Multi-point Layout Planning for Multi-energy Power System Based on Complex Adaptive System Theory

Shuqiang Zhao, *Member*, *IEEE*, Xun Suo, Yanfeng Ma, *Member*, *IEEE*, and Ling Dong

***Abstract*—Aiming at the problem of multi-point layout planning of a multi-energy power system, the output characteristics of a multi-energy power system composed of wind power generation, photovoltaic power generation, hydropower generation, traditional thermal power generation and solar thermal power generation are comprehensively analyzed. Combining power optimization planning with complex adaptive system theory, a multi-point layout planning model of multi-energy sources based on complex adaptive system theory is proposed. The model takes the minimum construction step size of each new energy source as the agent. Through the interaction between the agents and the accumulation of experience, the behavior rules are constantly changed, the installed positions of various types of power sources are adjusted, and the optimal layout scheme of various power capacities of each node is obtained. Moreover, an agent modeling method based on a simple rule emerging complex phenomena is proposed, which reveals the core idea of complex adaptive system theory—adaptability makes complexity. Taking an actual power grid in a certain region of China as an example, it is verified that the proposed method has a significant effect on improving the consumption of new energy, and has certain guiding significance for the actual engineering construction.**

***Index Terms*—Agent modeling, complementarity, complex adaptive system, multi-energy power system, power planning.**

I. Introduction

The depletion of fossil energy and the deterioration of environment are urgent problems for human survival and development. As an important way to solve the global energy and environmental crisis, renewable energy power generation has become a hot issue throughout the world [1]–[4]. Compared with the traditional power generation methods, photovoltaic power generation and wind power generation have less impact on the environment, and have better long-term economics, and are easier to widely apply [5], [6]. However, the output power of single photovoltaic power generation or wind power generation greatly fluctuates, which can cause a great impact on the connected power grid operations [7]–[9]. Making full use of the complementary characteristics between solar energy and wind energy and adopting the multi-energy complementary power generation mode can improve the reliability of the power system, reduce the impact on the power grid, and achieve the most reasonable energy utilization effects and benefits [10].

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A. Complex Adaptive System

Complex adaptive system (CAS) was raised by John H. Holland in 1994. which focus on adaptability created complexity. Traditional views tend to have difficultly capturing the highly nonlinear interactions that are common in the problems addressed by industry and government. These non-linear interactions regularly combine to produce emergent behavior, which is regularly exhibited by CAS. CAS developed a modeling method of bottom-up, whose response interrelates between micro and macro, as well as explains the evolution mechanism of complex systems [11], [12].

Business enterprises, financial markets, and the economy itself can all be viewed as CAS and they give rise to practical problems that are often mathematically intractable. The methods developed to study CAS, as well as the insights derived from these studies, have been applied to all these areas with some success [13]–[15]. Other CAS simulation techniques, such as spin glass models, sand piles, and random Boolean networks have been, for some time, standard tools in certain relatively narrow areas, such as condensed mater physics [16], [17].

B. Multi-energy Power System

The multi-energy power system is also a typical CAS. It is composed of multiple power generation forms. The various forms of power supply cooperate with each other and coordinate with each other, so as to adapt to the coordinated development of the environment and other agents in a more efficient and comprehensive way.

How to use a variety of intermittent power supply scientifically and reasonably has been frequently studied. In paper [18], a new generation planning method for large-scale new energy grid connection is proposed under the framework of investment decision-making and operational analysis. Considering the seasonal fluctuation characteristics and rapid investment and construction characteristics of new energy, the power investment decision-making idea based on monthly investment time unit is proposed. Based on game theory, this paper [10] established the capacity planning decision-making model of a photovoltaic-wind power-storage hybrid power system. The investors of wind power generation, photovoltaic power generation and energy storage battery were regarded as participants in the game. The Nash equilibrium results of each mode were solved and analyzed and compared with each other. Paper [19] considers each power node as the research object, adjusts the installed capacity of various types of power supply to adapt to the development of the power system, and obtains the optimal configuration scheme of various power capacity under each node.

Based on the theory of CAS, this paper analyzes the generation mechanism of the complexity of a multi-energy power system, and proposes a multi-point layout planning and design method of a multi-energy power system with wide area complementary. The rest of this paper is organized as follows. Section I briefly introduces the CAS and multi-energy power system. Section II summarizes the characteristics of multi-energy power system from the perspective of CAS theory. In Sections III and IV, the multi-point layout planning model of a multi-energy power system is constructed by agent modeling, and the effectiveness of the proposed method is verified by an example. Finally, Section V presents the conclusion.

II. Characteristics of A Multi-energy Power System

John H. Holland identifies the properties and mechanisms common to CAS. CAS have seven factors in the process of adaptivity and evolution, such as, aggregation, nonlinearity, flows, diversity, tag, internal models and building blocks. The first four are properties and the last three are mechanisms. John H. Holland considered that the system which have the seven properties is CAS [20].

