Analysis of Unbalanced and Inadequate Development of Power Grids

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Abstract. The principal contradiction facing Chinese society has evolved. What we now face is the contradiction between unbalanced and inadequate development and the people’s ever-growing needs for a better life. As power grids play a significant role in energy resource distribution and utilization, the quality of power grid development is the foundation of healthy social and economic development of China. This paper analyses the unbalanced and inadequate development of power grids. Firstly, current situation and problems of power grid development are analysed. Secondly, an evaluation system of unbalanced and inadequate development of power grids is built to quantitatively assess the development of power grids. The unbalanced development index system is composed of secondary indicators of unbalanced urban and rural grid development, unbalanced regional grid development and unbalanced load development. The inadequate development index system is divided into scale indicators, quality indicators, automation indicators and management indicators. Each secondary indicator is then further detailed into tertiary indicators. Then, a case study of provincial power grid is applied to prove the effectiveness of the proposed index system. Study results highlight some problems, for example, unbalanced transmission and distribution grid development, unbalanced urban and rural grid development, unbalanced regional grid development, inadequate distribution grid development, inadequate automatization etc. Lastly, future improvements and measures are pointed out.

1. Introduction

At present, the principal contradiction facing Chinese society has transformed into the contradiction between the people’s ever-growing needs for a better life and the unbalanced and inadequate development. China has entered the coexistence era of structural excess and structural insufficiency from the past shortage era. In the field of energy, the principal contradiction of energy development has changed from satisfying the basic supply to a contradiction between the people’s ever-growing energy needs for a better life and the unbalanced and inadequate development of energy resources. The new expectation of increasing energy use puts forward new requirements for the scientific construction of power grids and building a clean, low carbon, safe and efficient energy system. It is necessary to continuously increase the input of power grids, strive to improve the overall efficiency of power grids, eliminate the contradiction of the unbalanced and inadequate development of power grids, give better play to power grids as the basic platform in the allocation and conversion of energy resources, and help local economic and social development. Therefore, this paper firstly summarizes the evaluation index system of power grid development at different stages at home and abroad, and
then proposes the evaluation index system of unbalanced and inadequate development of power grids. Finally, the built index system is applied to evaluate the imbalance and inadequacy problem in the development of certain power grid.

2. Power grid index system
This paper summarizes the main evaluation index systems of domestic power grids in different development stages.

2.1. “Two Type” Power Grid Index System
“Two-type” power grid stands for “resource-saving, environmental-friendly” grid. Based on the intrinsic safety, reliability and economic efficiency index system of the power grid, the index system further reflects the resource saving effect and the environmental friendly degree. Firstly, the work of planning, design, construction, operation and technical innovation in the power grid development are analyzed in terms of the “two-type” power grid construction, and the measure index is built; then, effects of various means are analyzed and the effectiveness index is built as Table 1[1][2][3].

Table 1. “Two-type” power grid index system

| Measure index | Primary indicator | Secondary indicator | Tertiary indicator |
|---------------|-------------------|---------------------|-------------------|
| Planning      | Power intensification | Power generation proportion of renewable energy, etc. |
|               | Power grid scale   | Scale of cross-regional (provincial) grid connection, etc. |
|               | Application of advanced technology | UHV AC transmission proportion, etc. |
| Construction  | Standardization construction | Substation general design application rate, etc. |
|               | Optimal design     | Tower optimal design rate, etc. |
|               | Environmental protection | Acceptance rate of environmental protection in power transmission and transformation projects, etc. |
|               | Scheduling operation | Completion rate of maintenance plan, etc. |
|               | Technical revamping | Transformation rate of high energy consuming transformer, etc. |
| Operation     | Demand side management | Application quantity of demand side management system, etc. |
|               | Economize construction scale | Replacement rate of installed capacity, etc. |
|               | Energy conservation | Transmission loss reduction rate, etc. |
|               | Land resources saved | Substation land-saving rate, etc. |
|               | Equipment and material saved | Economize on generating equipment, etc. |
|               | Emission reduction | SO2 emission reduction, etc. |
|               | Environmental control | Electromagnetic environment control rate, etc. |

