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Coordinated Operation of Source Network Load in Comprehensive Energy Distribution Network

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Abstract The comprehensive energy distribution network (DN for short here) integrates multiple energy sources, which is the main direction for the development of the power system DN. To solve the problems of low efficiency in collaborative allocation between power sources, power grids, and loads in traditional integrated energy DN coordination operation models, difficulty in meeting power quality requirements, and susceptibility to interference from external environmental factors, this article analyzed the traditional integrated energy DN coordination operation model. This paper summarized the key technologies of the distribution scheme between the coordinated operation power supply, power grid and load, and optimized the coordinated operation structure of the integrated energy grid based on the distribution demand and particle swarm optimization algorithm. This can improve the intelligence level of the decision-making scheme for coordinated operation of source network load. Finally, this article conducted comparative experiments to verify the performance improvement of optimizing the comprehensive energy DN. From the results of the comparative experiment, it can be seen that compared to traditional comprehensive energy DN, the optimized comprehensive energy DN has shorter decision-making time, better equipment management ability, and stronger risk response performance. In the application comparative experiment, the evaluation index of risk response performance increased by 18%. The optimization of the comprehensive energy DN in this article has played an important role in the development process of the DN, and it is one of the excellent solutions to promote large-scale energy allocation and consumption. Its coordinated operation between power sources, power grids, and loads is also more efficient and smooth, fully tapping the potential of various energy sources, and it has more objective prospects in technological updates and iterations.

Index Terms Integrated Energy, Distribution Grid, Coordinated Operation, Energy Consumption, Intelligent Decision

I. Introduction

In the past, due to the development and utilization of energy and the progress of economic and social development, people gradually began the process of optimizing the power system. With the continuous increase in energy demand, comprehensive energy utilization is becoming increasingly widespread, and DN, as an indispensable part of the development process of new electricity, have also proposed higher construction standards. At present, people are in a period of rapid construction and improvement of the comprehensive energy distribution system. Due to factors such as limited capacity, low load, and regional economic differences in urban power supply grids, there are certain obstacles in the coordinated operation between the comprehensive energy DN and various users when connected to the urban system. The rapid increase in energy consumption in various regions and the increasingly serious contradiction between supply and demand in distribution systems urgently require optimization research on the coordination system among power sources, power grids, and loads. In order to promote the development of the power grid economy, it is of great significance to study a comprehensive energy DN that has low energy consumption and can meet the power supply needs of the DN.

The comprehensive energy DN has great potential in the coordinated operation of multiple energy sources. To achieve efficient and intelligent decision-making and coordinated operation plans, it is necessary to start from the needs of the comprehensive energy DN and analyze specific problems. The comprehensive energy DN is one of the forms that combine comprehensive energy and power systems. In order to meet the intelligent decision-making of high-quality distribution schemes, it is necessary to optimize and improve the economy, safety, and flexibility of traditional distribution systems, which can effectively alleviate the environmental pressure of regional energy systems [1], [2]. In order to improve the overall energy efficiency of the integrated energy distribution system, Hao Xiao optimized the planning and design scheme of the integrated energy system (IES), and increased the power generation penetration rate of the IES with a distributed structure. The power load side exhibits more levels of uncertainty in response to demand [3]. Mingyu Yan proposed a regional coordinated operation plan for the comprehensive energy distribution system. He used electrical technology to establish a regional bidirectional flow model, meeting the decision-making flexibility demand for comprehensive energy distribution schemes under extreme conditions [4]. Bahador Fani studied the security and practicality of coordinated protection schemes for DN and proposed a method to maintain protection coordination, thereby reducing the probability of network equipment damage [5]. The above research provides prospects for optimizing the performance of comprehensive energy DN based on actual needs.

