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A FRAMEWORK OF HIGH PROPORTION RENEWABLE ENERGY INTELLIGENT ASSESSMENT AND ADJUSTMENT

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ABSTRACT

The high proportion renewable energy access is an important feature and trend of future power system development. With large scale access of wind power and photovoltaics, high proportion renewable energy will bring strong uncertainty, making the safety and stability characteristics increasingly complex and difficult to control, thus bringing large impact to the operation of traditional power system. As an important feature of the system operation mode, power flow will be deeply affected by the power supply structure change. Aiming at the problem that the traditional power system analysis is difficult to cope with the change of operation mode caused by renewable energy access, this paper proposes a framework of system operation assessment and adjustment: first build a set of assessment indicator system based on flow rationality, and then adopts artificial intelligence method to learn the training adjustment strategy, and finally realizes the intelligent adjustment of system operation mode which meets the operation requirements of safety, high efficiency, economy and intelligence in the case of high proportion renewable energy access.

Keywords: High proportion renewable energy, power system operation mode, System assessment, Intelligent flow adjustment, Artificial intelligence

NONMENCLATURE

Abbreviations	
HPRE	High Proportion Renewable Energy
PVs	Photovoltaics
AI	Artificial Intelligence

1. INTRODUCTION

Under the background of the global energy security problem and the intensification of environmental pollution, vigorously developing renewable energy such as wind power and PV is a major demand for sustainable development of energy in the world [1]. According to the renewable 2018 global status report [2], in 2017, the installed capacity of renewable energy has reached 2195GW, while PV and wind power reaching have increased by 29% and 11%, reaching 402GW and 538GW respectively. In China, major changes will be made in the way of energy production and consumption. It is estimated that by 2050, the proportion of renewable energy in energy consumption will reach over 60%, accounting for more than 85% of total power generation, which forms a renewable energy-based energy system [3]. It can be seen from the future development plans that the power system will exhibit the characteristics of HPRE and large-scale AC-DC hybrid.

The most obvious impact of large-scale HPRE access to power system is the diversity of operation modes. Wind power and PVs increase the number and types of power generation scenarios, which makes the number of power system operation modes and calculation scale gradually increase. Traditional analysis methods are difficult to meet the diversified and refined requirements of operation modes. The calculation of operation mode involves many aspects, where the result of power flow calculation provides a basis for quantitative analysis of the rationality of the operation mode as well as the safety, reliability and economy of the power system operation plan. Therefore, the most important thing in the adjustment of the system operation mode is the power flow adjustment.

In order to obtain a rational, safe and economical operation mode, it is necessary to establish an assessment of the power system and formulate appropriate adjustment strategies. In terms of power system assessment, [4] proposes a set of safety indicators from the perspective of power system planning, which covers the description of power loss and user load loss, and finally system safety assessment indicators reflecting the severity of the accident are obtained. Aimed at uncertainty of renewable energy, [5] establishes a flexible transmission network planning method based on robust and stochastic programming theory. [6] proposes a risk assessment for analyzing the safety of power system operation planning under high-permeability wind power generation, involving steady-state voltage, overload assessment and frequency response characteristics. [7] proposes an assessment method for power system flexibility to adapt to the uncertainty of demand and power generation, and to assess annual, weekly and daily flexibility requirements through a set of indicators based on spectrum analysis. [8] designs a series of flexibility evaluation index system for power system optimization planning. By analyzing the cumulative probability distribution of various flexible resources, the probability and expectation of flexibility margin distribution and lack of flexibility are obtained thus achieving an assessment of system flexibility. At the level of power grid operation evaluation, [9] and [10] evaluate comprehensively from daily dimension and time point dimension respectively to guide the operation through the construction of a multi-level indicator system. It can be seen from the existing research that the assessment of operation state is usually limited to the conventional power system, while the evaluation of HPRE system is mostly oriented only to the planning level. The research oriented to the operational level usually focuses on the day ahead dispatching [11-12]. [11] studies the joint optimization scheduling of the wind power, PVs and hydro power, and realizes stable delivery of electricity by tapping the complementary characteristics of renewable energy. [12] further considers the safety constraints of N-1 and studies the joint and studies the joint optimization scheduling of coal-fire-solar-hydro-wind-storage power system.

