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Active and Reactive Power Cooperative Management Method of Distributed Generation Based on Dispatching and Cloud Platform

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Abstract. With the massively distributed generation (DG) connected to the distribution network (DN), the traditional operation control method of the DN is facing severe challenges. To resolve this problem, a hierarchical and partition dispatching method of DG based on dispatching and cloud platform (DCP) is proposed in this paper. First, a DCP is built based on cloud computing technology to standardize the management and analysis of massive DG' operation data. Second, relying on the DCP, based on the Copula theory, the joint modelling method of regional DG is present considering the Spatial-temporal characteristics of DG, which can accurately describe the randomness of massive DG. Finally, according to the voltage level and jurisdiction, the DCP is subdivided into three layers to realize the hierarchical and partition control of massive DG. A case study on the IEEE-33 bus test distribution system verifies the effectiveness of the proposed method.

Keywords: active distribution network, dispatching and cloud platform, distributed generation, hierarchical and partition control

1. Introduction

With various kinds of distributed energy resources (DERs) connected to the distribution network (DN), the traditional operation control of the DN has become more and more complex. The operation characteristics of these DERs represented by distributed generation (DG), i.e., wind turbines (WTs) and photovoltaic (PVs), are quite different from those of traditional generation units. Therefore, the existing scheduling methods need to be changed. In this context, the concept of an "active distribution network" (ADN) arises at the historic moment, whose goal is to actively and flexibly control the internal DERs of the DN [1]. However, due to the fast response speed and strong uncertainty, the DG are difficult to schedule. In addition, a large number of different types of DERs access to the network, such as WTs, PVs, micro-gas turbines (MTs), and energy storage (ES), with different operating response characteristics, which will also make the system scheduling process more complex [2]-[3].

To resolve the above challenges, researchers have done a lot of research on smart grids [4]. There are some preliminary discussions on the construction of smart grid dispatching technical support system using cloud computing technology (CCT), which can be used as inspiration for related works, that is, the application of CCT to the construction of massive data storage and processing, system unified management and flexible expansion, computing capacity integration and other problems [5]. Reference [6] constructs a cloud disaster preparedness system with integrated power grid dispatching and mutual preparation through the application of cloud computing technology, which can effectively improve the stability of power grid operation and the ability of disaster prevention. In [7], based on the cloud computing delivery model, combined with power grid business requirements, such as power grid model, data, search, planning, computing, etc., an application framework is designed to effectively integrate CCT and dispatching automation system. Through the big data processing power of CCT, the dispatching and cloud framework. Topology and workflow are designed in [8]. The prototype conceptual design of the dispatching automation system based on CCT is carried out in [9]. The concept of power grid operation data pool and the architecture solution of dispatching automation system based on CCT is proposed in [10]. Besides, CCT is also adopted to study cloud simulation, information standardization, big data analysis, intelligent scheduling and other ADN technical problems [11-19].

The above-mentioned literature has made a useful attempt on the massive DG management solution. However, these researches are too abstract and general, only stay at the theoretical level, and cannot exploit the advantages of CCT for exact modelling and coordinated management of DG, which has important practical significance and is also the focus of this paper. In short, the contributions of this paper are summarized as follows:

(1) the cloud computing technology is introduced into the collaborative management system of the distribution network to build a dispatching and cloud platform. Relying on the data processing capability of the DCP, the joint model of massive DG is presented, which weakens the impact of renewable energy sources' randomness on the DN. Besides, the proposed scheduling and control system standardizes the management of DG.

(2) Based on the joint modelling technology of DG and the establishment of DCP, a hierarchical and partition control framework of DG is proposed, which reduces the management and control difficulty of massive DERs on the distribution side.

The structure of this paper is organized as follows. Section II introduces the structure of dispatching and cloud platform, the joint modelling of distributed generation and the hierarchical and partition regulation framework of an active distribution network based on DCP. Section III describes the active and reactive power collaborative management model of DG. Section IV carries out the case study and the analysis. Section V gives the conclusion.