For the optimization and improvement of the performance of the comprehensive energy DN, in order to facilitate the coordinated operation of the power grid, power supply, and compliance, this can enable timely identification and resolution of risk issues in the vast power operation system. Therefore, research on various optimization schemes is essential. Shuhan Yao proposed a generation scheduling and network reconfiguration scheme in the distribution system, which enhances the resistance of the distribution system to large-scale power outages [6]. In order to improve the utilization efficiency of various types of energy and achieve the important goal of safe and stable allocation of energy networks in the planning and operation of comprehensive energy DN, the structural form of distributed comprehensive energy distribution systems and the distribution method of coordinating multiple server sources can be studied. This can enhance the load elasticity of the DN while reducing energy waste [7], [8]. Guangsheng Pan proposed a comprehensive energy planning model for the future development of integrated energy DN. While considering hydrogen production and storage technologies, he developed a reasonable model with startup and shutdown constraints to address the uncertainty of power generation load [9]. M.V. Tejeswini explored protection coordination and optimization solutions for distribution systems based on voltage and current protection algorithms, combined with solar power generation technology. He ultimately used differential evolution algorithms to improve relay performance and meet the growing demand for power supply [10]. The above research has proposed optimization solutions for some systems, but further research is needed.

The optimization of the comprehensive energy DN is the basic strategic deployment for the development of the energy internet. With the gradual improvement of the construction of smart grids, the coordination and interaction of various links of the power system’s source grid load has become an inevitable requirement. In order to solve the problems of traditional comprehensive energy DN planning being single, lack of connection and overall planning among various links, low efficiency of coordination schemes between power sources, power grids, and loads, and excessive uncertainty factors in coordination and scheduling tasks, this article conducts an in-depth analysis of the components of traditional comprehensive energy DN. This article summarizes the differences and commonalities between various parts of the system, and optimizes the operational process and work structure of the comprehensive energy DN more reliably. Based on intelligent decision-making technology, combined with sensor networks and particle swarm optimization algorithm, this paper constrains the established goals and preconditions in the operation of integrated energy DN. This can enable the optimized comprehensive energy DN to have a higher level of intelligence, which can meet the growing demand for distribution scheduling and departmental coordination.

II. Operation Structure of Particle Swarm Optimization

Comprehensive energy has become a long-term and stable energy source due to the integration of multiple energy sources within a certain area, enabling the DN to meet power supply needs to the maximum extent possible. Properly scheduling the operation of source network load in the comprehensive energy DN and achieving stable power supply of the power system has become an important direction for the development of intelligent power transportation. In order to ensure the good parallelism and robustness of the integrated energy DN in the operation process, this paper tentatively introduces particle swarm optimization algorithm to optimize the performance of the system initialization and intelligent decision-making of each working link.

II. A. Objective Function Determination Process

The operation of integrated energy DN is a multi-objective and multi-constraint nonlinear problem. This article takes the coordination cost between various links in the operation process of integrated energy DN as an example for model analysis. Formula (1) is the coordination cost calculation formula for the comprehensive energy DN during operation [11].

$$minQ(x) = [minQ_{Cost}(x), minQ_{Evni}(x)]^T \tag{1}$$

Among them, $Q(x)$ is the objective function for coordinating costs during the operation of the comprehensive energy DN; $Q_{Cost}(x)$ is the power generation cost of the comprehensive energy DN; $Q_{Evni}(x)$ represents the environmental cost of the comprehensive energy DN; T is the number of time periods during which the comprehensive energy DN operates. When calculating the minimum generation cost of a comprehensive energy DN, this article only considers the maintenance cost, start-up cost, and energy consumption cost of coordinated operation between distributed power sources and loads in the comprehensive energy DN. The specific calculation is carried out by Formula (2).

$$minQ_{Cost}(x) = \sum_{t=1}^{T}[H_{OM} + H_F + H_{SC}] \tag{2}$$

Among them, H_{OM} represents the operation and maintenance cost of the comprehensive energy DN; H_{SC} is the start-up cost of each unit; H_F is the cost of energy consumption. The process of comprehensive energy power generation would generate various oxides to pollute the air. The environmental cost of the comprehensive energy DN is the sum of the environmental losses and pollutant treatment costs that cause pollution to the environment during the power generation and supply process. The calculation formula for the minimum environmental cost is shown in Formula (3) [12].

$$minQ_{Evni}(x) = \sum_{i=1}^{P} \alpha_i \cdot \beta_i \tag{3}$$

Among them, α_i represents the emission of pollutants from Group i power supply with power P; β_i represents the converted cost of pollutants in Group i power supply.

