Multi-scenario generation technology considering extreme scenarios in energy system modeling

Zhicheng Xu1*, Gang Lu1, Jiujin Zhao2
1State Grid Energy Research Institute CO., Ltd., Beijing, 102209, China
2State Grid Corporation of China, Beijing, 100031, China
Corresponding author’s e-mail: xu-zhicheng2008@163.com

Abstract. In energy system planning and modeling, due to the increase in the proportion of renewable energy, its volatility and randomness require that the energy planning model be more detailed. Generally, typical scenarios are used to simulate changes in annual timing characteristics, so the generation of typical scenarios is particularly important. The characterization of the scenario requires that the generated scenario is representative and complete at the same time, and completeness requires the extreme scenarios should be considered. Extreme scenario-based energy system stress tests not only help policymakers consider previously overlooked stress or stress sources but also assess the potential extent of their impact and the affordability of these risks to energy systems, while also giving effective coping strategies.

1. Introduction
At the beginning of 2020, the world entered a "state of emergency", China's COVID-19 outbreak [1], Australia fire, African locust plague, Japan earthquake, the United Kingdom superstorm, a variety of major disasters cause significant losses that are difficult to estimate. Sudden major disasters alert and motivate us to think about how to improve the ability to cope with major disasters under complex factors in the field of energy and power, so as to do well in advance to ensure safe and reliable operation of energy and power and prevent damage to national security and social stability [2-5]. In conventional energy and power system planning, the so-called optimal planning scheme is usually obtained by the method of optimal planning. At this time, the planning scheme is more suitable for system operation in typical scenarios. Once a crisis scenario occurs, the planning scheme is often difficult to deal with possible problems. In order to effectively deal with the impact of extreme scenarios on the energy system [6-11], it is necessary to include the description of extreme scenarios into the planning stage and analyze the impact of extreme scenarios on the planning and operation of the energy system. Based on the “scenario-based thinking” of energy and power, this paper combs out the extreme scenarios that energy security may face, refines the deduction and response methods of extreme scenarios and also puts forward the corresponding enlightenment.

2. Definition of extreme scenarios and their characteristics

2.1. Definition of extreme scenarios
In energy power planning and operation simulation, "typical scenarios" are usually used instead of "full scenarios" to describe the actual planning and operation of the energy system, which proves to be
effective in most application scenarios. However, energy system today is always facing major natural disasters, cyber-attacks, geopolitical risks and even local warfare and other major force majeure factors, once any of these extreme scenarios occurs, it will bring serious social and economic losses. Therefore, in addition to the description of the "typical scenario" based on predictions, the impact of the "extreme scenario" on energy and electricity system should also be given high priority. Extreme scenarios are mainly influenced by internal factors (e.g. hardware and software destruction), external factors (meteorological geological disasters, wars, etc.), and other related factors (mainly chain reactions from other industries). A complete scenario is made up of “typical scenarios” and “extreme scenarios”, as shown below.

2.2. Characteristics of the extreme scenarios

Extreme scenarios usually have the following three characteristics:

(1) **Small probability and big impact.** Extreme scenarios are "small probability events" compared to typical scenarios, and are generally considered "impossible to occur", but the damage caused by multiple extreme scenario overlay resonances is often difficult to estimate.

(2) **Unpredictability.** The occurrence of extreme scenarios is generally difficult to predict, and some scenarios are difficult to imagine in advance or obtained through simulation such as the major disasters facing the world by 2020.

(3) **Mutations and chain reaction.** Extreme scenarios often take the form of leaping mutations rather than incremental changes that are difficult to respond to and respond promptly.

3. The practical significance of studying extreme scenarios

The study of extreme scenarios can expand the field space of the scenarios. The essence of the scenario description is a classification, but also a kind of clustering. It brings together similar categories of scenarios into one category, and scenarios with large differences are depicted in different scenarios as much as possible. Therefore, scenario depiction needs to be typical and representative, but also should have a certain degree of completeness. Only by combining "typical scenarios" and "extreme scenarios" and constantly expanding the boundaries of the scenario domain space can make the simulated scenario more abundant, and the scenario set can be continuously complete. Only after identifying the "mini-scenario" and the "super-scenario" can the energy system be described in different crisis environments, and the appropriate response strategy is selected accordingly. When we get the "mini-scenario" and "super-scenario", we can choose the appropriate response strategy accordingly.
Figure 2. "Mini-scenario" and "super-scenario" for the energy extreme scenarios analysis

Simulation of extreme scenarios is an indispensable stress test for energy systems. Based on the “scenario-based thinking” of energy and power, this paper combs out the extreme scenarios that energy security may face, refines the deduction and response methods of extreme scenarios and also puts forward the corresponding enlightenment.

4. General steps for extreme scenarios analysis

Through the above analysis, the general ideas and steps of extreme scenarios analysis can be drawn:

**Step 1:** Assume the possible extreme scenarios and identify the "mini-scenario" and "super-scenario". The search for extreme scenarios can be described according to different levels of influence factors such as war, network attacks, destruction of energy transmission channels and so on.

