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SYSTEM PARAMETER DESIGN FOR COMMUNITY MICROGRID ENERGY SYSTEM BASED ON A BI-LEVEL OPTIMIZATION MODEL

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ABSTRACT

With the increasing use of renewable energy in the context of global climate change, microgrids are expected to be a promising form of accessing and distributing renewable energy sources. However, existing design methods for microgrid energy systems usually consider the system planning and system operation as separate problems, which cannot guarantee the safety, reliability and cost economy of microgrids from a holistic view. To fill this gap, we propose a system parameter design approach for community microgrid based on a bi-level optimization model. This approach can generate optimal system configuration parameters and operation parameters for a community microgrid energy system in an integrated way. To demonstrate the validity of the proposed approach, we use the construction and operation of a medium-sized community microgrid system in a southern-China city as the illustrative example. The results show that the generated system planning and operation strategies can effectively improve the reliability and lower the operation cost of the microgrid system without raising customers' power consumption expenditures. In addition, the influence of the environmental sensitivity of renewable energy and the dynamics of customers' power consumption patterns on the reliability and economy of microgrid are also examined and discussed. Our study contributes to the development of advanced design and operation methods for smart-community energy systems.

Keywords: smart community, microgrid energy system, system reliability, system economy

1. INTRODUCTION

Energy has been playing an increasingly significant role in the technological and economic development of human societies [1]. With the continuous growth of demand for energy and the limited reserves of fossil fuels, traditional power grid supply suffers from problems such as inflexible operation, high cost and poor environmental friendliness [2]. In order to solve the contradiction among energy demand, resource utilization and environmental protection, countries around the world are vigorously developing new energy supply modes characterized by clean energy and low carbon economy [3]. However, the distributed renewable energy such as photovoltaic and wind power has a random and fluctuating nature, which brings difficulties to the operation and dispatch of the power grid and limits the effectiveness of distributed power sources [4].

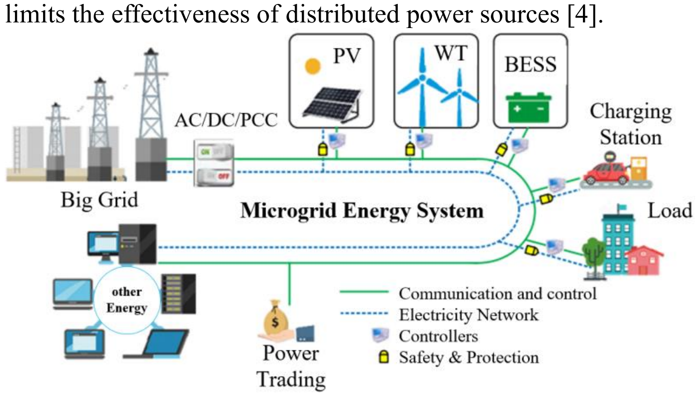

FIGURE 1: BASIC STRUCTURE OF A TYPICAL COMMUNITY MICROGRID.

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As a new energy supply and management mode, microgrid is an integrated energy supply system consisting of distributed power sources (e.g., wind turbines (WT), photovoltaic (PV)), energy storage units (e.g., Battery Energy Storage System (BESS)), loads (e.g., charging, lighting) and Energy Converter (e.g., AC (Alternating Current), DC (Direct Current), PCC (Point of Common Coupling)). Microgrids can be operated flexibly in grid-connected or islanded mode, effectively improving the operation flexibility, economy and reliability of power system and able to meet the various power needs in smart communities, as shown in Figure 1 [5-7].

With the advancement of information physical technology and network control technology, as well as the pressure from population growth and resource scarcity, integrated energy services and smart energy utilization models are becoming prevalent in industrial parks and residential communities. Microgrids are developing in the direction of multiform (e.g., Island or Grid-connected), intelligent regulation and real-time interaction between supply and demand. Traditional system architecture, planning methods and optimization models are challenged to adapt to the construction of microgrids in smart communities (e.g., economic issues, safety accidents) [8]. Therefore, it is important to develop new operation and planning methods to adapt to different operation and control modes and energy use characteristics of smart community microgrids.

In this paper, we focus on the planning and operation levels of an intelligent community microgrid in a multi-dimensional uncertain environment. We first analyze the multidimensional uncertainties (e.g., capacity, quality, failure) in the operating environment of smart community microgrids. Then we propose a new approach for the system design of community microgrid based on EIoT (Energy Internet of Things), consider how to configure smart community microgrids and how to arrange the power output of different types of energy sources. A medium-sized residential community in southern-China is used as an example to demonstrate that the proposed approach can provide secure, reliable and flexible microgrid system for the community. The main contributions of this paper include:

(1) A community microgrid system architecture based on EIoT is proposed. The community microgrid architecture of wind-solar-storage based on EIoT is constructed to connect various heterogeneous energy networks in community microgrids and to set the groundwork for community microgrid's scheme and operation. This architecture combines the technical characteristics of wind, solar, electricity and energy storage units, and can analyze the power output characteristics of distributed energy sources in microgrids and the multidimensional uncertainty of the operating environment.