A. Aggregation

Aggregation is the relationship between agents. As the basic unit of the main aggregation, their interaction will form a large-scale complex system, this aggregate can also be used as a basic unit to form a larger scale complex system. This is often a turning point when the macro nature of the system changes. Therefore, aggregation contains the interaction between agents. There are many forms of aggregation in a multi-energy power system: a single type of power supply forms a large capacity collection station through aggregation; different types of power supply are sent out in the form of bundling through aggregation. At the system level, the spatial network is the carrier of various types and capacities of power sources, and the aggregation in time scale ensures the real-time source load balance of the multi-energy power system. These complex aggregation bodies formed by aggregation determine the development scale and complexity of a multi-energy power system.

B. Nonlinearity

A multi-energy power generation system is not equal to the simple sum of all parts of the power supply. There are many factors that affect power generation. The influence of these factors on the power generation system is not independent, but interactive, and the output fluctuation of any generation agent will affect the output of other generation entities. Each agent adapts to each other and develops together in the nonlinear environment. It is initiative and adaptability that make the system complex.

C. Flows

According to the theory of CAS, the transmission channel and speed of "flows" directly affect the evolution of the system. Because the interaction between agents is nonlinear, the "flows" cause a chain reaction. "Flows" produces an emergence effect among the agents and presents a continuous and dynamic process.

In the multi-energy power system, the agents are connected by energy flow, information flow and capital flow. Power flow is a typical factor flow in multi-energy power system. The power flow varies with time, and the agents will adjust its capacity to achieve the most efficient state.

D. Diversity

The adaptability of multi-energy power system is a process of differentiation, which forms the complexity of its structure and the diversity of its morphology. The agents of each power supply exist not only in the natural environment, but also in the environment created by other agents. The completion of each adaptation process opens up the possibility for the next adaptation, so as to maintain the continuous renewal of multi-energy power system.

E. Tag

In the multi-energy power system, how to realize its own advantage development is the premise of coordinated and complementary operation and development of the whole system. The identification of different types of power supply agents is precisely its time sequence output characteristics. For example, wind power output is "low at noon and high at night, " while photovoltaic output is "high at noon and low at night." The output characteristics of different types of power supply are different, and the differentiated guidance marks play an important role in the complementary and coordinated development of multi-energy power system.

F. Internal Models

The internal model is the interaction rules between the building blocks of the agents or system. For a given agent in a system, once the range of possible stimuli is specified and the possible response set is estimated, the rules that the agent has can be determined. Due to the existence of the internal model, the agent can make a forward-looking judgment on the environment, and make adaptive changes to the interactive behavior and its own behavior according to the pre-judgment.

In the power planning problem of multi-energy power system, the application of internal model is ubiquitous. Internal model is a guidance tool for the current behavior under the prediction of some expected future states, which is often the constraint condition in the modeling process. According to the feedback information from the internal model, each agent adjusts its capacity to adapt to the change of environment.

G. Building Blocks

The concept of system building blocks provides convenience for analyzing the hierarchical problems of complex systems. By encapsulating the contents and rules of the next level, ignoring its internal details temporarily, and participating in the interaction of higher-level systems as a whole, it is convenient to study the interaction rules between higher-level systems.

The concept of system building blocks is used to encapsulate the subsystems, which is convenient to study the operation law of the system and the interaction between the subsystems in different regions from the system level, so as to scientifically analyze the complementary operation mechanism of the multi-energy power system and the interaction mechanism among the subsystems in each region.

III. Planning Model

The planning model is established on the basis of a series of agents. Five types of power sources, namely wind power, photovoltaic power, hydropower, thermal power and solar thermal power, are selected to model with their minimum construction steps as an agent. These agents can make decisions independently and interact with the environment. These decisions are based on the information received by each agent from the environment, and also depend on the characteristics of the agent itself.

The environment is a space, which contains the decision-making activities of all agents in the simulation, as well as the information sources needed to carry out decision-making and subsequent behaviors. Through the monitoring and statistics of specific indicators in the environment, we can analyze the status of all the established agents at different evolution times in different real-time scenarios, and analyze the process of agents changing with time.

A. Agent Model

The agent in the model is dynamic and has two characteristic attributes: a behavior selection mechanism and objective function. In this paper, all agents can choose to move to any node position, calculate the objective function value obtained from the current behavior, and compare it with the objective function value obtained from the previous behavior to guide the behavior decision of the agent, so as to achieve the system level planning of a multi-energy power system.

The objective function of the agent is related to the operation consumption, and the output model of each type of agent is as follows.

1) Wind Power

The output power of the fan is closely related to the wind speed. The wind speed generally follows the *Weibull* distribution, and its probability density function is expressed as follows:

$$f(v)=\frac{k}{c}\left(\frac{v}{c}\right)^{k-1}\exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{1}$$

where: v is the real-time wind speed; k, c are shape parameters and scale parameters respectively. The relationship between fan output power $P_{\text{win},t}$ and wind speed is as follows:

$$P_{\text{win},t}=\begin{cases}0 & v\leq v_{\text{ci}}, v>v_{\text{co}}\\ \dfrac{v-v_{\text{ci}}}{v_{\text{N}}-v_{\text{ci}}}P_{\text{win,N}} & v_{\text{ci}}<v\leq v_{\text{N}}\\ P_{\text{win,N}} & v_{\text{N}}<v\leq v_{\text{co}}\end{cases} \tag{2}$$

where: $P_{\text{win,N}}$ is the rated power of the fan; v_{ci}, v_{co}, v_{N} are the cut in wind speed, cut-out wind speed and rated wind speed of the fan respectively.