2.2. Evaluation Index System of Power Grid Development
The research on the evaluation index system of power grid development mainly carries out in-depth exploration for the quantitative index of measuring economic development, power grid development speed, construction scale, development quality and benefit for the evaluation of power grid development level under the environment of rapid development of power grids. Based on economic efficiency and safety analysis of power grid development, the evaluation index system of power grid development is established in five aspects: safety, economy, excellence, coordination and intelligence, by introducing social and environmental factors as Table2[4][5].

Table 2. Evaluation index system of power grid development

| Primary indicator                          | Secondary indicator                                      |
|-------------------------------------------|----------------------------------------------------------|
| Safety                                    |                                                          |
| Structural safety                         | N-1 pass rate, etc.                                      |
| Operational safety                        | Number of equipment accidents, etc.                      |
| Stability                                 | Voltage stability, etc.                                  |
| Adequacy                                  | Loss of load expected (LOLE), etc.                       |
| Capacity for resisting natural disasters  | Emergency power supply capacity, etc.                   |
| Economy                                   |                                                          |
| Power grid scale benefit                  | Transmission capacity of unit transmission line, etc.    |
| Benefits from grid interconnection        | Standby benefits from grid interconnection, etc.         |
| New construction benefit                  | New income from fixed assets, etc.                       |
| Power grid construction economy           | Unit capacity cost, etc.                                 |
| Excellence                                |                                                          |
| Power grid operation quality              | Power quality etc.                                       |
| Power grid construction quality           | Progress indicator, etc.                                |
| Power grid energy saving capacity         | Generating side etc.                                    |
| Harmony                                   |                                                          |
| Resource harmony                          | Harmony with load, etc.                                  |
| Social harmony                            | Harmony with user needs, etc.                            |
| Economic harmony                          | Harmony with national economy, etc.                      |
| Environmental harmony                     | Harmony with atmospheric environment, etc.               |
| Intelligence                              |                                                          |
| Foundation of the power grid development scale | Intelligent transmission and transformation, etc.     |
| Technical support capacity for power grid development | Integrated communication technology, etc.              |
| Intelligent application effect            | Generating side etc.                                    |

2.3. IBM Power Grid Development Maturity Model
The development maturity model of power grids is the result of cooperation between IBM, APQC and the Global Grid Development Alliance. The basic functions of power grid development are positioned
on: Improving the reliability and efficiency of the system, accepting more new energy, and enabling users to interact more with the power grid. The development maturity model of the power grid divides the power grid development into five different maturity stages: (1) There is only a scenario for the power grid development, with no clear planning and development strategy. (2) There is a certain strategic planning and at least one important business area of the power grid development begins to invest and implement. (3) Various components of the power grid development begin to integrate with each other and realize integration of two or more business areas or upgrading of the industrial chain. (4) The power grid can achieve comprehensive observation and comprehensive control across links throughout the enterprise. It is possible to form a new economic or business model. (5) The power grid has the ability to make best use of and develop new business, operational, environmental and other opportunities when they arise. IBM divides the evaluation of power grid development into 8 fields from the aspects of personnel technology and operation flow as Table 3[6][7].