2. Hierarchical and Partition Control Framework Based on Dispatching and Cloud Platform

2.1. The Structure of Dispatching and Cloud Platform

According to the classical delivery model of cloud computing and the principles of open components, open architecture and open ecology, each dispatching and cloud platform node is composed of three layers, i.e., infrastructure as a service (IaaS), platform as a service (PaaS) and software as a service (SaaS), as shown in Fig.1.

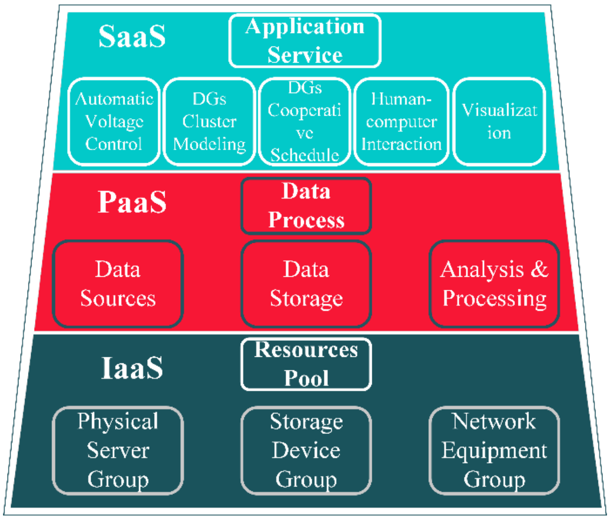

Fig. 1: Schematic diagram of DCP composition

The IaaS layer establishes a pool of terminal resources by virtualizing physical IT resources such as servers, storage devices, and network devices. Therefore, the coverage monitoring, efficient allocation and intelligent management of terminal resources can be realized.

PaaS layer is an important foundation for DCP, which embodies a series of cloud ecological characteristics, such as standardization, openness and service. It mainly includes supporting the storage, analysis and processing of various types of data. By standardizing the communication protocol and standardizing the data format, the sharing and fusion of different professional data are achieved, and the data exchange efficiency of the system is improved. The PaaS layer can call all kinds of resources of the IaaS layer in real-time, and provide the development environment and standardized service interface for the SaaS layer. According to the operational characteristics and business requirements of power grid regulation and control, the DCP divides the PaaS layer into four supporting sub-platforms from the perspective of data dimension: model data cloud platform (MDCP), operational data cloud platform (ODCP), real-time data cloud platform (RtDCP) and big data platform (BDP).

The SaaS layer is the application layer of DCP. SaaS can call the standard interface provided by the IaaS and PaaS directly in a software-defined form. According to the concept of "fat service and thin client", SaaS provides cloud users with basic data retrieval and query, automatic voltage control, distributed power cluster modelling, distributed power supply cooperative scheduling, human-computer interaction, visualization, big data application and other DN operation and management applications.

It should be pointed out that dispatching cloud is an enterprise private cloud for power grid dispatching and operation, which has five characteristics adapted to its business: security, continuity, real-time, decentralization and synchronization.

2.2. Joint Modelling of Distributed Generation Based on the DCP

As aforementioned, relying on the DCP, operators are able to conduct an in-depth analysis of the vast amount of historical data and operating data of DG. This brings the dawn for the distribution network operator (DNO) to deal with the scheduling difficulties caused by the rapid growth of DG permeability. The main difficulty brought by DG is the random power flow issue, which is determined by the randomness of DG in nature. In this paper, we analyze the massive DG in the same area based on the PaaS layer in the DCP, and then get the joint probability distribution of DG, and realize the joint modelling. The advantages of DG' joint modelling mainly lie in the following two points: (1) The temporal-spatial correlation between DG units can be considered, which realize the high-precision modelling of DG' output. (2) It can consider the randomness of massive DG at the same time and reduce the computational burden. This is mainly because, in the traditional random modelling method based on the scenario method, there is an exponential relationship between the number of scenarios and the number of DG units. However, in the joint modelling based on DCP and Copula function proposed in this paper, the relationship is linear.