2) Photovoltaic Power

The light intensity γ obeyed the *Beta* distribution in a certain period, the probability density function $f(\gamma)$ is:

$$f(\gamma)=\frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}\gamma^{\alpha-1}(1-\gamma)^{\beta-1} \tag{3}$$

where: $\alpha\beta$ are the shape parameters and $\Gamma()$ is the *Gamma* function. The relationship between photovoltaic power $P_{\text{pv},t}$ and light intensity is as follows:

$$P_{\text{pv},t}=\begin{cases}P_{\text{pv,N}} & \gamma>\gamma_{\text{N}}\\ P_{\text{pv,N}}\dfrac{\gamma}{\gamma_{\text{N}}} & \gamma\leq\gamma_{\text{N}}\end{cases} \tag{4}$$

where: $P_{\text{pv,N}}$, γ_{N} are rated power and rated light intensity of the photovoltaic power respectively.

3) Hydropower

The output power of hydropower $P_{\text{hyd},t}$ meets the following constraints:

$$\begin{cases}P_{\text{hyd,min}}\leq P_{\text{hyd},t}\leq P_{\text{hyd,max}}\\ P_{\text{hyd,down}}\leq P_{\text{hyd,downmax}}\\ P_{\text{hyd,up}}\leq P_{\text{hyd,upmax}}\end{cases} \tag{5}$$

where: $P_{\text{hyd,min}}$, $P_{\text{hyd,max}}$ are the minimum and maximum output power of the hydropower plant; $P_{\text{hyd,up}}$, $P_{\text{hyd,down}}$ are the climbing and downhill power of the hydropower plant; $P_{\text{hyd,upmax}}$, $P_{\text{hyd,downmax}}$ are the maximum climbing and downhill power of the hydropower plant.

4) Thermal Power

The output power of thermal power $P_{\text{the},t}$ meets the following constraints:

$$\begin{cases}P_{\text{the,min}}\leq P_{\text{the},t}\leq P_{\text{the,max}}\\ P_{\text{the,down}}\leq P_{\text{the,downmax}}\\ P_{\text{the,up}}\leq P_{\text{the,upmax}}\end{cases} \tag{6}$$

where: $P_{\text{the,min}}$, $P_{\text{the,max}}$ are the minimum and maximum output power of the thermal power plant; $P_{\text{the,up}}$, $P_{\text{the,down}}$ are the climbing and downhill power of the thermal power plant; $P_{\text{the,upmax}}$, $P_{\text{the,downmax}}$ are the maximum climbing and downhill power of the thermal power plant.

5) Solar Thermal Power

The relationship between the output power of solar thermal power $P_{\text{stp},t}$ and light intensity is as follows:

$$P_{\text{stp},t}=\begin{cases}\eta_{\text{p,e}}P_{\text{stp,N}} & \gamma>\gamma_{\text{N}}\\ \eta_{\text{p,e}}P_{\text{stp,N}}\dfrac{\gamma}{\gamma_{\text{N}}} & \gamma\leq\gamma_{\text{N}}\end{cases} \tag{7}$$

Solar thermal power stations generate electricity through a steam turbine unit, so it has similar operational constraints as a conventional steam turbine unit. In addition, the charging

/ discharging power of the energy storage tank of the photo thermal power station can be continuously adjusted within the limited range, but the charging / discharging cannot be carried out simultaneously.

$$\begin{cases} 0 \le P_{\text{stp,sto,in}} = \eta_{\text{p,h}} P_{\text{stp,N}} \dfrac{\gamma}{\gamma_{\text{N}}} \le P_{\text{hea,sto,in}}^{\max} \\ 0 \le P_{\text{stp,sto,out}} = \eta_{\text{h,e}} P_{\text{stp,N}} \dfrac{\gamma}{\gamma_{\text{N}}} \le P_{\text{hea,sto,out}}^{\max} \\ P_{\text{stp,sto,out}} \times P_{\text{stp,sto,in}} = 0 \end{cases} \tag{8}$$

where $P_{\text{stp,N}}$, γ_{N} are the rated power and rated light intensity of the photovoltaic. $P_{\text{stp,sto,in}}^{\max}$, $P_{\text{stp,sto,out}}^{\max}$ are the maximum charging and discharging power. $\eta_{\text{p,h}}$, $\eta_{\text{h,e}}$, $\eta_{\text{p,e}}$ are photothermal, thermoelectric and photoelectric conversion efficiency.

B. Environment Model

The agent receives the change of objective function value caused by the change of the behavior decision from the environment. Therefore, in the traditional stochastic production simulation calculation process, the power flow calculation, climbing constraints and the division and restriction of the cross-section are added in this paper, and the calculation is carried out in the unit of year and the step size of hour.