Table 3. IBM Power Grid Development Maturity Model

| Primary indicator                          | Secondary indicator                                                                 |
|-------------------------------------------|--------------------------------------------------------------------------------------|
| Strategy, management and regulation       | Vision, strategic planning, decision-making, strategy implementation and rules, regulation, investment process, etc. |
| Organization                              | Communication, culture, organization structure, etc.                                |
| Technology                                | Information, engineering, integration of information and operation, standards, analytical tools, etc. |
| Society and environment                   | Environmental protection and green plan, sustainable development, economic efficiency and feasibility of integrating alternative and distributed energy sources |
| Power grid operation                      | Observability of advanced power grid and operation control, quality and reliability of advanced power grid |
| Personnel and asset management            | Optimization of assets and resources                                                |
| User management and experience            | Retail, customer care, price selection and control, advanced services, power quality, and visual presentation of performance |
| Value chain integration                   | Demand and supply management, distributed generation management, load management, market opportunities |

2.4. Evaluation Index System of European Power Grid Development Income

The main driving force behind the European grid development is to addressing energy and environmental challenges. Europe describes the power grid development as a way to integrate the behaviour of all the users connected to it, including power producers, consumers and all other connected customers, which has realized intelligent power network with sustainable, economic and safe power supply. The goal of EU power grid development is to realize low carbon power grid and energy system through power grid development as Table 4[8][9].

Table 4. Evaluation index system of European power grid development income

| Primary indicator         | Secondary indicator         |
|---------------------------|-----------------------------|
| Increase sustainability   | CO2 emission reduction      |
Can effectively transmit the electricity generated by generators based on all kinds of energy to users.

- Distributed power supply capacity
- Reduce discarded quantity of electricity from distributed power due to congestion
- Maximum injection power that can be safely accommodated

Open, uniform access standards that enable users to connect to the grid

- Reduce processing time for new users to connect to the grid
- Uniform user access standards

Safer and higher quality electricity supply

- Load peak cutting rate
- Increase the proportion of new sources of energy
- Reduce average outage time for customers
- Improve voltage quality
- Improve the coordinated operation ability of transmission and distribution networks
- Improve the efficiency of emergency prediction and control
- Coordinated capacity for recovery of power supply after emergency time

Improve the efficiency and quality of power grid operation and power supply

- Power grid loss reduction
- Increase the proportion of demand-side participation
- Improve electric energy service efficiency through user participation
- Electric vehicle capacity
- Improvement of system equipment reliability
- Available capacity of the power grid
- Provision of ancillary services for transmission and distribution networks

Support the European power market through power flow control, reduce circular current and enhance grid interconnection capacity

- Increase in the capacity of transnational link lines

3. Unbalanced and inadequate development evaluation index system of power grids

3.1. Index system structure
The evaluation index system of unbalanced and inadequate development of power grids is firstly divided into two evaluation subsystems in the light of the imbalance and inadequacy of development. The unbalanced development subsystem is composed of three main aspects of unbalanced development of power grids, they are the gap between urban and rural development, regional
development gap, and load imbalance; the inadequate development subsystem is composed of four main aspects of inadequate development of power grids, namely, the development scale, development quality, intelligence level, and management level. Then, they are subdivided into tertiary indicators for indicator screening, and the index system undergoes inspection of operability, representativeness, independence, comprehensiveness, regional nature, and industry. Based on opinions of experts and the research, similar indicators are merged, indicators with strong correlation and low maneuverability are deleted or adjusted, and hence forming a scientific and improved comprehensive evaluation index system of power grid development. Finally, the comprehensive evaluation index system of power grid development is analyzed, connotations of indicators are defined, and the acquisition path or calculation method of the index data is defined. In line with the above principles and methods, from two aspects of imbalance and inadequacy of the power grid development, this paper develops a comprehensive evaluation index system of unbalanced and inadequate development of power grids. The index system consists of 2 primary indicators, 7 secondary indicators and 20 tertiary indicators.

3.2. Unbalanced index
The unbalanced index system consists of 3 secondary indicators and 8 tertiary indicators as Table 5:

Gap between urban and rural development: including household average distribution and transformation capacity, power supply reliability and comprehensive voltage pass rate under the city jurisdiction and in the county territory.

Regional development gap: including 750-35 kV grid transformation capacity-load ratio, 750-220 kV grid line capacity-load ratio and household average distribution and transformation capacity in each prefecture-level city.