The copula modelling method has the advantages of less calculation and faster calculation speed, and it is a powerful method in constructing data dependence and correlation structure. Through the Copula function, such as t Copula, we can connect the dispersed marginal distribution function and get the joint distribution function of multiple random variables (RVs). Because the marginal distribution function of each RV is calculated independently, the calculation dimension can be greatly reduced. The basic principle of Copula theory is the Sklar theorem, which is described as follows:

Mathematically, any joint distribution of multiple random variables can be written as multiple marginal distributions and a Copula function, in which the Copula function is used to describe the dependence between variables.

Suppose the marginal distribution function of the RV $x_1, x_2, \cdots x_N$, e.g., the active power output of WTs and PVs, is $F_1(x_1), F_2(x_2), \cdots, F_N(x_N)$ respectively. Then, according to Sklar's theorem, the joint distribution function of random vectors $(x_1, x_2, \cdots x_N)$ can be expressed as follows:

$$F(x_1, x_2, \cdots, x_N) = C(F_1(x_1), F_2(x_2), \cdots, F_N(x_T)) \tag{1}$$

Where C is a Copula function. At present, there are many kinds of Copula functions that are widely used. In this paper, we consider the normal Copula functions which can be used to construct high-dimensional uncertainties of DG.

It should be noted that by fitting the joint probability density function of DG, a joint model considering the spatial-temporal correlation of DG can be obtained, which greatly reduces the operation risk of the system. The correlation coefficient matrix in the Copula function can directly reflect the spatial-temporal correlation between DG units.

2.3. Hierarchical and Partition Regulating Framework based on the DCP

This paper proposes a hierarchical and partition coordination management framework of DG based on the DCP, which consists of four layers, as shown in Fig.2. The first layer is the provincial dispatching center, which optimizes the transmission network status and regulating resources within the jurisdiction, and sends the control signal to the next level. The second layer is the prefecture-level DCP, which conducts the Volt/VAR optimization of the high-voltage distribution network under its jurisdiction by adjusting the transformer taps and the shunt capacitor banks. The regional DCP is located in the third layer, which aggregates a variety of DERs in the medium and low voltage distribution network. In addition, it employs the regional energy management system provided by the SaaS layer to coordinate and optimize the active and reactive power of plenty various distributed resources within its jurisdiction (that is, resource level, the fourth layer, including but not limited to PVs, WTs, ESs, MGs, and DR), which is not only the difficulty of the current system's operation but also the focus of this article.

It is worth pointing out that all data flows in both directions between different levels. The lower layer sends equipment operation data or model data to the upper layer, and the upper layer sends control signals to the lower layer or responds to lower data requests. In addition, the joint modelling of DG is implemented by the DG cluster modelling application of the regional DCP (SaaS layer, according to the method proposed in subsection 2.2) to call the PaaS interface. The operation data of DG analyzed by PaaS is provided by the advanced metering infrastructure located in the fourth layer.

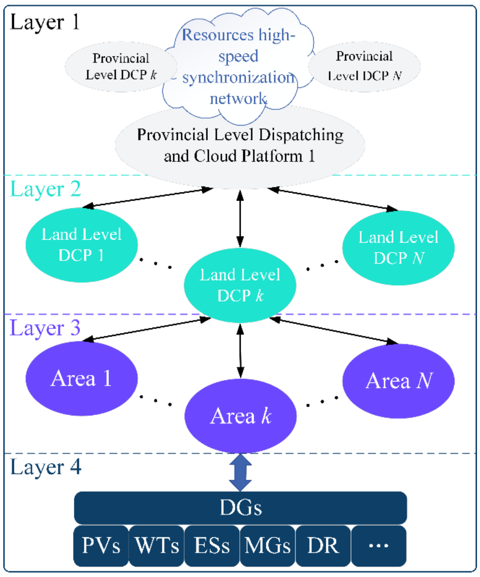

Fig. 1: Hierarchical and partition management framework based on DCP

3. Problem Formulation

In the proposed DCP-based hierarchical and partition scheduling framework, we focus on the collaborative management of DG, that is, the interaction and optimal decision-making between layer 3 and layer 4. Due to the increased penetration of DG, this has become a difficult point in the dispatch and control of the distribution network. The cooperative management method of active and reactive power of DG has been described in Section II. Here we will give its mathematical model, which is essentially a mathematical optimization problem.