(2) An optimization model for the system parameter planning of the community microgrid is developed. Analytical models for capacity, cost and environmental impact as well as constraint models for power balance, SOC (State of Charge) and reliability are established. Optimization algorithms are used to obtain the optimal configuration parameters for the community microgrid, providing support for the operation and scheduling of the community microgrid.

(3) An operational level co-optimization model is established. Through the analysis of energy resources, microgrid capacity and configuration scheme of a medium-sized community in southern-China at the planning level, a dynamic economic dispatching model of the microgrid system is established. With selecting 24 h as the time scale, this model can obtain the optimal operation scheme of the community microgrid and feed the decision results to the planning level.

The rest of this paper is structured as follows. Section 2 introduces the bi-level optimization theory and related work in community microgrid. Section 3 provides a system architecture based EIoT of the intelligent community microgrid and a bi-level optimization model for the planning and operation of microgrid. Section 4 presents a case study on community microgrid design to validate the proposed approach and discusses the study results. Section 5 provides a summary of our work and suggests the future research directions.

2. THEORY AND RELATED WORK

2.1 Bi-level Optimization Theory

Bi-level optimization is widely used in many design and planning problems, which is divided into upper and lower optimization objectives [9,10]. The optimization of community microgrid can also use the bi-level structure. The results of the upper planning level generally affect the operational scheduling of the lower level, while the lower level feeds the decision results to the upper level. There are certain interaction factors between the upper and lower models, thus achieving mutual decision-making between the upper and lower level. The model and definition of bi-level optimization was first deduced by Bracken and McGill [11], and the mathematical expression can be generally written as follows:

$$\begin{cases} \begin{cases} F_1 = min\, F(x,y) \\ s.t. G(x,y) \le 0 \end{cases} \\ \begin{cases} F_2 = min\, f(x,y) \\ s.t. H(x,y) \le 0 \end{cases} \end{cases} \tag{1}$$

where, F(•) and f(•) are the objective functions of upper and lower level, x and y are the decision variables, and G and H are the constraints, respectively.

The key control variables created by the various energy conversion planning models serve as the foundation for optimizing microgrid operation, and they reflect the characteristics of hierarchical decision-making. So, according to the energy supply mode characteristics, which include multiple power sources complement, active load coordination and two-way electrical energy interaction, the bi-level optimization basic model of community microgrid is formed based on bi-level planning theory, as shown in Figure 2 [12,13]. The upper level of planning, consisting of wind, solar and energy storage, obtains the basic configuration and parameters of the system, including the type, number and capacity of equipment. The lower level is an operational optimization model that provides the optimal dispatch decision for each energy subsystem, with the two levels interacting with each other [14].

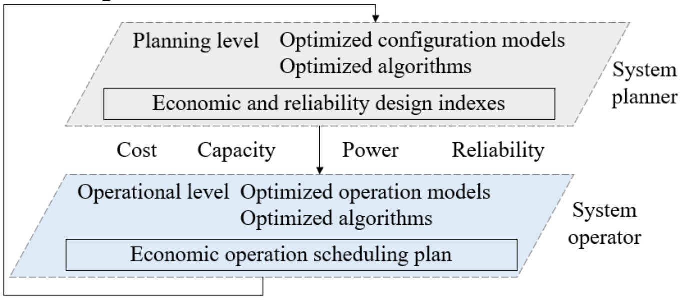

FIGURE 2: BASIC BILEVEL OPTIMIZATION MODEL.

The upper and lower level in the bi-level optimization model address distinctive objectives with different time considerations. The upper level aims at system design optimization for long-term planning, while the lower level deals with system scheduling optimization for daily operations. As shown in Figure 2, the upper level serves as the system design module, which determines the optimal configuration of the microgrid system (e.g., the number and capacity of wind turbine, photovoltaic and energy storage units). After obtaining such system parameters, the lower level acts as the system scheduling module, which determines the optimal operating strategy of the microgrid system in daily scheduling (e.g., how much electricity power is purchased from or sold to the public grid per day). Over time, the lower level's operational decision results, such as capacity and deployment methods, are fed back to upper level for major maintenance of the microgrid system (e.g., add or obsolete certain wind turbine, photovoltaic and energy storage units).

2.2 Related Work

With regard to the economy, reliability and security of new community energy systems containing microgrids, academia and research institutions have focused on the core technology, architecture, planning and design of microgrids as well as operation and scheduling optimization [15]. The research on architecture is mainly focused on the operation mode, energy harvesting mode and load composition. Typical studies include Island Microgrid [16], Grid-connected Microgrid [17] and Combined Grid-Connected and Island Microgrid [18]. These approaches are characterized by their simplicity of implementation, but are overly dependent on available resources and application scenarios and do not fully consider the generalization of the planning architecture.