Load imbalance: including the percentage distribution of maximum load and equivalent average power of the line to economic transmission power, maximum load rate and average load rate distribution of main transformer.

| Unbalanced index | Secondary indicator                                                                 |
|------------------|-------------------------------------------------------------------------------------|
| Gap between urban and rural development | household average distribution and transformation capacity under the city jurisdiction and in the county territory |
|                  | Power supply reliability under the city jurisdiction and in the county territory    |
|                  | Comprehensive voltage pass rate under the city jurisdiction and in the county territory |
| Regional development gap | 750-35 kV grid transformation capacity-load ratio in each prefecture-level city |
|                  | 750-220 kV grid line capacity-load ratio in each prefecture-level city             |
|                  | Household average distribution and transformation capacity in each prefecture-level city |
| Load imbalance   | Percentage distribution of maximum load of the line to economic transmission power |
|                  | Percentage distribution of maximum load rate of main transformer to economic transmission power |

3.3. Inadequate index
The inadequate index system consists of 4 secondary indicators and 12 tertiary indicators as Table 6:

Scale indicator: including 750-220 kV average single circuit line length and 110-35 kV single line length.
Quality indicator: including 110-35 kV transformer N-1 pass rate, 110-10 kV line N-1 pass rate, 10 (20) kV grid line interconnection rate, high loss distribution transformer number ratio, 10 (20) kV cable conversion rate, and 10 (20) kV overhead insulation rate.

Intelligence level: distribution network automation coverage rate, intelligent electric meter coverage rate.

Management indicator: Grid assets O&M cost per 10,000 yuan and unit transformation capacity / long line support load.

Table 6. Inadequate Index System of Power Grid Development

| Primary indicator | Secondary indicator |
|-------------------|---------------------|
| Scale indicator   | 750-220 kV average single circuit line length |
|                   | 110-35 kV single line length |
|                   | 110-35 kV transformer N-1 pass rate |
|                   | 110-10 kV line N-1 pass rate |
|                   | 10 (20) kV grid line interconnection rate |
| Quality indicator | high loss distribution transformer number ratio |
|                   | 10 (20) kV cable conversion rate |
|                   | 10 (20) kV overhead insulation rate |
| Intelligence level| Distribution network automation coverage rate |
|                   | Intelligent electric meter coverage rate |
| Management indicator| Grid assets O&M cost per 10,000 yuan |
|                   | Unit transformation capacity / long line support load |

4. Unbalanced and inadequate development analysis of power grids

In this paper, the unbalanced evaluation index system of power grid development is applied to a power grid A. The analysis results are as follows:

In general, there is still a certain degree of imbalance in the development of Grid A: there is a big gap between urban and rural development, and there is weakness in the rural household average distribution transformer capacity; the unbalanced degree of regional development is low, except for the rapid development of a few regions, the development quality gap of other regions is not big; in terms of local gap, there exists the coexistence problem of adequate overall power supply capacity and tight local power supply. Grid A scale is relatively adequate, able to meet the needs of economic and social development and moderately leading. However, there are inadequate development in many aspects: in terms of safety level, there is much room for improvements in the distribution network N-1 pass rate indicator; in the aspect of power supply quality, the household average outage time needs to be further reduced; in terms of operation efficiency, the 66 kV and below power grid heavy load needs to be improved, the light-load proportion is high, and the utilization efficiency needs to be improved; due to the peak-shaving capacity shortage of nuclear power, the absorption of clean energy is also faced with a tough test; in the aspect of intelligence, Grid A has obvious weakness with a big gap of automation coverage rate with economically developed provinces.

4.1. Unbalanced development of power grids

From the perspective of the gap between urban and rural development, the difference of household average distribution transformer capacity between municipal and county households is 0.87 kVA per household, the interconnection rate of 10kV power grids is 40.37 percentage points, and the power
supply reliability is 0.2078 percentage points, the household average blackout time is 18.2 hours and the pass rate of comprehensive voltage is 0.794 percentage points. That high loss distribution transformers are mainly concentrated in the county area and has not yet been eliminated.