The DG' collaborative management application (Area level, SaaS layer) in the regional DCP can be intuitively understood as the regional DNO. The optimization goal is the lowest regional operation cost, which mainly includes the operation cost of various DERs and the power purchase cost from the main grid, as shown in (2). The first term is the cost of purchasing electricity for the main grid. The second item is the cost of network losses. The third item is the operation cost of distributed PVs. The fourth item is the operating cost of ES. The last item is the operation cost of MG. In this paper, only the day-ahead scheduling model is given, considering the intra-day and real-time phase models are similar.

$$\min F = \sum_{t}^{T} \left(C_{\mathrm{Grid},t} + C_{\mathrm{Loss},t} + C_{\mathrm{PV},t} + C_{\mathrm{ES},t} + C_{\mathrm{MG},t} \right) \tag{2}$$

$$C_{\mathrm{Grid},t} = \rho_{\mathrm{G},t} P_{\mathrm{Grid},t} \tag{3}$$

$$C_{\text{Loss},t}^{\text{DA}} = \rho_{L,t} \sum_{ij}^{L} \left(I_{ij,t} \right)^2 \times r_{ij} \tag{4}$$

$$C_{\text{PV},t} = \rho_{\text{P},t} P_{\text{PV},t} \tag{5}$$

$$C_{\text{ES},t} = \rho_{\text{E},t} (P_{\text{ES},t}^{\text{charge}} + P_{\text{ES},t}^{\text{discharge}}) \tag{6}$$

$$C_{\text{MG},t} = \rho_{\text{M},t} P_{\text{MG},t} \tag{7}$$

Whereas $\rho_{\text{G},t}$ is the electricity price of the main network. $P_{\text{Grid},t}$ is the exchange power between the ADN and the main grid, $\rho_{L,t}$ is the loss cost coefficient. $I_{ij,t}$ is the branch current. r_{ij} is the branch resistance. $\rho_{\text{P},t}$ is the distributed photovoltaic cost coefficient. $P_{\text{PV},t}$ is the PV active power output. $\rho_{\text{E},t}$ is the unit cost of ES. $P_{\text{ES},t}^{\text{charge}}, P_{\text{ES},t}^{\text{discharge}}$ is the charge/discharge power of ES, respectively. $\rho_{\text{M},t}$ is the unit cost of MG, and $P_{\text{MG},t}$ is the active power output of MG.

Besides, the operation of the distribution network should also meet the following constraints.

3.1. Power Flow Equations

The power flow equation reflects the physical constraints of the DN. In this paper, the branch power flow equation is adopted, which is shown as follows:

$$P_{j,t} = \sum_{k}^{D} P_{jk,t} - \sum_{ij}^{U} \left(P_{ij,t} - r_{ij} \left| I_{ij,t} \right|^2 \right) \tag{8}$$

$$Q_{j,t} = \sum_{k}^{D} Q_{jk,t} - \sum_{i}^{U} \left(Q_{ij,t} - x_{ij} \left| I_{ij,t} \right|^2 \right) \tag{9}$$

$$\left| V_{j,t} \right|^2 = \left| V_{i,t} \right|^2 - 2 \left(P_{ij,t} r_{ij} + Q_{ij,t} x_{ij} \right) + \left(r_{ij}^2 + x_{ij}^2 \right) \left| I_{ij,t} \right|^2 \tag{10}$$

$$\left| I_{ij,t} \right|^2 = \frac{P_{ij,t}^2 + Q_{ij,t}^2}{\left| V_{i,t} \right|^2} \tag{11}$$

Where U and D represent the set of upstream and down-stream nodes. $P_{j,t}$ and $Q_{j,t}$ are the injected active and reactive power of node j. $P_{jk,t}$ and $Q_{jk,t}$ are the active and reactive power on the distribution line between node *i* and *j*. $V_{i,t}$ is the bus voltage of node *i*.