II. B.Constraint Analysis Process

In order to conduct a more rigorous study on the coordination cost of the operation of integrated energy DN models, this article analyzes a series of constraint conditions to prevent the values of attributes from contradicting the application semantics in the calculation process of the model. At any time during the power supply of the integrated energy DN, the sum of power generated by each distributed power source needs to match with the power required by the user to achieve power balance. The constraint conditions for power balance are shown in Formula (4).

$$P_Z^t = [P_{TC}^t + P_{BT}^t + P_{PV}^t + P_{DEG}^t] \tag{4}$$

Among them, P_Z^t represents the user's demand power at t time, while $P_{TC}^t, P_{BT}^t, P_{PV}^t, P_{DEG}^t$ represent the power released by the trend, energy storage, photovoltaic, and diesel engines at t time. In addition to power balance constraints, in order to ensure the stable operation of the comprehensive energy DN, the output power of each distributed power source must also be constrained. This can limit the actual output power of each distributed power source in the comprehensive energy DN to a certain range at any time. Formula (5) is the output power constraint condition.

$$P_{i,min} \le P_i \le P_{i,max}, \forall i = 1,2,3,4 \tag{5}$$

Among them, $P_{i,min}$ is the minimum output power of the i group power supply; $P_{i,max}$ is the maximum output power of the i group power supply; i represents four types of distributed power sources: tidal current, energy storage, photovoltaic, and diesel.

II. C.Analytical Process of Particle Swarm Optimization

In order to analyze the operation process of the integrated energy DN, particle swarm optimization algorithm is tentatively introduced to solve the model in this paper. This can enable the comprehensive energy DN to more efficiently formulate decision-making plans during the coordinated operation process, save energy, and more stably execute coordinated power supply tasks. Particle swarm optimization is an algorithm based on the dynamic behavior of birds in nature. For example, the cost problem that arises during the coordinated operation of a comprehensive energy DN is the position of particles in the search space, which is the solution to the cost problem. The flight speed of each solution determines the flight direction and distance of the solution. Through the flight experience of each solution, continuous iteration of the solution can be achieved, and ultimately the optimal decision can be obtained. The iterative updating process of intelligent decision scheme of particle swarm optimization can be obtained from Formula (6).

$$V_j^{t+1} = \partial V_j^t + e_1 \cdot s_1 \cdot (l_{bestj}^t - c_j^t) + e_2 \cdot s_2 \cdot (k_{bestj}^t - c_j^t) \tag{6}$$

Among them, V_j^t represents the speed of the jth solution of the coordinated operation cost problem of the comprehensive energy DN at t time; c_j^t is the position of the jth solution at t time; l_{bestj}^t is the individual optimal value of the jth solution at t time; k_{bestj}^t is the global optimal value of all solutions at t time. e_1, e_2 are a random number between (0,1); s_1, s_2 are the learning factor; ∂ is the inertia weight value. The introduction of particle swarm optimization algorithm enables the integrated energy DN to make efficient and intelligent decisions in the process of coordinated operation of source network load. Compared to traditional comprehensive energy DN, the performance is superior, saving a lot of manpower and material costs, and improving the automation level of system decision-making.