From the perspective of regional development gap, there are large gaps in such indicators as 500-220 kV line capacity-load ratio, 220-66 kV substation capacity-load ratio, 66-10 kV N-1 pass rate, 10 kV interconnection rate, unit investment in increasing electricity sales, and the unit investment in increasing supply load, and there is an imbalance. 66 kV power distribution points are not enough, and the connection rate of 10 kV lines is only 57.2%, which lags behind the national average level of 57.5%.

From the perspective of overall and local gaps, there is an imbalance between the overall power supply adequacy and the local power supply tension. The capacity-load ratios of 500-66 kV levels have reached the upper limit of the guidelines, but the local power supply capacity inadequacy problem remains.

For the coordinated development problem of grid, power source and load, the power source development is not matched with load development and peak-shaving ability of power grids. First of all, the development of power installed capacity is significantly faster than the development of load. The installed capacity of new energy maintains a rapid development trend, the total PV installed capacity registers a sharp increase by 328% on a yearly basis. Secondly, the contradictions of various power operations are intensified, and new energy development space is limited. The minimum technical output of thermal power units increases year by year during heating period, at the same time, the operation mode of nuclear power unit increases year by year, which will also squeeze new energy consumption space.

4.2. Inadequate development of power grids

Power grid development scale and speed are relatively adequate. Since the 12th Five-Year Plan, the speed of power grid construction has been 1.3 percentage points higher than the economic growth and 3.5 percentage points higher than the load growth.

The trunk networks of power grids are relatively strong and its development is relatively adequate, but it still needs to be further improved. The N-1 pass rate of the 500 and 220 kV grids is both 100%, 500kV mainstay networks are basically completed, but trunk networks in some areas require further optimization. The situation of adequate overall power supply capacity and tight local power supply requires gradual improvement until the phenomenon is eliminated.

Distribution network development is relatively inadequate, power supply capacity and network structure construction needs to be strengthened. The overall power supply capacity of distribution networks is adequate, but the local development is unbalanced, which affects the regional power supply capacity to some extent. In some areas, the reliability of 66 kV distribution network is not high, the distribution automation level is low, and the coverage of intelligent terminals is less than 10%, so it is necessary to increase the investment in distribution automation.

Power grid development efficiency and benefits are relatively adequate, equipment utilization efficiency and investment efficiency need to be improved. Firstly, the maximum load rate of 500 kV and 220 kV transmission lines and equivalent average load rate all need to be improved. 66 kV heavy-load main transformer and line proportion need to be reduced. The utilization level of 10kV distribution transformer needs to be improved, and the “power supply radius” needs to be further optimized. Secondly, since the 12th Five-Year Plan, the supply load and power sales increased by cumulative unit grid investment have been relatively low, the investment efficiency needs to be further improved. It is necessary to coordinate the development of safety, benefit and load, and rationally use automatic safety devices and overload capacity of main transformer during the transition period of power grid development in a bid to increase the precision investment level.

5. Conclusion
The new expectation of increasing energy use puts forward new requirements for the scientific construction of power grids and building a clean, low carbon, safe and efficient energy system. It is necessary to diagnose and analyze the problems of unbalanced and inadequate development of power grids, and give better play of the basic platform function of power grids in the energy resource allocation and the conversion utilization. This paper first summarizes the evaluation index system of power grid development at various stages at home and abroad, including the “two-type” power grid index system, the evaluation index system of power grid development, the IBM power grid development maturity model, European power grid development income evaluation index system and so on. Then, the paper proposes the unbalanced and inadequate evaluation index system of power grid development, which is composed of 2 primary indicators, 7 secondary indicators and 20 tertiary indicators. Finally, the built evaluation index system is applied to evaluate the imbalance and inadequacy problem in the development of a power grid.

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