3.2. Bus Voltage and Branch Current Constraints

The bus voltage should meet the requirements of voltage quality. The branch current should meet the requirements of the line set value. The following two constraints ensure the safe and stable operation of the distribution network.

$$V_i^{\min} \le V_{i,t} \le V_i^{\max} \tag{12}$$

$$I_{ij}^{\min} \le I_{ij,t} \le I_{ij}^{\max} \tag{13}$$

Where $V_i^{\max}$ and $V_i^{\min}$ are the bus voltage upper and lower limits. $I_{ij}^{\max}$ and $I_{ij}^{\min}$ are the current upper and lower limits of the branch *ij*.

3.3. Main Grid Tie-line Constraints

The exchange power between the regional distribution network and the superior network should meet the capacity constraints of the tie line, as follows:

$$\Delta P_{\text{Grid}}^{\min} \le P_{\text{Grid},t} - P_{\text{Grid},t-1} \le \Delta P_{\text{Grid}}^{\max} \tag{14}$$

$$\Delta Q_{\text{Grid}}^{\min} \le Q_{\text{Grid},t} - Q_{\text{Grid},t-1} \le \Delta Q_{\text{Grid}}^{\max} \tag{15}$$

$$P_{\text{Grid},t}^2 + Q_{\text{Grid},t}^2 \le S_{\text{Grid}}^2 \tag{16}$$

Where $\Delta P_{\text{Grid}}^{\max}, \Delta P_{\text{Grid}}^{\min}, \Delta Q_{\text{Grid}}^{\max}, \Delta Q_{\text{Grid}}^{\min}$ are the upper/lower limit of the active/reactive power of the tie line, respectively. S_{Grid} is the transmission capacity limit of the tie line.

3.4. Distributed Generation Constraints

This paper uses a broad definition of DG, including distributed PVs, distributed WTs, ES, MG (such as micro-gas turbines, MTs), demand response (DR) resources and so on. The models are as follows:

$$P_{\text{RES},i,t} \le P_{\text{RES},i,t}^{\text{Pred}} \tag{17}$$

$$0 \le P_{\text{ES},i,t}^{\text{charge}} \le S_{\text{ES},i,t}^{\text{charge}} P_{\text{ES},i,t}^{\text{charge,max}} \tag{18}$$

$$0 \le P_{\text{ES},i,t}^{\text{discharge}} \le S_{\text{ES},i,t}^{\text{discharge}} P_{\text{ES},i,t}^{\text{discharge,max}} \tag{19}$$

$$S_{\text{ES},i,t}^{\text{charge}} + S_{\text{ES},i,t}^{\text{discharge}} \le 1 \tag{20}$$

$$E_{\mathrm{ES},i,t+1} = E_{\mathrm{ES},i,t} + P_{\mathrm{ES},i,t}^{\mathrm{charge}} \eta_{\mathrm{charge}} - P_{\mathrm{ES},i,t}^{\mathrm{discharge}} / \eta_{\mathrm{discharge}} \tag{21}$$

$$E_{\mathrm{ES},i}^{\min} \le E_{\mathrm{ES},i,t} \le E_{\mathrm{ES},i}^{\max} \tag{22}$$

$$0 \le P_{\mathrm{MG},i,t} \le S_{\mathrm{MG},i} \tag{23}$$

$$\left(P_{\mathrm{MG},i,t}\right)^2 + \left(Q_{\mathrm{MG},i,t}\right)^2 \le \left(S_{\mathrm{MG},i}\right)^2 \tag{24}$$

$$\Delta P_{\mathrm{MG},i}^{\min} \le P_{\mathrm{MG},i,t+1} - P_{\mathrm{MG},i,t+1} \le \Delta P_{\mathrm{MG},i}^{\max} \tag{25}$$