Most of the above studies evaluate power system from different angles, and less involve the adjustment of power system operation mode, thus making it difficult to give guidance on adjustment of power flow mode. The most important adjustment in the operation mode of power system is flow adjustment. Due to the complexity of the structure, the heavier power load and high permeability of renewable energy, it is difficult to obtain a convergence or rational power flow by manually adjusting to generate an operation mode. Since current research is less involved assessment of HPRE power system, and most of the existing researches separate the system evaluation from adjustment strategy, it is difficult to guide adjustment operation mode by evaluation. This paper designs a systematic evaluation system and adjustment framework, and also proposes a HPRE power system operation mode evaluation system. AI method is used to intelligently adjust the system operation mode to generate rational mode which meet the operation requirements.

2. PAPER STRUCTURE

The main content of this paper includes following parts:

1) Power system operation mode. This section introduces basic information about power system operation mode.

2) Methods and framework. This section includes four parts: operation mode assessment, synthetic indicator framework construction, deep Q-learning model and intelligent flow adjustment. These parts illustrate the details of the relative theories, methods and application.

3) Conclusion.

3. POWER SYSTEM OPERATION MODE

The power system operation mode is the overall technical solution for the production and operation of power system complied by dispatching apartment. With the increasing complexity of the power system structure and higher HPRE access, the number and calculation scale have increased dramatically. If only the extensive and inefficient manual adjustment of power flow are used to extract typical operation mode, it will be difficult to adapt to the demand or refined management of power system.

In China, the operation mode can be divided into different categories from different perspectives as shown in Fig.1.

In the formulation process of power system operation mode, it is necessary to consider generator output, maintenance plan, load curve prediction, power

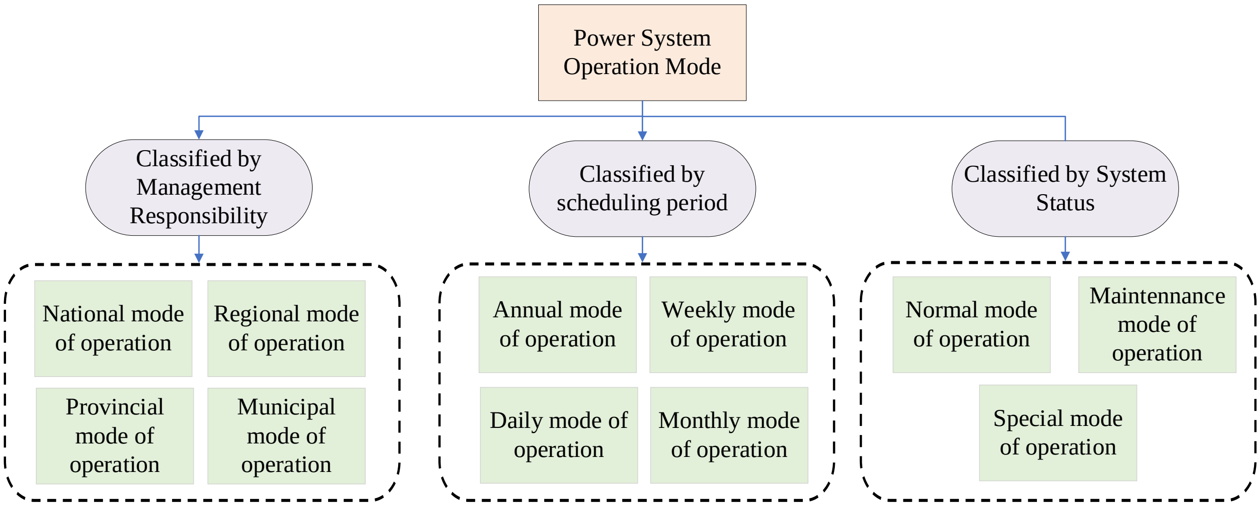

Fig 1 Classification of Power System Operation Mode

transmission plan, power balance and so on. According to the characteristics, the following should be considered when formulating operation mode:1) Large amount of basic information, including grid topology, load demand and power generation capacity; 2) Large number of calculations, including flow calculation, N-1 safety check, and stability calculation.

4. METHODS AND FRAMEWORK

4.1 Operation mode Assessment

The assessment system target is the operation mode of power system. The unified principle to be followed when constructing the evaluation indicators system is that the selected peer indicators should be independent of each other and cannot have an inclusive relationship. This paper proposes the concept of a comprehensive assessment indicator system framework with three levels, each of which is subdivided into multiple indicators. Fig 2 lists some of indicators. First rank indicator is qualitative that includes the safety, economy, cleanliness and flexibility of the system, while the flexibility indicator measures the impact of HPRE access on power system and assess how the system operates in terms of flexibility.