Planning and design research is to obtain design parameters by algorithmically optimizing the performance of the microgrid to improve the economy and practicality of the microgrid, such as multi-objective optimization algorithms, typically represented by PSO (Particle Swarm Optimization) [19], GA (Genetic Algorithm) [20] and NSGA-II (Non-dominated Sorting Genetic Algorithm-II) [21]. Such algorithms have certain limitations in single and simple scenarios, resulting in low efficiency and inaccuracy of parameter optimization. Another category of methods is to integrate application scenario features into parameter design. Typical methods include SQP-GS (Sequential Quadratic Programming with Gradient Sampling) [22], Nelder-Mead [23] and SCA-AOA (Sine augmented scaled arithmetic optimization algorithm) [24]. These methods effectively avoid the influence of different application scenarios on parameters, but they do not consider the multidimensional form (e.g., offline, online) and uncertainties of community electricity consumption. They cannot ensure the safe and stable operation of the distribution network. The typical methods include Hierarchical Optimization [25], Bi-Level Robust Optimization [26,27] and Tri-level optimization [28]. Such methods tend to lead to the community resource distribution with unbalanced load and poor economy because they consider hierarchical optimization to achieve multi-energy optimization, but less consider collaborative optimization between planning level and operational level.

In recent years, researchers have made some progress in the operational and planning methods of micro power networks. However, there are still limitations in the design methods of community microgrid architecture, planning parameters design methods and collaborative optimization operation methods under multi-dimensional uncertain environment. Therefore, this paper intends to preliminarily address the above issues and consider both the system parameter planning and operation optimization of smart community microgrids. Our research will balance the benefits of smart community energy systems in both planning and operation stages.

3. SYSTEM ARCHITECTURE AND OPTIMIZATION MODEL FOR THE COMMUNITY MICROGRID ENERGY SYSTEM

3.1 Basic Architecture of Community Microgrid System

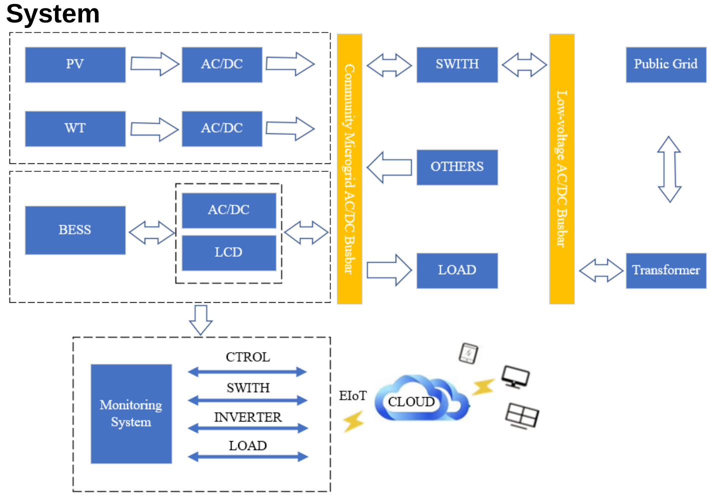

FIGURE 3: SCHEMATIC DIAGRAM OF THE MICROGRID SYSTEM STRUCTURE.

Figure 3 shows a schematic diagram of the microgrid system studied in this paper. It consists of wind turbine, photovoltaic cell, battery energy storage system and load, which are connected to the microgrid through AC/DC (Alternating Current/Direct Current) converter and finally to the public grid through point of common coupling.

Based on the above microgrid system structure and bi-level optimization theory, in order to achieve interconnection and interoperability, efficient and stable operation between multiple heterogeneous energy networks in the community microgrid, we propose a community microgrid architecture based on EIoT using IoT technology [29], as shown in Figure 4.

The system takes the energy supply, energy management, equipment management, energy consumption analysis and energy intelligent operation and maintenance of energy flow as the main line. It connects the various links of energy production, distribution and transmission, consumption and energy saving, combines the interconnection of people and things. The architecture constitutes the community intelligent micro-grid planning and operation system architecture, realizes cloud-side interaction through cloud services, enhances system connectivity and collaborative computing capabilities, and provides the basis for community micro-grid planning and operation. It provides the basis for collaborative optimization. The architecture adopts a hierarchical and distributed structure, with the following five main components.

(1) Sensor layer: Connected to various sensors in the micro-grid system, it collects real-time information on wind power generation devices, photovoltaic power generation devices, energy storage systems and electricity consumption loads, providing basic data for the operation and management of the micro-grid.

(2) Network layer: The data collected from the sensing layer is converted and stored by the intelligent gateway in the network layer, and then shared and fed back through the wired and wireless networks.

(3) Data layer: The data layer mainly completes data processing, data storage and data interaction, and obtains useful information from the massive basic data and feeds it back to the platform layer to provide effective solutions for the microgrid's operation and decision-making. The data processing in this layer mainly involves data collection, data cleaning and data analysis. The algorithms used for data processing include cluster analysis (e.g., K-means, K-modes, CLARANS), regression analysis (e.g., Linear Regression, Logistic Regression, Polynomial Regression), feature analysis (e.g., Principal Component Analysis, Factor Analysis) and so on.

(4) Application layer: It contains application servers and cloud servers, which can provide human-computer interaction interface for users through web and app on PC (Personal Computer) or mobile side, and various users of the operation layer can access and operate the platform.

