11] points out that robust decision analysis is one of the four major types of investment decision analysis methods facing deep uncertain systems.

At present, researches on power system evolution using exploratory modeling methods, are mostly based on system dynamics models and do not consider power system characteristics. Based on a total of 10 models that couple energy technology and economic and social studies, the article [12] uses exploratory modeling to study the impact of significant growth in natural gas and oil production on primary energy structure, energy prices, and global political stability in 4 regions. The article [13] examines the evolutionary paths of two types of measures: green water management and traditional pipeline drainage, and finds that many evolutionary paths can be clustered according to typical paths. The impact of subsidy policies on the production of biomethane in the Netherlands under mutually exclusive targets and parameter uncertainties is analyzed [14]. Based on the system dynamics model, Ref. [15] uses a combination of qualitative description and exploratory modeling to explore the transformation of the Indian power system. It considers the dual dominant model of government / marketization, the triple development goals of security / fairness / sustainability, and uncertainties in new energy technology advancements, energy policies, as well as population growth.

2. Steps for exploratory modeling of power system evolution
On the premise of the government and the public’s active choice of the direction of transition, the literature [15] proposed a 4-step exploratory modeling framework for the study of power system transition. Based on this framework, this paper embeds the power planning model as the core to reflect the operating characteristics of the power system. This is because when the power system has a large proportion of renewable energy and large-scale energy storage development, the short-time scale system operation characteristics such as power balance and peak shaving will directly affect the long-term power system development.

The first step is to review the development history of the power system, and to clarify the possible structural form of the future power system in combination with the goals of the modern energy system construction.

The second step is to propose a power system planning model adapted to the corresponding structural form based on the future structural form of the power system.
The third step is to target selected sources of uncertainty and range of uncertainty for the depth to be observed.

The fourth step is to generate massive scenarios based on the evolution models adapted to the structural morphologies of different power systems, using computer experiments.

The fifth step is to analyze the massive scenarios generated by the data mining-based scenario discovery technology to identify the key elements of evolution, time sequences and types of evolution, and the combination of their deep uncertainties.

Figure 1. Steps for exploratory modeling of power system evolution

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