1) Power Flow Constraint

In order to simplify the calculation, the DC power flow calculation method is adopted:

$$P = B * \theta \tag{9}$$

where P is the column vector of active power injected into the node.B is the node admittance matrix. θ is the phase angle column vector of node voltage.

2) Climbing Constraints

$$\begin{cases} \Delta P_{i,\text{up}}^{t} \le P_{i,\text{the,maxup}}^{t} + P_{i,\text{hyd,maxup}}^{t} + P_{i,\text{stp,maxup}}^{t} \\ \Delta P_{i,\text{up}}^{t+1} \le P_{i,\text{the,maxup}}^{t+1} + P_{i,\text{hyd,maxup}}^{t+1} + P_{i,\text{stp,maxup}}^{t+1} \end{cases} \tag{10}$$

where $\Delta P_{i,\text{up}}^{t}$ is the climbing power of node i at time t. $P_{i,\text{the,maxup}}^{t}$, $P_{i,\text{hyd,maxup}}^{t}$, $P_{i,\text{stp,maxup}}^{t}$ are the maximum climbing power of thermal power, hydropower and solar thermal power of node i at time t.

$$\begin{cases} \Delta P_{i,\text{down}}^{t} \le P_{i,\text{the,maxdown}}^{t} + P_{i,\text{hyd,maxdown}}^{t} + P_{i,\text{stp,maxdown}}^{t} \\ \Delta P_{i,\text{down}}^{t+1} \le P_{i,\text{the,maxdown}}^{t+1} + P_{i,\text{hyd,maxdown}}^{t+1} + P_{i,\text{stp,maxdown}}^{t+1} \end{cases} \tag{11}$$

where $\Delta P_{i,\text{down}}^{t}$ is the downhill power of node i at time t. $P_{i,\text{the,maxdown}}^{t}$, $P_{i,\text{hyd,maxdown}}^{t}$, $P_{i,\text{stp,maxdown}}^{t}$ are the maximum downhill power of thermal power, hydropower and solar thermal power of node i at time t.

3) Capacity Constraints

$$\sum_{i=1}^{N} C_{\text{type,new}}^{i,y} = C_{\text{type,plan}}^{y} \tag{12}$$

where $C_{\text{type,new}}^{i,y}$ is the new type power capacity of node i in the y year; N is the total number of nodes; $C_{\text{type,plan}}^{y}$ is the total capacity of *type* power supply planned to be added in the y year.

4) Section Constraint

$$\sum_{l=1}^{n} P_{i,l} \le P_{i,\text{section,max}} \tag{13}$$

where $P_{i,l}$ is the transmission power of line l in the section of node i; $P_{i,\text{section,max}}$ is the maximum transmission power of node i.

C. Model Solving

Papers [21] and [22] define CAS by three properties: (1) Diversity and individuality of agents. (2) Localized interactions among those agents. (3) An autonomous process that uses the outcomes of those interactions to select a subset of those agents for replication or enhancement.

Applying this definition to a multi-energy power system stresses the importance of having heterogeneous systems, interactions among these systems, and the ability to self-organize. Based on the above three characteristics, the proposed model is solved.

1) Diversity and Individuality of Agents

Take the minimum construction step size of different types of new energy sources (wind power, photovoltaic and solar thermal) as an independent decision-making agent. The input data of agents primarily come from the external environment and the behavior of other agents. Through time series production simulation, the objective function value of each agent is calculated, and the actual effect of the simulated agent's behavior can be quantified. All agents take the maximum amount of their own consumption as the objective function, and can arbitrarily move to all nodes in the system, and compare the change of objective function value to determine their own node position. As all agents choose the node location with the same goal, the new energy consumption of the whole system gradually increases, and finally converges to the maximum value.

All agents have autonomy and nonlinear interaction. All agents have the same decision-making behavior and a unified objective function, and respond to various stimuli in the environment in parallel and evolve. In different time and space, the agent has different states, while in the system level, there are new structures and new states, and corresponding characteristics emerge.

2) Localized Interactions

In CAS, a differentiated tag is a mechanism that exists behind agents for mutual identification and selection, aggregation and boundary generation. The function and efficiency of an individual tag are very important in the interaction between individual and environment.

In the multi-energy power system, the cooperation between the agents can be reflected as complementarity. Due to the lack of a large amount of energy storage, the real-time balance of source and load is needed. The definition of complementarity in time scale is determined by the operation characteristics of the power system.

Based on the above analysis, the statistical output characteristics of all types of power sources for 24 hours in a year constitute the feature tag sequence:

$$\Psi_k = [\phi_{1,n}^k, \phi_{2,n}^k, \cdots, \phi_{24,n}^k] \tag{14}$$

Ψ_k is the tag sequence of the n iteration of the k agent. Where:

$$\phi_{i,n}^k = \frac{\sum_{t=1}^{8760} P_{t,n}^k}{\max\left(\sum_{t=1}^{8760} P_{t,n}^k\right)} \begin{cases} t = d * 24 + i \\ d = 0, 1, \cdots, 364 \end{cases} \tag{15}$$

where $p_{t,n}^k$ is the actual output at time t of the n iteration of the k agent. $\max\left(\sum_{t=1}^{8760} P_{t,n}^k\right)$ is the maximum absorption value of agent k statistics in 24 hours. The sequence of agent feature identification is a real number between [0, 1].