III. Coordinated Operation Mode of Comprehensive Energy DN

With the development of economy and society and the improvement of technological level, people's demand for electricity is constantly increasing. How to make the coordinated operation of the power grid more smooth and efficient has become one of the primary problems that need to be solved in the current power system. This article analyzes the coordinated operation decision-making scheme between traditional power grids, power sources, and loads under the comprehensive energy supply method. It has been found that the decision-making speed of traditional comprehensive energy DN for coordinated operation schemes between power grids, power sources, and loads is slow. When faced with power supply risk issues, they lack the ability to respond in a timely manner and cannot make timely decisions on solutions with the ability to address risk issues. This would lead to irreparable significant economic losses [13]. In response to the call for the development of smart grid construction in the current power system, this article explores the power supply mode and optimization direction in the comprehensive energy DN. Electric energy transmission and distribution play a very important role in the entire power supply process, and the efficiency of electric energy transmission directly affects the development of economic benefits and the improvement of quality of life.

This paper analyzes the power supply mode of the integrated energy DN, and introduces particle swarm optimization algorithm to intelligently decide solutions to the risk problems encountered in the coordinated operation of the integrated energy DN. By collecting, analyzing, and predicting real-time parameters of various links through the comprehensive energy DN, it can save a lot of costs while efficiently maintaining the stability of the power supply process. Distributed power mainly includes flexible scheduling of micro units and energy storage devices, among which wind and photovoltaic units have intermittent characteristics. The coordinated operation between power supply, power grid, and load is the main content of traditional comprehensive energy DN scheduling. Table 1 shows the relevant technical parameters of the energy storage device.

Table 1: Technical parameters related to energy storage devices

Parameter		Parameter value
Energy storage	Maximum power	13 MW
	Total capacity	40 MW
	Consumption rate	0.0583

Before the operation of the comprehensive energy DN, it is necessary to first confirm the power supply demand with the user. On the basis of the successful establishment of the power supply project, various power generation scheduling plans for units can be formulated, and electricity can be sold to the main network when there is surplus electricity. When the power supply is insufficient, electricity can be purchased from the main network, which ensures the daily power supply needs of users through this transaction process. The elasticity coefficient of electricity demand at different time periods is shown in Table 2 [14], [15].

Table 2: Elasticity coefficient of electricity demand at different time periods

Period of time	Value		
Low ebb	-0.11	0.02	0.009
At ordinary times	0.02	-0.12	0.014
Peak	0.029	0.017	-0.13

With the rapid development of the economy, the environmental and energy crisis has become increasingly serious. In order to maintain a stable power supply quality, it has promoted the intelligent construction of the integrated energy DN. The traditional integrated energy DN has insufficient energy absorption capacity and backward coordination and dispatching methods for all links. This can seriously constrain the construction process of smart grids and slow down the trend of large-scale application of comprehensive energy DN. This paper optimizes the coordinated operation structure of traditional integrated energy DN based on sensor network and particle swarm optimization algorithm, and takes active coordinated control mode for source network load, making the scheduling process more flexible. Figure 1 shows the coordinated operation structure of the comprehensive energy DN.