**Step 2:** Build a simulation model to quantify the degree of risk impact of extreme scenarios on the energy system. Extreme scenarios depictions need to take into account different time scales and spatial scales. The time scale is divided into planning level and operational level. The planning level refers to the extreme scenarios on the large time scale, such as the five-year plan of the national economy, etc., and the operational level refers to the extreme scenario depiction on the small time scale, such as the total solar eclipse in Germany and the "Stuxnet" in Iran, etc. The space scale can be divided into domestic and international levels. The domestic level can be subdivided into community-level, provincial, regional, national, and other. The international level refers to geopolitics, international oil and gas pipeline planning, and its safety and other extreme scenarios.

**Step 3:** Observe the evolution of the system in a given extreme scenario and its impact. The impact of different system parameters on the system in an extreme scenario is observed, and the performance indicators of the system are also evaluated. And constantly change the corresponding parameters, find out the inflection points (using the system to not heal and normal recovery as the reference scenario) to form the system parameter threshold corresponding to each extreme scenario.
5. Conclusions

(1) **Giving a high position for the energy extreme scenarios management.**

Energy authorities and strategy development and planning researchers should attach great importance to stress testing of energy systems based on extreme scenarios simulation. The extreme scenarios simulation should be considered as an important part of energy system risk management and should be integrated into energy and power system planning and strategy formulation. We should also establish a crisis-response team, make appropriate talent reserves, and form a decision-making team (such as implementation, strategy, or investment committee) to make the risk assessment long-term and institutionalized.

(2) **Make the extreme scenario as complete as possible.**

Since extreme scenarios are usually "unexpected", cross-industry cooperation is required. Researchers should not stick to reality and give full play to their imagination, assuming different internal and external risk sources, different severity, a variety of small probability event overlay, and other scenarios, considering the technical, financial, legal, geopolitical and other risks on the impact of energy systems. Forming an extreme set of scenarios under the combination of far and near, macro- micro, rigid, and flexible.

(3) **Build a fully functional simulation platform.**

A simulation platform for energy systems that can consider extreme scenarios should be developed, and the dynamic deduction of energy systems can be performed visually, simulating the changes and effects of energy systems after the overlay of a single extreme scenario or multiple extreme scenarios. Due to the complex diversity of extreme scenarios, it is possible to consider combining new technologies such as energy and power technology such as energy big data, artificial intelligence, blockchain and other technologies to realize the simulation, deduction and self-learning process of large-scale scenarios, and to find out the extreme scenario set by the simulation of mass scenarios and the sensitivity analysis of parameters.

(4) **Prepare effective coping strategies through the analysis of extreme scenarios.**

The study of extreme scenes is not an end but a means. The study of the extreme scene is to give their corresponding coping strategies. When the actual situation occurs, it can be identified and matched with the existing extreme scene set, and quickly find a response method from the strategy set to improve the risk response speed and response capacity.
Acknowledgments
This work was supported by the Science and Technology Project of State Grid Corporation of China: Research on Key Technology and Application for Evaluation and Deduction of New Generation energy development strategy (1300-201957272A-0-0-00).

References
[1] Mehta P, McAuley D F, Brown M, et al. COVID-19: consider cytokine storm syndromes and immunosuppression[J]. The Lancet, 2020, 395(10229): 1033-1034.
[2] Reza S E, Nitol T A, Abd-Al-Fattah I. Present scenario of renewable energy in Bangladesh and a proposed hybrid system to minimize power crisis in remote areas[J]. International Journal of Renewable Energy Research (IJRER), 2012, 2(2): 280-288.
[3] Shrestha R M, Malla S, Liyanage M H. Scenario-based analyses of energy system development and its environmental implications in Thailand[J]. Energy Policy, 2007, 35(6): 3179-3193.
[4] Eid A, Dardeer M, Caldon R. Control and performance of micro-grids under extreme gust wind scenarios[C]// IEEE International Conference on Harmonics & Quality of Power. IEEE, 2014.
[5] Pernigotto G, Prada A, Gasparella A. Development of Extreme Reference Years for Building Energy Simulation Scenarios[J]. Applied Mechanics and Materials, 2019, 887:129-139.
[6] Pryor S C, Barthelmie R J, Clausen N E, et al. Analyses of possible changes in intense and extreme wind speeds over northern Europe under climate change scenarios[J]. climate dynamics, 2012, 38(1-2):189-208.
[7] Berglund C, Söderholm P. Modeling technical change in energy system analysis: analyzing the introduction of learning-by-doing in bottom-up energy models[J]. Energy Policy, 2006, 34(12): 1344-1356.
[8] Davari B, Williams S T, Pecht P A, et al. Energy system modeling apparatus and methods: U.S. Patent 7,974,826[P]. 2011-7-5.
[9] Ghanadan R, Koomey J G. Using energy scenarios to explore alternative energy pathways in California[J]. Energy Policy, 2005, 33(9):1117-1142.
[10] Falcone P M, Lopolito A, Sica E. Policy mixes towards sustainability transition in the Italian biofuel sector: Dealing with alternative crisis scenarios[J]. Energy research & social science, 2017, 33: 105-114.
[11] Turner K H. Nuclear power for the future: Implications of some crisis scenarios[J]. Transactions of the American Nuclear Society, 1996, 74: 266.