The tag of the agent is related to its time sequence output characteristics, and the value shows the characteristics of the agent, such as wind power output characteristics are high at night and low at noon, and photovoltaic output characteristics are high at noon and low at night. Due to the difference of the location, nodes and natural resources of the agent, with the development of the evolution process, the time series output of the agent will also change through the calculation of the sequential production simulation. Therefore, the tag of agents under different spatiotemporal conditions has the characteristics of time-varying and diversity, which provides the data basis for the diversity cooperation among the agents.

The criterion of cooperation between the agents is based on the volatility index. The fluctuation should be a relative index, that is, the closeness between the power output and the load curve. For example, if the real-time output of a wind farm is consistent with the load curve, the wind power output is considered to have no volatility compared with the load. Therefore, it is necessary to make full use of the complementarity of multi-energy to reduce the fluctuation between source and load.

Similar to the tag process of the agent, the load tag is established ($\Psi_{\text{load}} = [\phi_1^{\text{load}}, \phi_2^{\text{load}} \cdots \phi_{24}^{\text{load}}]$). Since the load does not change in the planning level year, its tag array is relatively fixed. The matching degree can be obtained by comparing the tag of agent and load:

$$\eta_n^{k,\text{load}} = \sum_{j=1}^{24} |\phi_{j,n}^k - \phi_j^{\text{load}}| \tag{16}$$

$\eta_n^{k,\text{load}}$ is the matching degree between the k agent and the load in the n iteration.

It can be seen from the above formula that the smaller the matching degree is, the smaller the volatility is, that is, the better the complementarity is. The cooperation mechanism among agents is determined as follows:

$$\begin{cases} \eta_n^{k,\text{load}} \geq \eta_n^{k,l,\text{load}} \\ \eta_n^{l,\text{load}} \geq \eta_n^{k,l,\text{load}} \end{cases} \tag{17}$$

where $\eta_n^{k,l,\text{load}}$ is the matching degree of combined output and load of the k agent and the l agent. If $\begin{cases} l\eta_n^{k,\text{load}} \geq \eta_n^{k,l,\text{load}} \\ \eta_n^{l,\text{load}} \leq \eta_n^{k,l,\text{load}} \end{cases}$ or $\begin{cases} \eta_n^{k,\text{load}} \leq \eta_n^{k,l,\text{load}} \\ \eta_n^{l,\text{load}} \geq \eta_n^{k,l,\text{load}} \end{cases}$ is satisfied, the k agent and the l agent cooperate with each other in a certain probability to form a unified agent. Moreover, when the agent's consumption becomes smaller, if the other agent's consumption increases and the increase value is greater than the decrease value, the two agents will also aggregate.

3) An Autonomous Process

Due to the changing environment, the agent is always in the process of development, recession and mutation. Because of the existence of an identification and cooperation mechanism, it promotes the interaction and aggregation between agents. In the process of system evolution, aggregates usually have robustness, reliability and diversity, so that they can adapt to a wider range of environmental conditions, and then dominate the evolution of the system. The overall behavior of the system is the result of many individual agents making a lot of decisions at any time [23].

IV. Example Analysis

Taking the actual power system of a province in China as an example, the power layout optimization simulation is carried out. The system structure is shown in Fig. 1, and seven sections are divided according to the actual operation. In the case of the same total capacity, the method proposed in this paper is used to calculate the specific distribution of various types of power supply capacity.

When the underlying agents are taken as objects for modeling, the agents are autonomous and have nonlinear interaction. All agents have the same decision-making behavior and a unified objective function, use the tag to determine the cooperation, and respond to various stimuli in the environment in parallel and then evolve. In a different time and space, the agent has different states, while in the system level, there are new structures and new states, and corresponding characteristics emerge. The evolution process of the system is as follows.

The average annual electricity consumption of each type of agent is shown in Fig. 2 (average consumption of agent = total consumption / number of agents).

At the beginning of the evolution (when the number of iterations is about 30), the average consumption of solar thermal agents increases to the maximum. Because the solar thermal agent has a certain regulation performance, its time series output characteristics change greatly, and the cooperation with other agents is full of uncertainty, resulting in frequent changes in its average consumption value.

At the system level, the consumption of new energy is shown in Fig. 3 and Fig. 4.