The second rank indicators are qualitative indicators used to subdivide first rank indicators. Third rank indicators are qualitative which describe second rank from multiple angles.

In security indicators, the flow interface that has an important impact on security of system operation is selected. The maximum line load rate and voltage over limit rate are calculated as follows:

$$line\ load\ rate = \max_{i\in\Omega}\left(\frac{P_i}{P_{i\max}}\right) \tag{1}$$

$$voltage\ over\ limit\ rate = \frac{n}{N} \tag{2}$$

Where P_{imax} is the maximum load that ith line or interface can withstand; P_i is the actual load of the line or interface; Ω is the selected line set; n denotes the number of nodes with over limit voltage and N denotes the number of nodes.

In economic indicators, equipment utilization rate and load rate are similar to line rate. The line loss is calculated as (3):

$$line\ loss = \frac{P_{loss}}{P_g} \tag{3}$$

Where P_{loss} is the active power loss of the system network, and P_g is the total power generation.

In flexibility aspect, assessment indicators about system regulation capabilities can be built. Take regulation capability as an example: $\triangle P_{up\_i}$ and $\triangle P_{down\_i}$ denote the upward spare capability and downward spare capability of node i respectively, then the available upward and downward regulation capability indicators of the system are shown in (4).

$$C_{up} = \sum_{i=1}^{n}\Delta P_{up\_i},\quad C_{down} = \sum_{i=1}^{n}\Delta P_{down\_i} \tag{4}$$

In environmental protection aspect, typical indicators are clean energy generation grid connection rate CR and generation rate GR, which are shown in (5) and (6).

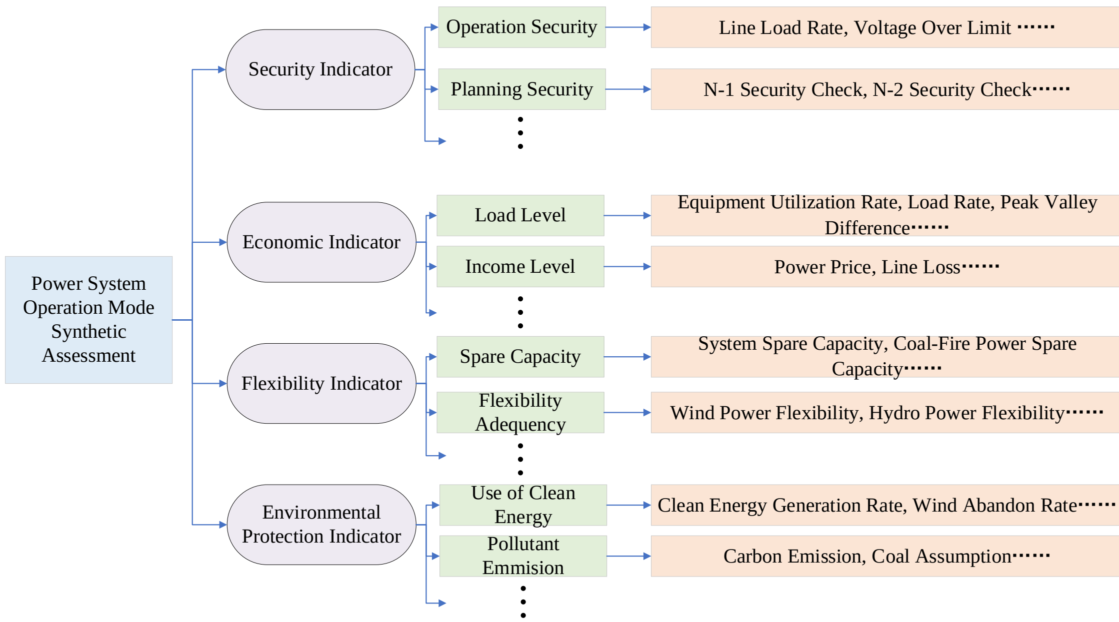

Fig 2 Power System Assessment Index

$$CR = \sum_{i\in\Omega_c}(P_iT_i) / \sum_{i\in\Omega_c} W_i \tag{5}$$

$$GR = \sum_{i\in\Omega_c}(P_iT_i) / W \tag{6}$$

Where P_i is the active power of generator i; T_i is grid connection time; W_i is total power generation of generator in the period; W is total power generation of the system; Ω_c is clean energy generator set.