(5) Safety layer: The main factors that trigger fires in the micro-grid are collected and analyzed without interruption, safety hazards in the micro-grid system are discovered in real time, and the safety status of community electricity consumption is assessed in real time.

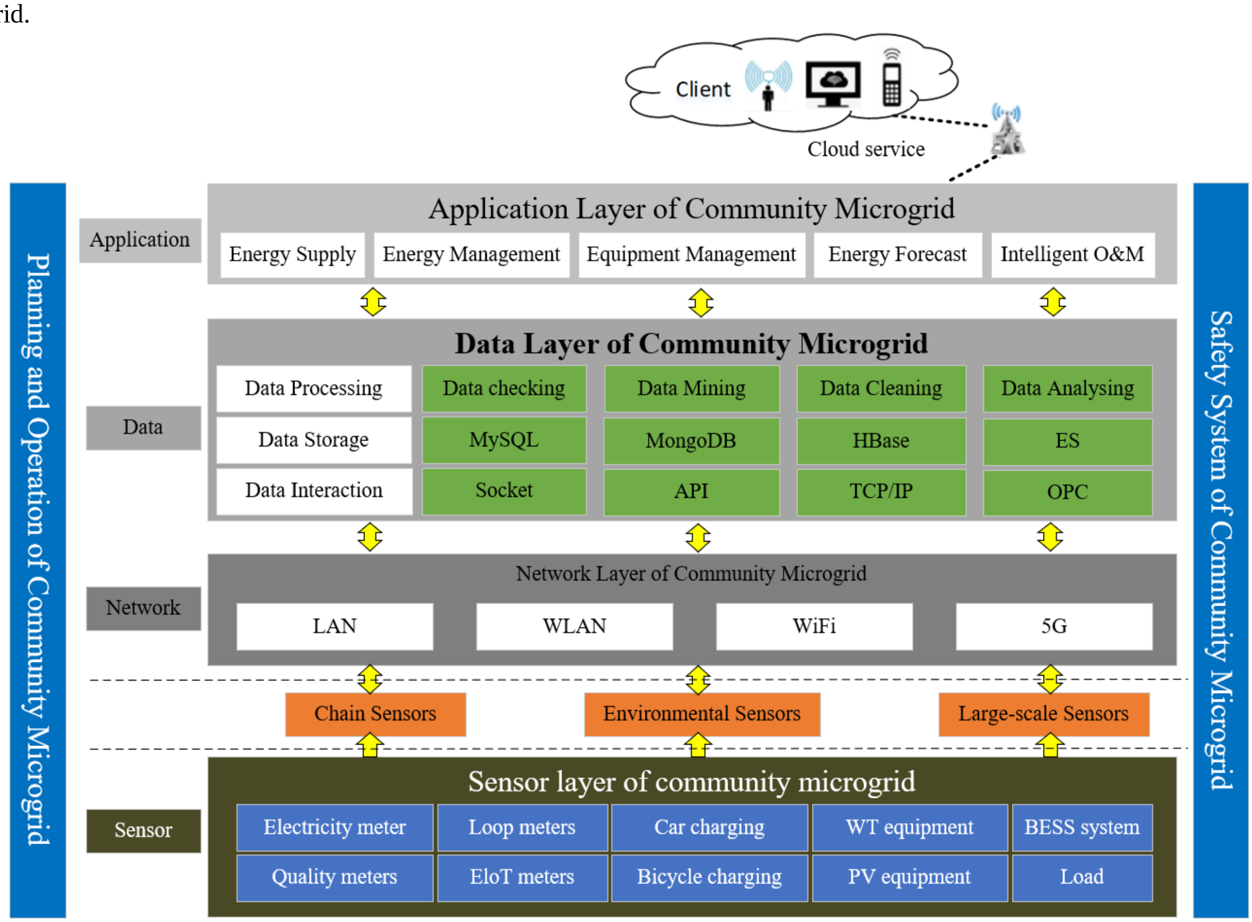

FIGURE 4: MICROGRID SYSTEM ARCHITECTURE BASED ON EIOT.

3.2 Optimization Models

3.2.1 System Models

(1) PV Model

The output power of a PV is related to the local light intensity and the output power can be expressed as [30].

$$P_{\mathrm{pv}} = \xi \eta_m A_p \eta_p \cos\theta \quad (2)$$

where, P_{PV} is the actual PV power, ξ is the light intensity, η_m is the light intensity conversion efficiency, A_p is the PV panel area, η_p is the PV cell efficiency, and θ is the light angle.

(2) WT Model

The output power of the fan is related to the wind speed. The relationship between the output power P_{WT} of the fan and the wind speed v can be expressed as.

$$P_{WT} = \begin{cases} 0, v \le v_{\mathrm{in}} or v \ge v_{\mathrm{out}} \\ \frac{v^3 - v_{in}^3}{v_r{}^3 - v_{in}^3} P_{rate}, v_{\mathrm{in}} \le v \le v_r \\ P_r, v_r \le v \le v_{\mathrm{out}} \end{cases} \quad (3)$$

where, P_{WT} is the actual power, P_r is the rated power. According to the actual situation, v_{in} is 3m/s, v_{out} is 25m/s, v_r is 14m/s.