Although the section abandoned electricity of new energy increased, the total abandoned electricity remained at a low level, and the rate of abandoned electricity was relatively low. The agent adjusts its own state automatically to adapt to the environment, cooperates or competes with other agents in order to obtain the maximum benefit function. Agent cooperation is produced from the conflict of many individual wills, which emphasizes the relationship between the agent and the internal factors in the system. The formation and operation of this relationship is based on the relationship among the

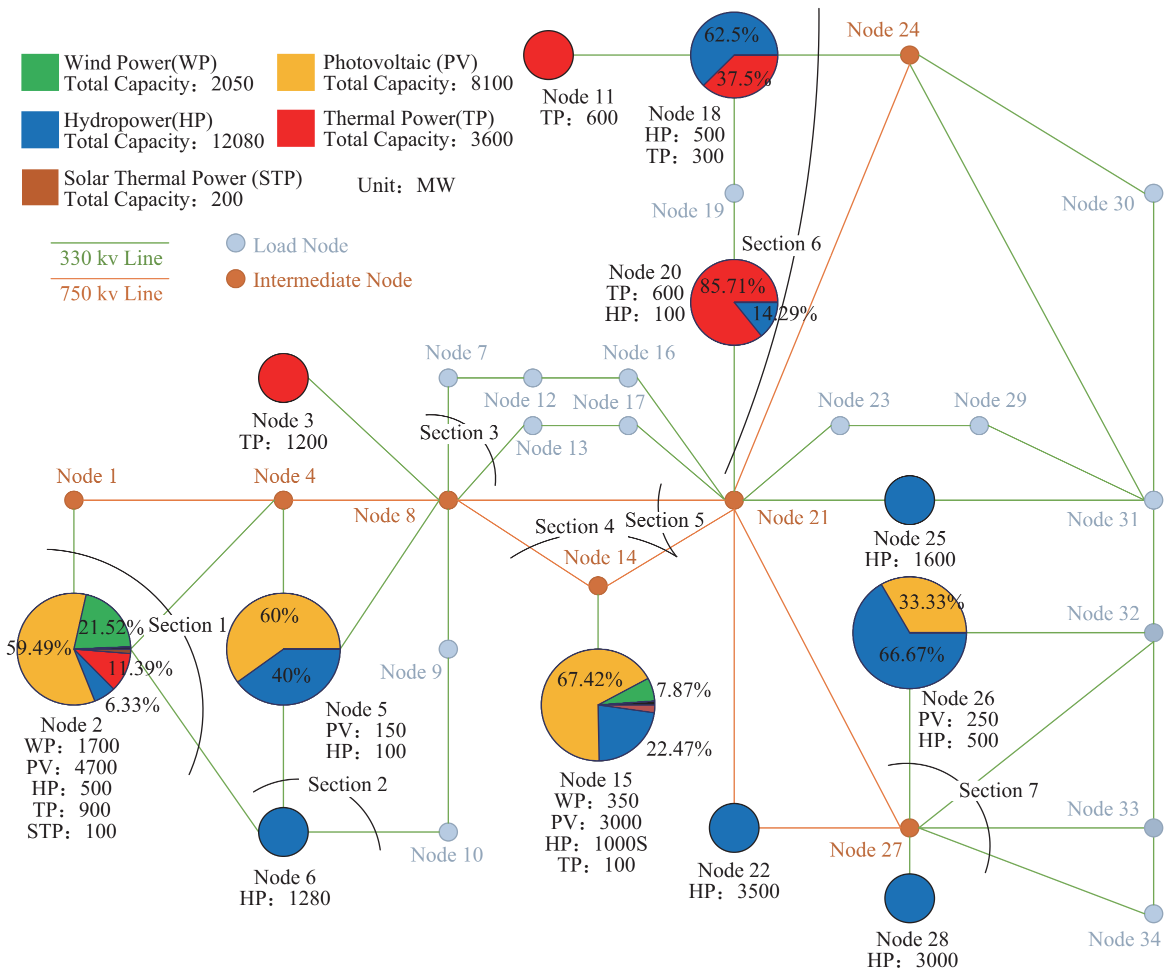

Fig. 1. Structural diagram of a multi-energy power system.

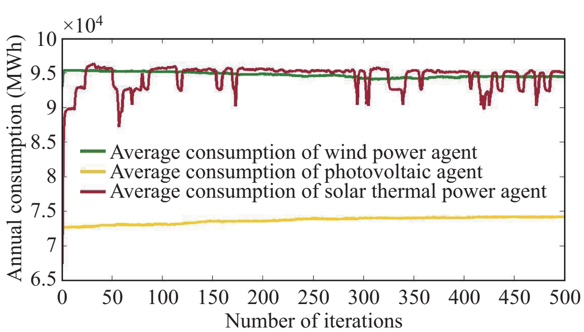

Fig. 2. Annual electricity consumption of various types of agents.

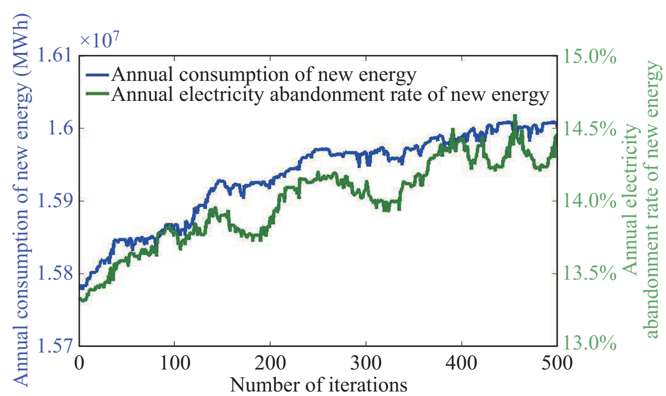

Fig. 3. New energy consumption.

various factors in the system. Due to the mutual cooperation between agents, it promotes the mutual aggregation of different types and different positions. After the multi-agent aggregation, it participates in the evolution process of the system as a whole. The aggregation experience presents the functions and characteristics that each part does not have. It has significant nonlinear characteristics and converges to a higher new energy consumption value. The introduction of cooperation mechanism based on tag characteristics is more in line with the idea of multi-energy complementary coordinated planning of a multi-energy power system.