$$\sum_{t=1}^{T} P_{DR,i,t} = P_{DR,i}^{0} \tag{26}$$

$$P_{DR,i,t}^{\min} \le P_{DR,i,t} \le P_{DR,i,t}^{\max} \tag{27}$$

Constraint (17) is the active power output constraint of PVs and WTs. $P_{\mathrm{RES},i,t}^{\mathrm{Pred}}$ and $P_{\mathrm{RES},i,t}$ are the prediction of active power output and the actual output of renewable energy sources. Constraints (18)-(22) give the charge and discharge constraints of ES in a scheduling cycle. $S_{\mathrm{ES},i,t}^{\mathrm{charge}}$ and $S_{\mathrm{ES},i,t}^{\mathrm{discharge}}$ are both the 0-1 variable, which represents the charge/discharge state of ES. $P_{\mathrm{ES},i,t}^{\mathrm{charge,max}} / P_{\mathrm{ES},i,t}^{\mathrm{discharge,max}}$ is the upper limit of charge/discharge rate, and $\eta_{\mathrm{charge}} / \eta_{\mathrm{discharge}}$ is the charge and discharge efficiency. $E_{\mathrm{ES},i}^{\max}$ and $E_{\mathrm{ES},i}^{\min}$ are the upper and lower limits of energy storage, and $E_{\mathrm{ES},i,t}$ is the real-time stored power of ES. Constraints (23)-(25) give the model of the MG. $P_{\mathrm{MG},i,t} / Q_{\mathrm{MG},i,t}$ is the active and reactive power of the controllable DG. $S_{\mathrm{MG},i}$ is the rated capacity of the inverter, and $\Delta P_{\mathrm{MG},i}^{\max} / \Delta P_{\mathrm{MG},i}^{\min}$ is the upper and lower limits of the ramping rate of the active power output. Constraint (26) reflects the model of the demand side resources, that is, the total power consumption of the flexible load remains unchanged during the scheduling cycle. (27) ensures that the demand-side resources are of load nature and will not exceed the set upper and lower limits, taking into account the comfort of the flexible load.

3.5. Reactive Regulating Resources Constraints

Reactive regulating resources mainly include on-load tap charger transformer (OLTC), shunt capacitor banks (CBs) and static VAR compensation (SVC) device. The models are as follows:

$$V_{m,t} = k_t^{\mathrm{OLTC}} V_{j,t} \tag{28}$$

$$k_t^{\mathrm{OLTC}} = k_{\min}^{\mathrm{OLTC}} + S_{ij,t}^{\mathrm{OLTC}} \frac{k_{\max}^{\mathrm{OLTC}} - k_{\min}^{\mathrm{OLTC}}}{N_{\mathrm{OLTC}}} \tag{29}$$

$$Q_{\mathrm{CB},i,t}^{\mathrm{Output}} = N_{\mathrm{CB},i,t}^{\mathrm{Output}} \times Q_{\mathrm{CB},i}^{\mathrm{Step}} \tag{30}$$

$$N_{\mathrm{CB},i,t}^{\mathrm{Output}} \le N_{\mathrm{CB},i,t}^{\max} \tag{31}$$

$$S_{\mathrm{CB},i,t} \le \left| N_{\mathrm{CB},i,t+1}^{\mathrm{Output}} - N_{\mathrm{CB},i,t}^{\mathrm{Output}} \right| \le S_{\mathrm{CB},i,t} \tag{32}$$

$$Q_{\mathrm{SVC},i}^{\min} \le Q_{\mathrm{SVC},i,t} \le Q_{\mathrm{SVC},i}^{\max} \tag{33}$$

Constraints (28)-(29) are the transformer constraints. k_t^{OLTC} is a discrete variable, representing the OLTC ratio. $k_{\max}^{\mathrm{OLTC}}$ and $k_{\min}^{\mathrm{OLTC}}$ represents the maximum/minimum turns ratio of the OLTC. $S_{ij,t}^{\mathrm{OLTC}}$ is an integer variable, representing the current turns ratio of OLTC. N_{OLTC} represents the total number of OLTC taps. Constraints (30)-(32) are the model of the capacitor banks. $Q_{\mathrm{CB},i,t}^{\mathrm{Output}}$ is the total reactive power output, and $N_{\mathrm{CB},i,t}^{\mathrm{Output}} / N_{\mathrm{CB},i,t}^{\max}$ are integer variables, which represents the current switching number of CBs and the total number, respectively. $Q_{\mathrm{CB},i}^{\mathrm{Step}}$ is the reactive power compensation capacity of a single group capacitor. $S_{\mathrm{CB},i,t}$ is a 0-1 variable, which represents whether the capacitor bank operates or not. Constraint (33) is the model of the SVC. $Q_{\mathrm{SVC},i,t}$ is the reactive power output of the SVC, and $Q_{\mathrm{SVC},i}^{\max} / Q_{\mathrm{SVC},i}^{\min}$ is the upper and lower limits of the SVC output.