4.2 Synthetic indicator framework construction

This section briefly describes the methods used in the assessment system. The assessment system includes indicators and weight calculations. In indicators framework, qualitative and quantitative indicators are used mainly, while subjective weighting methods or objective weighting methods can be used in weight calculation part, such as fuzzy decision method, entropy method, etc. In this paper, Improved Analytic Hierarchy Process (IAHP) is used to build evaluation system [9].

Both subjective and objective evaluation need to be considered when constructing the evaluation system. AHP algorithm is widely used for subjective weight calculation of various methods due to its strong reliability. In terms of objective aspect, the anti-entropy weight method can overcome the problem of large weight contrast caused by traditional entropy weight method. IAHP is based on AHP and anti-entropy weight method.

The calculation result of the AHP algorithm is the subjective weight vector of index set U:

$$\boldsymbol{w}' = [w_1', \dots w_i' \dots w_n'] \tag{7}$$

Where i = 1…n, n denotes the number of U_i in index set U; w_i' is the subjective weight of U_i relative to U.

According to [13], calculate the anti-entropy of each U_i:

$$h_i = -\sum_{k-1}^{t} c_{ik} \cdot \ln(1 - c_{ik}) \tag{8}$$

$$c_{ik} = r_{ik,cog} / \sum_{k=1}^{t} r_{ik,cog} \tag{9}$$

Where $r_{ik,cog}$ is the gravity value of U_i in area k.

Then, determine the objective weight vector w'':

$$\boldsymbol{w}'' = [w_1'', \dots w_i'' \dots w_n''] \tag{10}$$

$$w_i'' = h_i / \sum_{i=1}^{n} h_i \tag{11}$$

Further determine the overall weight vector:

$$\boldsymbol{w} = [w_1, \dots w_i \dots w_n] \tag{12}$$

$$w_i = w_i' w_i'' / \sum_{i=1}^{n} w_i' w_i'' \tag{13}$$

4.3 Deep Q-learning model

In the intelligent adjustment strategy, deep reinforcement learning is used to realize the rational adjustment of power system power flow. Reinforce learning is a kind of learning from environmental state mapping to action. The goal is to enable the agent to get the maximum cumulative reward in the process of interaction with environment, therefore the reinforcement learning is more focused on learning strategies to solve problems. Deep reinforce learning combines the characteristics of deep learning and reinforcement learning, which is an end-to-end perception and control system with strong versatility. The learning process can be described as follows:

1) At each moment, the agent interacts with the environment to obtain a high-dimensional observation, and uses the deep learning method to perceive the observation to obtain a specific state feature representation;

2) Evaluate the value function of each action based on the expected return, and map the current state to the corresponding action through a certain strategy;

3) The environment reacts to this action and gets the next observation. The optimal strategy for achieving the goal can be finally obtained by continuously looping through the above process.

Deep Q-Network (DQN) is one of the typical model which mainly made three improvements to the traditional Q learning algorithm:

1) DQN uses the experience playback mechanism during the training to process the transferred samples online;

2) In addition to use the deep network to approximate the current value function, DQN uses another network to generate the target Q value. Network parameters are updated by minimizing the mean square error between the current Q value and the target Q value. The error function is shown in (14).

$$L(\theta_i) = E_{s,a,r,s'}\left[\left(Y_i - Q(s,a \mid \theta_i)\right)^2\right] \quad (14)$$

Where $Q(s,a \mid \theta_i)$ denotes the output of current value network, and $Y_i = r + \gamma \max_{a'} Q_i(s',a' \mid \theta_i)$ approximately represents the optimization objective of the value function, i.e. the target Q value. Deviate the parameter to obtain the following gradient in (15).

$$\nabla_{\theta_i} L(\theta_i) = E_{s,a,r,s'}\left[\left(Y_i - Q(s,a \mid \theta_i)\right)\nabla_{\theta_i} Q(s,a \mid \theta_i)\right] \quad (15)$$

3) DQN narrows the reward value and error term to a limited interval, ensuring that both Q and gradient values are within a reasonable range, improving the stability of the algorithm and has a strong adaptability and versatility.

The training process of DQN is shown in Fig 3.