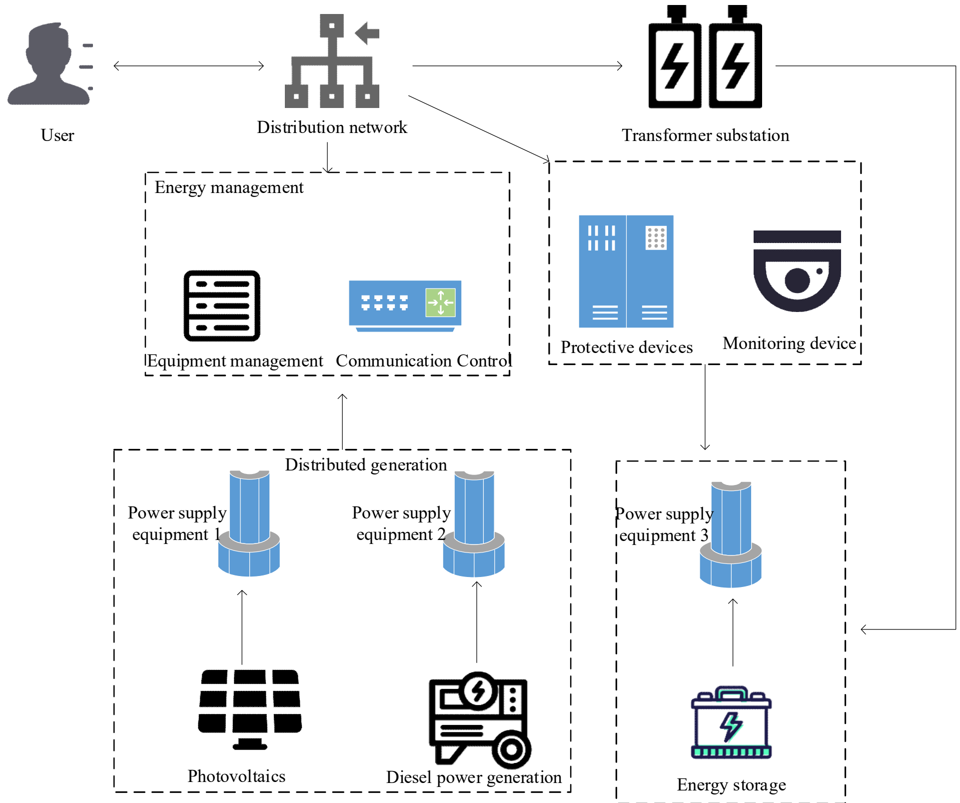

Figure 1: Coordinated operation structure of comprehensive energy DN

IV. Comparative Experiment on the Application of Comprehensive Energy DN

The comprehensive energy DN, as an important component of the entire power system, connects various links such as energy transmission, distribution, substation operation, and communication with users. This article tentatively optimizes the traditional comprehensive energy DN by collecting and analyzing the parameters of each link in the power supply process through a highly sensitive sensor network. It evaluates the operational quality of power supply equipment such as relays and power supplies, and predicts fluctuations in power supply stability through a more comprehensive inspection process. This can facilitate timely response to sudden power supply failures and efficient scheduling of coordinated operation between the power grid, power sources, and loads. However, the optimization of the comprehensive energy DN in this article still needs further experimental verification.

When conducting an application experiment on a comprehensive energy DN at a certain power company, it first confirms the distribution request of the system user. The distribution tasks in the same area were coordinated using traditional and optimized integrated energy DN, and the application experiments using traditional integrated energy DN were set as the control group. The application experiment of the optimized comprehensive energy DN can be set as an experimental group, during which the risk response performance, equipment management ability, and decision-making time of the energy network can be recorded. The performance of the optimized integrated energy DN with the introduction of highly sensitive sensor network and particle swarm optimization algorithm can be verified, and the application effects of the two integrated energy DN can be compared.

IV. A. Comparison of Risk Response Performance

This article conducts statistics on power supply faults in a certain area, using traditional and optimized integrated energy DN for processing. This article randomly samples 20 sets of fault handling processes for recording, and sets the experiment using traditional comprehensive energy DN as the control group. This article applies the optimized experimental setup of the integrated energy DN as the experimental group to evaluate the performance of two types of integrated energy DN in responding to sudden power supply failures. The establishment of evaluation standards is a prerequisite for accurately evaluating the risk response ability of comprehensive energy DN. In this evaluation, the upper limit of the evaluation index is 9, with 1-3 intervals indicating poor, 4-6 intervals indicating good, and 7-9 intervals indicating excellent. Figure 2 shows a comparison of risk response performance between traditional and optimized integrated energy DN.