4. Case Study

In this paper, the IEEE-33 node test system is adopted to verify the proposed DCP-based collaborative management method of massive DG. The network topology diagram is shown in Fig.3, and all the data is derived from [2]. All case study is implemented in MATLAB R2018b, solved by GUROBI (Ver9.0.3), and performed on a PC with an AMD Ryzen 5 4600H 3.0Ghz, 16 RAM. Besides, three cases are set to verify the superiority of the proposed method, which are as follows:

Case1: (basic case) Traditional Scheduling Mode, no Dis-patching and Cloud Platform.

Case2: Independent Modeling of DG Based on Dis-patching and Cloud Platform.

Case3: (the proposed method in this paper) Joint Modeling Based on Dispatching and Cloud Platform.

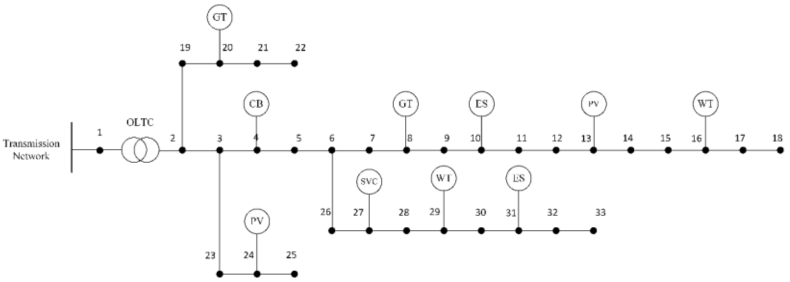

Fig. 3. IEEE-33 bus test system

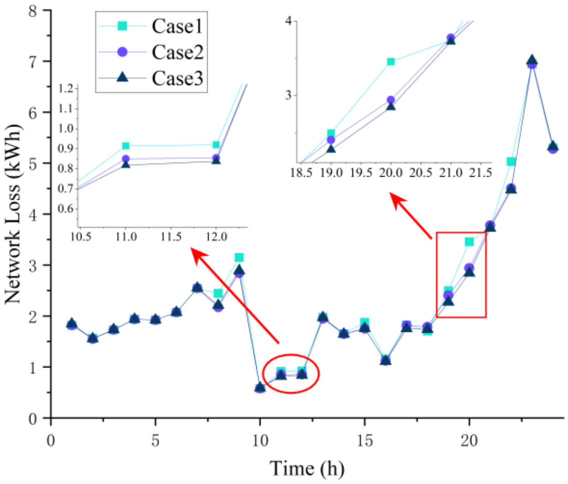

Fig. 4. Network losses

Fig.4 shows the network losses of the system over one day. It can be seen that the scheduling method based on the DCP can effectively reduce the system network losses, especially during the peak load period of the system, that is, 11:00-12:00 and 19:00-20:00. This is mainly owed to the DCP's ability to achieve the collaborative management of a variety of DERs. Fig.5 shows the active power purchased from the main network by the distribution network operator. It is easy to see from Fig.5 that the total power purchased by the DNO under method 3 is the lowest. In particular, the proposed method reduces the cost that the system pays to the main grid during the period of high electricity price. On the one hand, this is due to the reduction of network losses, as mentioned earlier, on the other hand, the proposed method improves the utilization rate of renewable energy sources.