(3) BESS Model

Energy storage systems can alleviate the uncertainty and intermittency of distributed energy in community microgrids, and the charging and discharging states of energy storage systems are expressed as.

$$P_{BESS}(t) = \begin{cases} P_{BESS}(t-1) + [P_{\mathrm{total}}(t) - \frac{P_{\mathrm{load1}}}{\eta_{\mathrm{inv}}})] \bullet \eta_{BESS}, Charge \\ P_{BESS}(t-1) - \left[\frac{P_{\mathrm{load1}}(t)}{\eta_{\mathrm{inv}}} - P_{\mathrm{total}}(t)\right], Discharge \end{cases} \quad (4)$$

$$P_{\mathrm{total}}(t) = P_{PV}(t) + P_{WT}(t) \quad (5)$$

Where, $P_{BESS}(t)$ is the stored energy at t time, $P_{load1}(t)$ is the electrical load at t time, $P_{total}(t)$ is the supply at t time, η_{inv} and η_{BESS} are the work efficiency and charge or discharge efficiency.

3.2.2 Planning Level Models

(1) Objective functions

In this paper, by selecting the system economy and environmental friendliness during the construction cycle of community microgrid as indicators for system planning, it can be described as [31].

$$\mathrm{Min}\ \mathrm{F}_1 = \min[f_1(x), \mathrm{f}_2(x)],\ \boldsymbol{x} = (x_1, \mathrm{x}_2) \in R^D \quad (6)$$

where, f_1 and f_2 denote the economic and environmental objectives respectively, and $\boldsymbol{x} = [X]T$ (e.g., WT, PV and BESS) is a vector of optimization variables that optimizes the capacity of distributed power sources, energy storage systems, etc. R^D is the decision variable space.

1) Economic objectives

The economy mainly considers the construction and operation costs of the microgrid composed of wind, solar and energy storage, and the total cost of the microgrid under the satisfaction of the system equation and inequality constraints can be expressed as [32].

$$f_1(x) = C_{\mathrm{WT}} + C_{\mathrm{PV}} + C_{\mathrm{BESS}} + IR \quad (7)$$

where, C_{WT}, C_{PV}, C_{BESS} and IR represent the total cost of wind, solar and storage respectively and the cost of interruptible load compensation.

$$C_{WT} = N_{WT}\left(e_{WT} P_{WT} \frac{r(1+r)^m}{(1+r)^m - 1} + u(P_{WT})\right) \quad (8)$$

$$C_{PV} = N_{PV}\left(e_{PV} P_{PV} \frac{r(1+r)^m}{(1+r)^m - 1} + u(P_{PV})\right) \quad (9)$$

$$C_{BESS} = N_{BESS}\left(e_{BESS} P_{BESS} \frac{r(1+r)^m}{(1+r)^m - 1} + u(P_{BESS})\right) \quad (10)$$

where, N_{WT}, N_{PV}, N_{BESS} denote respectively the number of WT, PV, BESS, $\mathrm{e}_{WT}, \mathrm{e}_{PV}, \mathrm{e}_{BESS}$ denote respectively the unit cost of them, P_{WT}, P_{PV}, P_{BESS} denote respectively the output power, m denotes the life of them, r denotes respectively the discount rate of them, and $u(P_{WT}), u(P_{PV}), u(P_{BESS})$ denote respectively the operating costs of them.

In this context, interruptible load means that the microgrid adopts an interruption strategy for non-critical loads at full load and compensates them economically.

$$IR = A + B \times P_H + C \times P_H^2 \quad (11)$$

where $\mathrm{A} = 6.14, \mathrm{B} = 1.2, \mathrm{C} = 1.23 \times 10^{-4}$ denote interruption cost factors according to previous research [32] and P_H denotes interruption power respectively.

2) Environmental objectives

As the WT and PV of the microgrid studied in this paper are clean energy sources, their environmental costs are not considered, and the environmental nature mainly considers the carbon emission penalty cost, which refers to the carbon emission penalty cost of the thermal power units resulting from the system's purchase of electricity from the grid.

$$f_2(x) = \begin{cases} k_e \sum_{n=1}^{N} P(n) \Delta t, P(n) > 0 \\ 0, P(n) \le 0 \end{cases} \quad (12)$$

where K_e is the carbon penalty cost factor per unit of electricity. The carbon penalty cost factor is to account for the carbon emissions associated with purchasing additional power from the public grid when the community microgrid system experiences a power shortage, since the wind-solar power generation units in microgrids do not generate carbon emissions. The public power may come from thermal power plants and produce carbon emissions. The carbon penalty cost factor quantifies the environmental costs associated with these additional carbon emissions. In our research, the carbon penalty cost factor is set to 0.598 kg/kWh according to reference [33]. And $P(n)$ is the exchanged power.