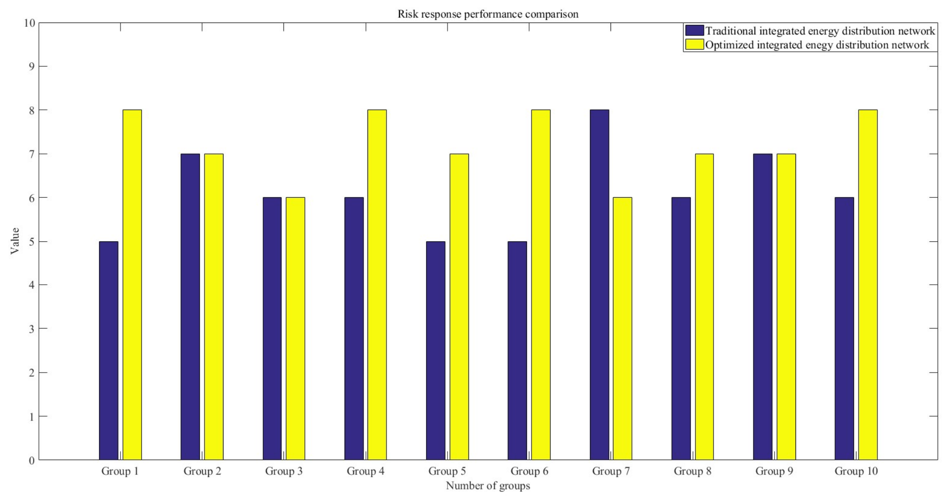

Figure 2: Comparison of risk response performance between traditional and optimized integrated energy DN

With the development of intelligent decision-making technology and highly sensitive electronic integrated circuits, higher requirements have been put forward for the construction of smart grids. The traditional comprehensive energy DN mainly obtains information through user reports and manual feedback, which results in delayed information acquisition, inability to solve sudden power supply failures in a timely and effective manner, and low automation of decision-making solutions. The integrated energy DN, which introduces particle swarm optimization algorithm and high sensitivity sensor network, can monitor the power supply process in real time. It can respond more promptly to sudden power supply failures and has a high degree of intelligence in decision-making solutions. As shown in Figure 2, in 10 traditional comprehensive energy DN risk response performance experiments, the average evaluation index was 6.1; in 10 sets of optimized comprehensive energy DN risk response performance experiments, the average evaluation index was 7.2. Compared to traditional integrated energy DN, the risk response performance evaluation index for optimizing integrated energy DN has increased by 18%. Advanced technology is not omnipotent. Tradition does not necessarily mean backwardness. Among the 10 comparative experiments, the evaluation index of the optimized system was not higher than that of the traditional system in the second, third, seventh, and ninth groups. Further exploration is needed in future research.

IV. B. Comparison of Equipment Management Capabilities

The comprehensive energy DN needs to collect and analyze the parameters of each link during the power supply process. The management ability of equipment plays a very important role, and real-time grasp of the working status of power supply equipment is of great significance for maintaining the stability of the power supply process and coordinating the operation of various departments. This article manages 30 power supply equipment in the same area using traditional and optimized integrated energy DN, and sets the experimental group that applies traditional integrated energy DN as the control group. This article sets up an experimental group that optimizes the comprehensive energy DN, records the number of power supply equipment failures under two different system management, and evaluates the equipment management capabilities of both systems. If the number of failures of power supply equipment is 0 within a month, the equipment management ability is optimal; If the number of faults in the power supply equipment is greater than 0 but less than or equal to 5, the equipment management ability is considered good; If the number of failures of power supply equipment exceeds 5, the equipment management ability is poor. Table 3 shows the comparison of equipment management capabilities between traditional and optimized integrated energy DN.

The optimization of power supply equipment management capability is the primary task for the comprehensive energy DN to achieve coordinated operation of source network load. The subtle control of the working status of power supply equipment can fully tap into the potential of various links in the power supply process, and promote the construction process of smart grids. The traditional comprehensive energy performance DN adopts a periodic inspection and maintenance mode for power supply equipment management, which consumes huge human resources and has little effect on equipment management. This article adopts a highly integrated wireless sensor network and adopts distributed power supply equipment management It can not only grasp the working status of power supply equipment in real-time, but also predict sudden power supply equipment failures, effectively preventing major accidents from occurring. As shown in Table 3, compared to traditional integrated energy DN, optimizing integrated energy DN has stronger equipment management capabilities.