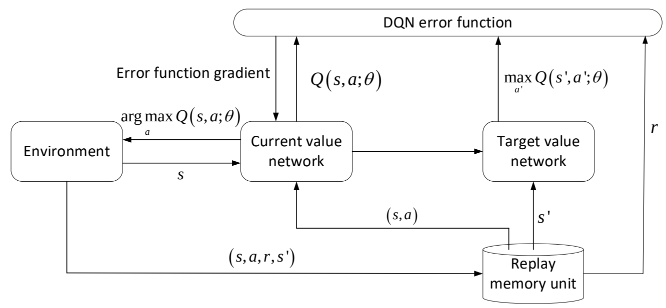

Fig 3 Training process of DQN

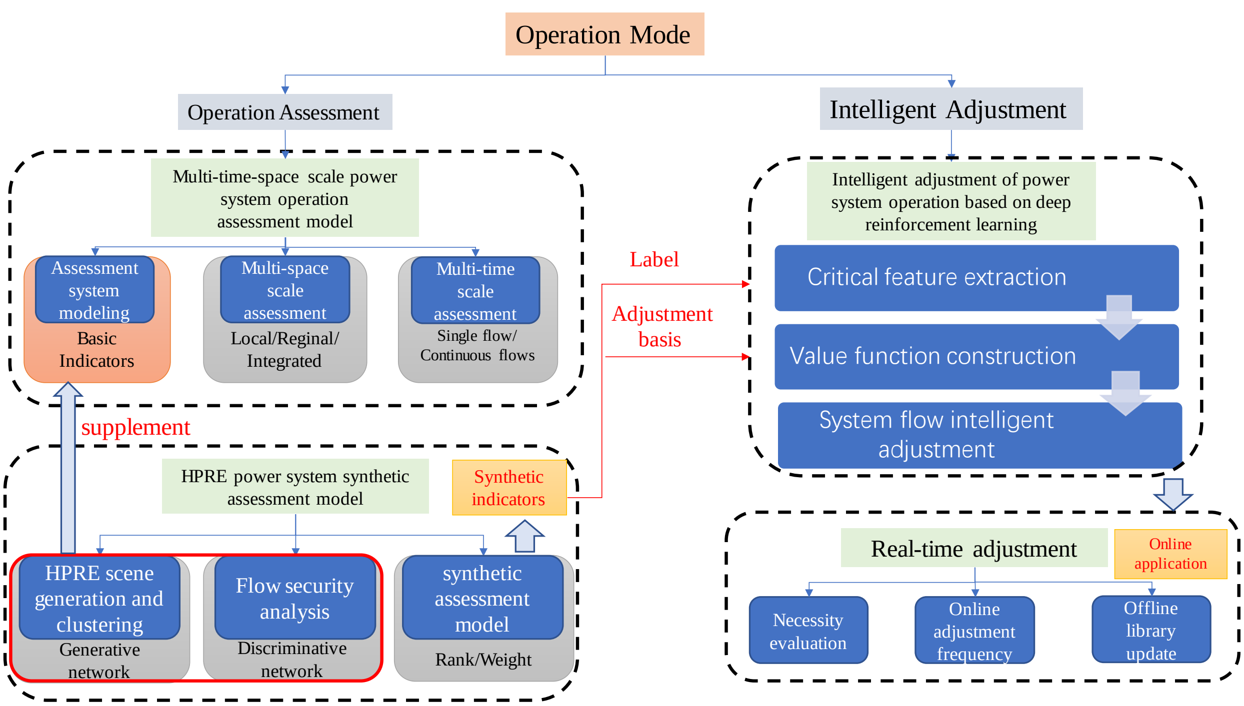

Fig 4 Intelligent flow adjustment framework

4.4 Intelligent flow adjustment

Deep reinforcement learning has strong self-learning ability, and has been successfully applied in many fields such as automatic power generation control, voltage stability control and emergency control strategies in power systems. In this paper, deep reinforcement learning method is adopted, and a set of power flow adjustment framework is designed based on the above comprehensive evaluation system, as shown in Fig.4.

5. CONCLUSION

This paper combines the objectives of safety, economy, flexibility cleanliness, etc., and builds a complete set of power system operation assessment system and intelligent adjustment framework for HPRE. It also provides a basis for generation of HPRE power system operation mode, lays a foundation for efficient, intelligent and refined dispatching of power system, and provides guidance for optimal operation of power systems, thereby improving the intelligence level of multi-energy power systems. In the subsequent research, it is necessary to further implement the proposed framework in test system and actual system and verify its rationality and effectiveness.

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