(2) Constraints

Since this is a multi-objective optimization problem, the objective function needs to be constrained within a certain range in order to ensure that the optimization objective is within an acceptable range.

$$f_i < f_{i,max} \quad i = 1,2 \quad (13)$$

3.2.3 Operational Level Models

(1) Objective functions

The time scale selected for the operation level scheduling optimization studied in this paper is 24h, and the daily operation cost is used as the objective function, mainly including the daily system power purchase cost and power sales revenue [34].

$$F_2 = min[\, y_1(x) + y_2(x)] = min \sum_{n=1}^{N} C(n)\, P(n) \Delta t \quad (14)$$

where $y_1(x)$ refers to the daily power purchase cost of the microgrid system, $y_2(x)$ is the daily revenue of the system from power sales, $P(n)$ is the power exchanged between the microgrid and the grid, $P(n) > 0$ means power purchase, $P(n) < 0$ means power sales, and $C(n)$ is the time-of-use tariff.

$$C_n = \begin{cases} C_{in}(n), P(n) > 0 \\ C_{out}(n), P(n) < 0 \end{cases} \tag{15}$$

where $C_{in}(n)$ and $C_{out}(n)$ denote the purchase price and sale price of electricity at time n, respectively.

(2) Constraints

1) Power balance constraint

$$P_G - P_S + P_{BESS} = P_L - P_{PV} - P_{WT} \tag{16}$$

where P_G indicates purchased power, P_S indicates power sold, P_{BESS} indicates energy storage, P_L indicates load power, P_{PV} indicates PV power and P_{WT} indicates wind power.

2) Energy storage SOC constraint

$$SOC_{min} \le SOC_t \le SOC_{max} \tag{17}$$

where SOC_{min}, SOC_{max} denote the storage charge state extremes respectively, and SOC_t denotes the storage charge state at time t.

3) System operating constraint

The following constraint should be met for the purchase and sale of electricity from community microgrid systems.

$$\begin{cases} 0 \le P_G \le P_{Gmax} \\ 0 \le P_S \le P_{Smax} \end{cases} \tag{18}$$

where P_{Gmax} and P_{Smax} indicate the system purchase and sale electrode values respectively [35].

3.3 Model Solving Methods

Based on the above microgrid architecture and models, the model is decomposed into a planning level and an operation level for collaborative optimization, and the optimization model is shown in Figure 5.

The basic process is:

(1) The objectives and parameters for the system to be obtained are determined by independently analyzing the electricity demand, electricity forecast, environmental factors, and development trend for the community microgrid.

(2) The microgrid structure will be built accordance with the findings of the analysis, include energy siting and energy planning. The objective functions and constraints for optimization at the planning level are established, and an optimization algorithm is chosen to solve for the microgrid's optimization parameters.

(3) The actual operation of the microgrid is simulated by the optimal design parameters solved at the planning level, the operational efficiency optimization model and constraints are established. The optimization algorithm is designed to solve the problem, obtain the optimal operational dispatch results of the community microgrid.

With the help of EIoT technology and community microgrid system architecture above, from a vertical perspective, coordination can be realized between network, power, load and storage. From a horizontal perspective, multi-energy complementarity can be realized.

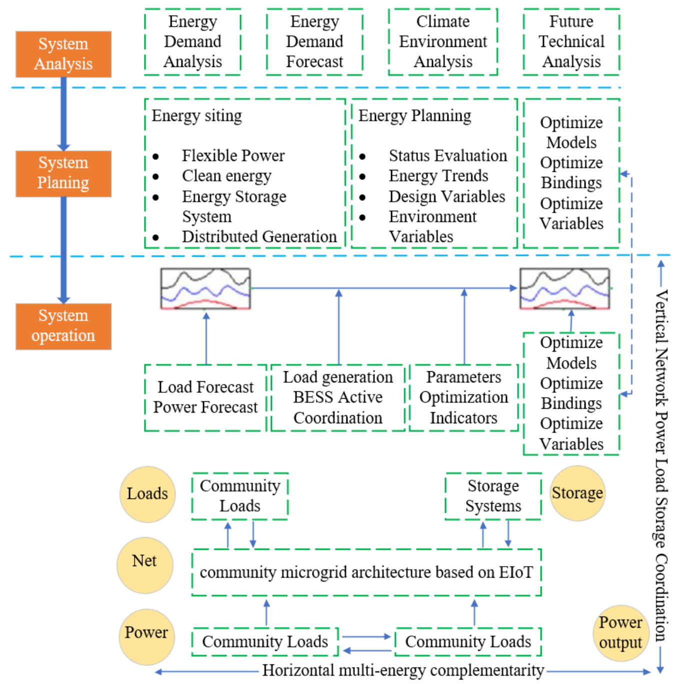

FIGURE 5: METHODOLOGICAL STRUCTURE FOR COORDINATED OPTIMIZATION OF MICROGRID.

In this paper, the planning level is solved by a particle swarm optimization algorithm to obtain the parameters. The operation level is solved by a linear programming algorithm to obtain the optimal operation strategy, simulating the actual operating conditions of community microgrid. In the collaborative bi-level optimization process, the lower level model feeds the scheduling results to the upper level for the evaluation of the individual adaptation degree of the optimization algorithm. Based on these, the upper level updates the WT, PV and BESS capacity of the microgrid through evolutionary computation operations with the economic and environmental objectives of the microgrid. These results will be fed back to the lower level until the algorithm converges and obtains the planning and design scheme of the microgrid.