It is assumed that the multi-energy power system is planned using a linear idea. In each iteration, the agent with the least consumption of each type of new energy (wind power, photovoltaic and solar thermal) is selected and moved to the node of the same type of agent with the largest consumption. In the evolution process, the consumption of new energy is shown in Fig. 5, Fig. 6 and Fig. 7.

In the process of evolution, the minimum output of each

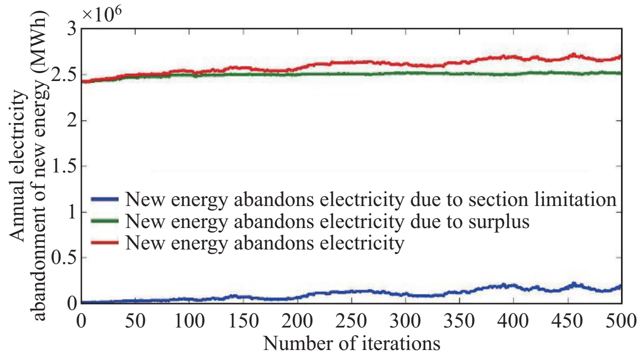

Fig. 4. Electricity abandonment of new energy.

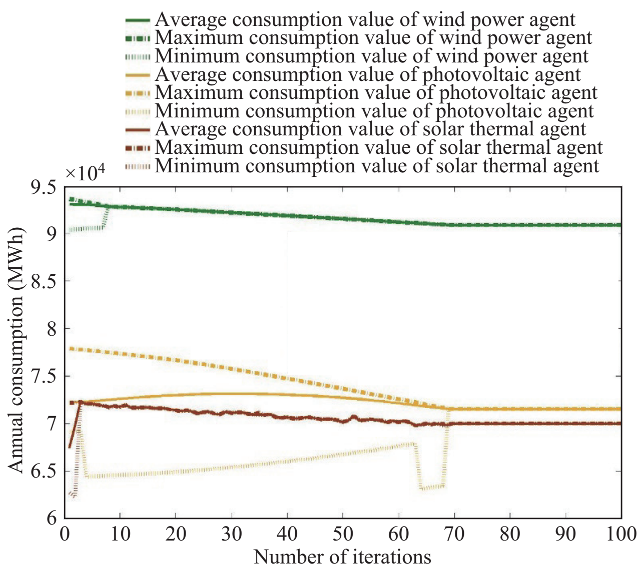

Fig. 5. Annual electricity consumption of various types of agents.

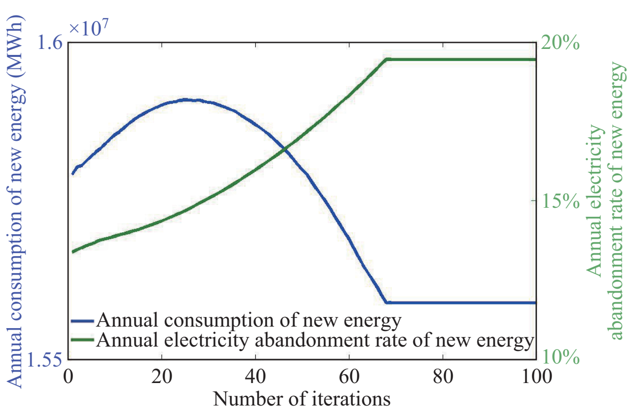

Fig. 6. New energy consumption.

type of agent increases at the beginning stage, and the total consumption value of new energy becomes larger. However, with the development of the evolution process, as the agent moves to the node location with rich natural resources, the abandoned electricity generated by the section limitation increases sharply, and the consumption value of the agent with the original maximum output will also decrease. The agent movement of a new energy source not only affects

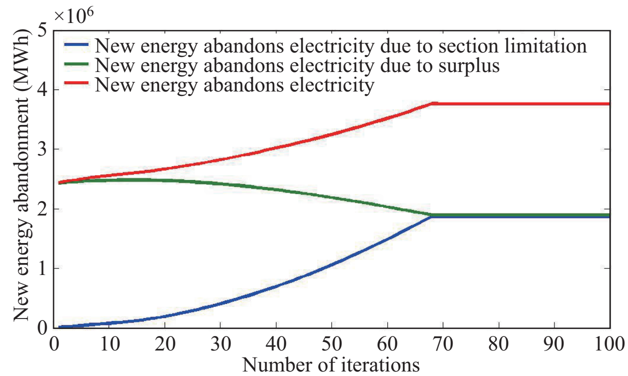

Fig. 7. Electricity abandonment of new energy.

the consumption of other power sources, but also affects the consumption of different types of power sources.