Table 3: Comparison of equipment management capabilities between traditional and optimized integrated energy DN

	Traditional DN		Optimized DN	
	Failure frequency	Evaluation results	Failure frequency	Evaluation results
Device 1	3	Good	0	Excellent
Device 2	2	Good	0	Excellent
Device 3	7	Bad	0	Excellent
Device 4	0	Excellent	1	Good
Device 5	1	Good	0	Excellent
Device 6	0	Excellent	0	Excellent
Device 7	0	Excellent	0	Excellent
Device 8	2	Good	0	Excellent
Device 9	0	Excellent	0	Excellent
Device 10	3	Good	0	Excellent
Device 11	5	Good	1	Good
Device 12	0	Excellent	0	Excellent
Device 13	0	Excellent	0	Excellent
Device 14	6	Bad	1	Good
Device 15	1	Good	0	Excellent

IV. C. Comparison of Decision Times

The scheduling of various components in the integrated energy DN faces many uncontrollable factors. In order to realize the coordinated operation of source network load, the particle swarm optimization can be used to put forward a timely decision scheme for emergency and complex power supply failure problems. To verify the intelligent decision-making ability of optimizing the comprehensive energy DN, this article uses traditional and optimized comprehensive energy DN for intelligent decision-making of 20 sets of power supply fault problems, and records the decision-making time. It sets the experiments that apply traditional and optimized comprehensive energy DN as the control group and experimental group, respectively. Table 4 shows the comparison of decision-making time between traditional and optimized integrated energy DN.

Table 4: Comparison of decision times between traditional and optimized integrated energy DN

	Decision time for traditional DN (S)	Decision time for optimizing DN (S)
Group 1	30	12
Group 2	28	15
Group 3	34	14
Group 4	56	16
Group 5	27	15
Group 6	32	14
Group 7	36	14
Group 8	27	13
Group 9	41	15
Group 10	31	12

The decision-making plan for power supply faults in traditional integrated energy DN is generally carried out by relevant personnel with professional knowledge for problem analysis and plan formulation. The decision-making method of traditional comprehensive energy DN relies too heavily on professional knowledge and industry experts, while also consuming a large amount of labor costs. The optimization of the comprehensive energy DN in this article not only saves resources but also ensures the efficient generation of decision-making plans. It also has more objective and professional analysis and decision-making in the face of complex power supply faults. As shown in Table 4, during the process of solving 10 sets of power supply faults, the average decision-making time for traditional comprehensive energy DN was 34.2 seconds, while the average decision-making time for optimizing comprehensive energy DN was 14 seconds. Compared to traditional integrated energy DN, the decision-making time for optimizing integrated energy DN is greatly shortened.

V. Conclusions

In the era of rapid development of new energy, the demand for energy in society is constantly increasing. In order to meet economic development and daily life, the development and utilization of comprehensive energy DN has become one of the important topics to promote social progress. The comprehensive energy DN is an important way to promote social and economic development and stabilize residents' stable electricity consumption. This article mainly studied the characteristics and structure of integrated energy DN, and analyzed the operation process of traditional integrated energy DN. Based on the current application status of traditional DN in practice, the shortcomings of traditional integrated energy DN were summarized. In response to the problems encountered in the coordinated operation of traditional integrated energy DN, this article tentatively applied a highly integrated sensor network to collect parameters from various links in the power supply process of the integrated energy DN. Combined with particle swarm optimization algorithm, this paper processed and analyzed the data, and can timely and effectively analyze and make efficient decisions in the face of sudden power supply failures. It can also more effectively coordinate and allocate resources among various components when dealing with risk failures. This article conducted comparative experiments to verify the application effect of optimizing the comprehensive energy DN. By comparing the experimental results, this paper introduced the particle swarm optimization algorithm and the optimization of sensor networks. The integrated energy DN has different degrees of optimization improvement in risk response, equipment management and decision-making time. This can save a lot of cost and resources, while better maintaining the stability of the power supply process, and making the coordinated operation between power sources, power grids, and loads more flexible and efficient.

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