4. EXPERIMENT AND DISCUSSION

4.1 Experiment Description and Setting

To verify the feasibility of the models and methods presented in this paper, we choose a residential community in southern-China as the background of the case study. The models and methods are implemented on a simulation platform based on MATLAB R2018a with the CPLEX solver and YALMIP toolkit. The platform runs on a computer with Intel i7-11700 processor and GTX1660 Ti-6G discrete graphics card. PV, WT and BESS system are built in the vacant area of the community. Based on the predicted wind, solar and power load, a bi-level collaborative optimization model is used to plan and schedule the operation of the community microgrid. By choosing one day as a calculation cycle and obtaining data every 15 minutes (i.e., 96 data points in total), the predicted trend of typical daily load, PV and WT output can be obtained, as shown in Figure 6. Assuming that the maximum charging and discharging power of BESS in the microgrid is 30kW, the capacity is 50kWh, and the interruptible load accounts for 15% of the total load, the microgrid power parameters are shown in Table 1, and the time-sharing tariff of electricity is shown in Table 2.

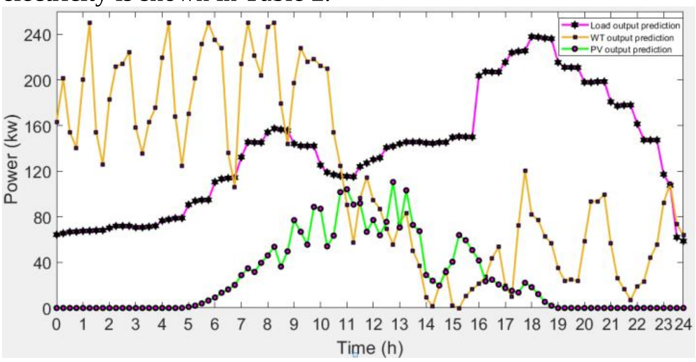

FIGURE 6: THE PREDICTED TREND OF COMMUNITY MICROGRID IN TYPICAL DAILY CYCLE.

TABLE 1. PARAMETERS OF DISTRIBUTED POWER IN MICROGRID

Type	Power (kW)		Cost(¥/kW)	Life(a)
	Max	Min		
WT	30	0	0.0296	10
PV	180	0	0.0096	20
BESS	30	0	0.0401	10

TABLE 2 THE TIME-SHARING TARIFF OF ELECTRICITY

Time	Buy Price (¥/kWh)	Sell Price (¥/kWh)
00:00~06:00	0.25	0.22
06:00~09:00	0.53	0.42
09:00~14:00	0.82	0.62
14:00~17:00	0.53	0.42
17:00~22:00	0.82	0.65
22:00~00:00	0.53	0.42

4.2 Experiment Results and Discussion

Figure 7 shows the Pareto frontier solution for the optimal configuration of the community microgrid planning level considering economy and environmental friendliness. From the figure, it can be seen that the relationship between the cost of environmental friendliness and the cost of economy is contradictory, and three of the representative regions are taken for discussion. Since different communities have different requirements on power supply system characteristics, the corresponding microgrid structures and configuration parameters vary. Communities with higher economic requirements can choose the configuration near region 1, when the community builds the smallest microgrid configuration and purchases the largest amount of electricity from the external grid, leading to increased environmental treatment costs. For communities that focus on clean and environmentally friendly energy, they can choose a configuration near region 3, where the microgrid is planned to have the lowest environmental output costs, but the cost of building the microgrid is large. Communities that wish to balance economy and environmental friendliness can choose the configuration parameters in region 2. In summary, communities can choose the reasonable microgrid planning according to their actual needs.

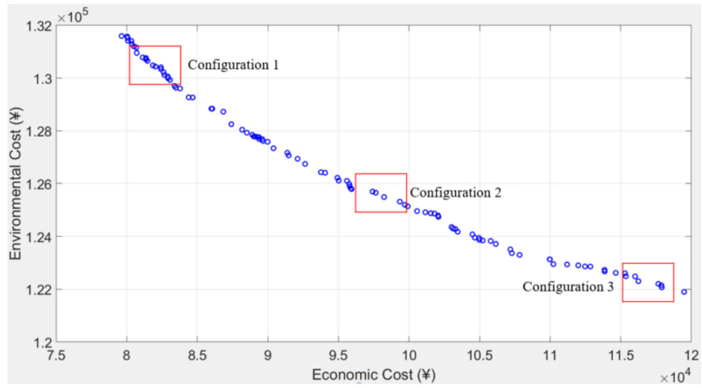

FIGURE 7: CONFIGURATION RESULTS OF THE COMMUNITY MICROGRID PLANNING LEVEL.

Figure 8 shows the SOC (state of charge) of BESS (battery energy storage system) in community grid. We can see that the SOC of the BESS has a large downward trend from 10:00 to 15:00 at noon and from 18:00 to 21:00 at night. Comparing the output curve of the wind-solar power unit and the load output curve, we can see that the wind-solar power output is far from satisfying the load demand at this time. Under the premise of satisfying the economic operation, there is a certain power shortage that needs to be replenished by the BESS, which can basically realize the full consumption of renewable energy and meet the purpose of the lowest cost of energy storage operation. At the same time, real-time dispatching of electricity power according to the SOC curve of BESS can play a role in peak-shaving and valley-filling for the big electricity grid, and can effectively reduce the operating cost of community microgrid.