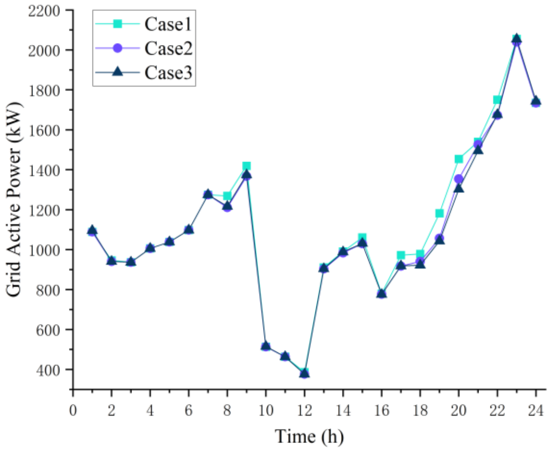

Fig. 5. Main grid active power

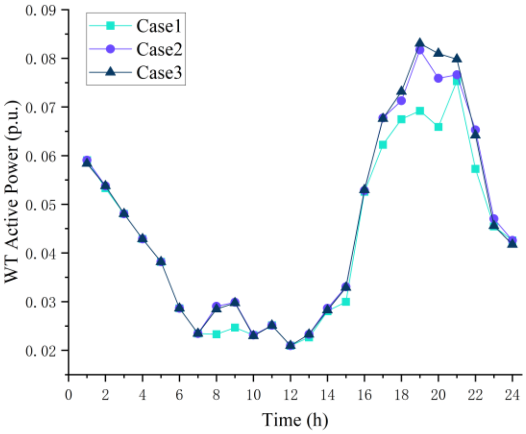

Fig. 6. Active power of WTs

Taking distributed WTs as an example, Fig.6 shows the total active power output of WTs. It can be seen that in Case 1, that is, the utilization rate of the traditional scheduling method for DG is lower compared with Case 2 and Case 3. This is due to the fact that the DCP increases the ability to fine model the randomness of DG. In particular, Case 3 has a higher distributed wind power output than Case 2, which is owed to the joint modelling of distributed generation based on Copula theory and dispatching and cloud platform. The joint model makes the stochastic modelling of DG more accurate. Due to the above-mentioned phenomenon, the proposed method in this paper can naturally reduce the overall operating cost of the system, as shown in the following table.

Table 1: Total operation cost

Method	Case 1	Case 2	Case 3
Total Operation Cost ($)	19669.57	19601.35	19532.54

In addition, due to the high penetration and high randomness of DG, the voltage security of the system is faced with challenges, especially for the terminal nodes of the distribution network. Fig.7 shows the bus voltage distribution of the #18 node. As can be seen from the figure, the bus voltage as a whole is within the safe operating range of the system, as expected. However, it can also be seen that under the traditional scheduling methods, the bus voltage inevitably fluctuates rapidly, which may cause trouble to end-users. On the contrary, the proposed scheduling method (Case 3) greatly provides voltage stability and voltage level, which means the improvement of power quality.

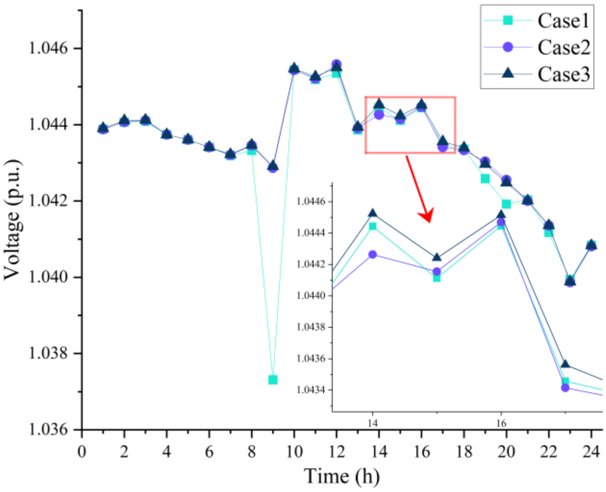

Fig. 7. Bus voltage of node 18

5. Conclusion

To effectively address the management pressure caused by the massive distributed generation in the distribution network, this paper proposes a hierarchical and partition cooperative scheduling method of DG based on the dispatching and cloud platform. The main conclusions are summarized as follows:

(1) DCP improves the online analysis capability of DNO, standardizes the data management of massive DG, and promotes the lean development of distribution network business.

(2) The proposed DG joint modelling application based on DCP (SaaS layer) can more accurately track the randomness of renewable DG and improve the security and economy of the system schedule.

(3) The proposed hierarchical and partition dispatch framework reduces the difficulty of collaborative management of massive DERs in the system and ensures the efficient and orderly operation of the DN dispatching business.

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