The above results show from the reverse that the multi-energy power system has very distinct nonlinear characteristics, and the influence relationship between the same type of power supply and different types of power supply is very complex. The relationships among agents, levels and between agents and system are nonlinear. The interaction between individuals is not a simple, passive, linear causal relationship, but an active adaptive relationship. The multi-energy power system itself and its evolution law cannot be correctly understood through the simple addition of its constituent elements. The complexity of the multi-energy power system must be reproduced by the indivisible holistic view, the interrelated organic view and the dynamic view of each element. In the face of more and more complex interconnected multi-energy power systems, the simple linear cognitive method has become invalid, and the cognitive method of complex system has become a necessity.

The specific distribution of various types of power supply capacity is rearranged. The calculation results are shown in Table I, and the simulation data of random production of the system are shown in Table II.

TABLE I
PLANNING SCHEME

Node Number	Wind Power (MW)	Photo-Voltaic (MW)	Hydro-Power (MW)	Thermal Power (MW)	Solar Thermal Power (MW)
2	1300	6000	10*50	3*300	200
3	0	0	0	2*600	0
5	0	1050	2*50	0	0
6	0	0	4*320	0	0
11	0	0	0	2*300	0
15	750	1050	10*100	0	0
18	0	0	5*10	2*150	0
20	0	0	2*50	2*300	0
22	0	0	5*700	0	0
25	0	0	4*400	0	0
26	0	0	10*50	0	0
28	0	0	10*300	0	0

It can be seen from the random production simulation data that under the premise of keeping the total installed capacity of all types of power sources unchanged, the thermal power output is reduced, and the consumption of new energy

TABLE II
RANDOM PRODUCTION SIMULATION DATA

Unit (MWh)	Original Scheme	Planning Scheme
Total wind power consumption	3814633.32	3777453.94
Total photovoltaic consumption	11694279.13	11945726.52
Total hydropower consumption	52509690.23	52326706.18
Total Thermal power consumption	10758104.98	10751700.00
Total wind power consumption	269640.64	285073.28
Total Solar thermal power consumption	3814633.32	3777453.94
New energy consumption	15778553.09	16008253.75
New energy abandons electricity	2426876.76	2686827.65
Electricity abandonment rate of new energy	13.33%	14.37%

is significantly increased. The renewable energy output can replace part of the thermal power generation, which helps to reduce fuel consumption and carbon emissions, and improve economic and environmental benefits.

Five days of new energy output in one year are randomly selected for comparison, as shown in Fig. 8.

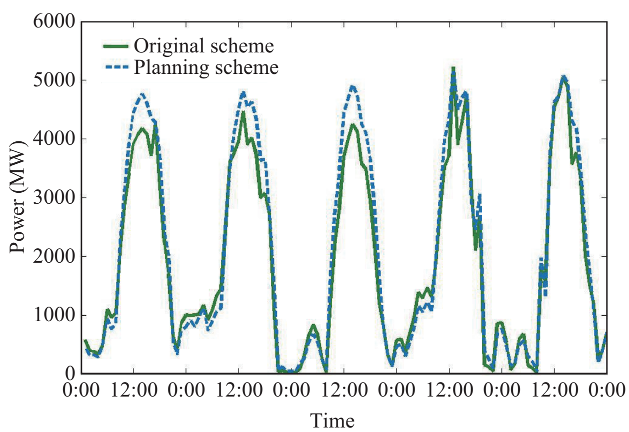

Fig. 8. New energy consumption.

The fluctuation of the sum of the new energy output power of the system is reduced after adopting the improved optimization scheme. This is because in the optimization model, each agent cooperates with the complementary identification, and takes the minimum volatility compared with the load as the aggregation interaction identification, so as to ensure that the system can make full use of the complementary characteristics of new energy and make the multi-energy power system more economical and feasible. It can then adapt to the environmental changes, maximize the rational use of renewable resources and effectively smooth the volatility of renewable energy, and realize the continuity and smoothness of power generation.

V. CONCLUSION

In view of the current situation and future development trend of large-scale multi-energy power systems, this paper studies the output complementarity of wind power, photovoltaic power, hydropower, thermal power and solar thermal power, and proposes a multi-point layout planning model of a multi-energy power system combined with CAS theory. The recommended scheme obtained from the model can guide decision makers to determine the final planning scheme, which has reference value for a multi-point power system layout.

The adaptive process of CAS is essentially a dynamic and generalized optimization process based on the group. The objective function of the agent is artificial. In this paper, the objective function of the agent is set as the maximum consumption. The sum of the parts of the whole is not equal to the whole because of the mutual adaptation and mutual influence. We must pay close attention to the emergence of structure and function from bottom to top in the system level brought by the combination of elements. CAS theory provides a good theoretical support for the study of dynamic, nonlinear and stochastic environmental problems. It can also be regarded as a new method to replace the traditional derivation analysis method.

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