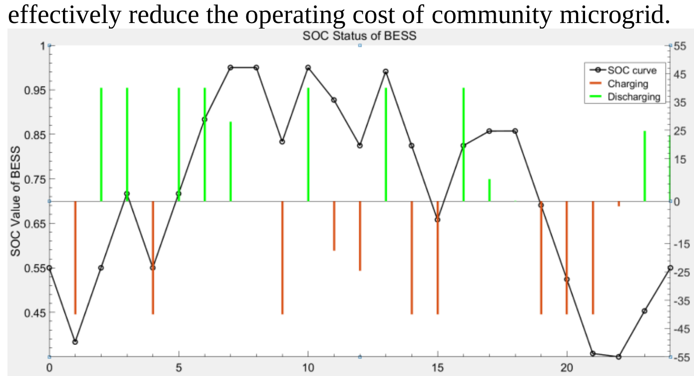

FIGURE 8: SOC STATUS OF THE BESS IN COMMUNITY MICROGRID.

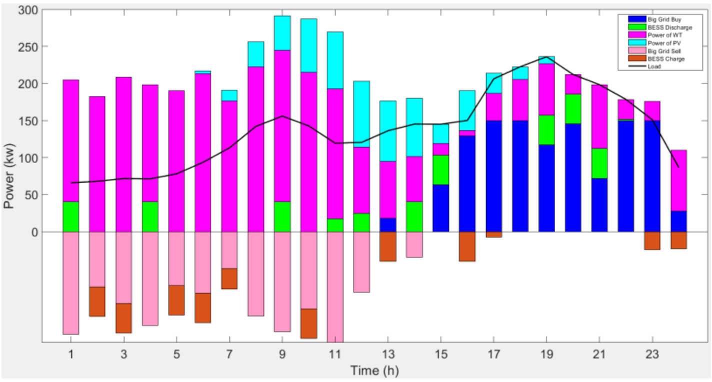

FIGURE 9: ECONOMIC OPERATION AND DISPATCH OF COMMUNITY MICROGRID SYSTEM

Figure 9 presents the analysis results of a community microgrid used a bi-level optimal operation configuration solution in one working day. When we choose economic dispatch plan, during the peak times at night, the community power load is very high. Since the PV arrays cannot provide electricity power, the needed power can be supplied by WT and BESS together. At the same time, the time-sharing tariff can impact the community microgrid system operation. In the lower and normal tariffs period, we can purchase electricity power from the public grid to charge the BESS. At the period of higher tariffs, the microgrid system would prioritize to use the WT and PV to meet the community residents' load demand. The shortfall load is supplemented by BESS discharges, and the electricity power will not be bought from the public grid. During the period of lower load, the BESS can be charged. The microgrid needs to track the output power of the WT and PV, monitor the SOC of BESS in real-time, adjust the output power, and reduce the charging cycles of the BESS to improve its life.

5. CONCLUSION

In this paper, considering the technical characteristics of wind power, photovoltaic, battery energy storage system and power used by community residents, we propose the community microgrid architecture of wind-solar-storage based on EIoT. Taking into account the random and intermittent nature of the output power of WT and PV, the premise of meeting the system constraints, and the economic and environmental objectives of the microgrid, we present a bi-level optimization design and operation model for community microgrid system, including the planning level model and the operational level model. The bi-level optimization approach can realize power source scheduling optimization between the distributed power in community microgrid. At the same time, the PSO algorithm and linear programming are used to solve the bi-level optimization problems.

We demonstrate the effectiveness of the proposed approach by using a community microgrid design in southern-China as the case study. From the case study results, we have the following findings:

(1) The economic and environmental performance of the community microgrid system is a pair of conflicting objectives, and the optimization results show a strong coupling between the capacities of the power devices. We can choose the reasonable microgrid planning configuration according to power needs and environmental requirements.

(2) The BESS can mostly realize the full consumption of renewable energy. Real-time dispatching the SOC curve of BESS can effectively reduce the operating cost of community microgrid.

(3) The power of PV arrays, WT and BESS can coordinate with each other, enabling the heterogeneous energy systems in the same community microgrids to work at optimal condition. This coordination can also reduce the operating costs of community microgrids, improve the environmental and reliability objectives, and form optimal community microgrid operation plans.

One limitation of this paper is that the developed optimization models lack consideration of different application scenarios in microgrid clusters. In further research, we will comprehensively consider the impact of the uncertainties in the operating environment on the scheduling plan, and build a collaborative optimization model for heterogeneous energy systems. We will consider different users' power consumption habits, different usage environments and more efficient solutions to the optimization problem. Machine learning algorithms can also be used to predict the scheduling plans, and provide a basis for remote intelligent operation and maintenance of microgrids by combining with cloud service technology.

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