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RESEARCH ON DISTRIBUTED SCHEDULING ALGORITHM FOR VIRTUAL CITY POWER PLANTS BASED ON BLOCKCHAIN TECHNOLOGY

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Abstract. In order to solve the problem that allocating the whole virtual power station is not centralized and promoting the free access of power distribution, a research on distributed scheduling of urban power network based on blockchain technology is proposed. and a scheme is proposed. Based on the consistency of decentralized virtual power plant and blockchain in decentralized point-to-point interaction and decentralized cooperation, this paper proposes to use blockchain consensus mechanism to realize distributed scheduling of virtual power plant. According to the principle of continuous micro- increment cost, the optimal economic dispatch of virtual power system is realized by taking the micro- increment characteristic as the variable. and the optimal economic dispatch strategy is realized. As a node of the blockchain, each distributed energy in the virtual power plant has a complete backup of the key data of the whole network. When the load changes, each node uses the PBFT consensus algorithm to independently calculate the new power of each unit. The new power data is stored on the chain, and the global consistency of micro incremental features is maintained to realize the reasonable load distribution among units. The experimental results show that, when the initial $t = 1$, the λ the values of each unit are different. The system does not meet the principle of constant consumption micro-increase rate, and the system does not operate in the optimal state. After a PBFT consensus, λ variable reaches the same value at t=8, and the system reaches the optimal operating state. Conclusion: The simulation experiment verifies the effectiveness of the algorithm, realizes distributed scheduling by using blockchain, and provides a feasible reference scheme for the operation mode of decentralized virtual power plant.

Key words: Consensus mechanism, Distributed scheduling, Completely distributed, Virtual power plant, Blockchain

1. Introduction and examples. With the rapid development of renewable energy such as wind and light, the pattern of distribution of electricity entering the distribution network is increasingly in the direction of access go high and high speed. However, a large number of new energy sources are interconnected, and their randomness and uncertainty will have an important impact on the operation, dispatching and trading of the power grid. Virtual power plant technology is an important part of the integration of multiple power distribution sites to participate in the power market and promote new energy use [1]. Virtual power plant technology can effectively balance the supply and demand relationship of electricity, improve the reliability and stability of electricity, and promote the use and popularization of new energy by integrating and managing multiple small distributed energy resources. In addition, virtual power plant technology can also provide more flexible and efficient trading methods for power producers and consumers through the participation of the electricity market, while also reducing the cost and risk of electricity trading.

As a new form of energy aggregation, virtual power plant provides a feasible method for a large number of distributed energy sources to be reliably connected to the grid. Through advanced communication technology, virtual power plant aggregate control of distributed energy, and make distributed energy coordinated and optimized operation, so as to achieve mutual adjustment of output, reliable grid connection. Compared with traditional power plants, virtual power plants have more diversified resources, are more environmentally friendly, and are more competitive in the power market, which promotes the transformation of the power industry and the development of the whole power system [2].

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Block chain is a new type of data structure formed by a large number of blocks linked together in an orderly manner, and block refers to the collection of relevant data information, is the basic unit of block chain [3].

2. Literature review. It adopts advanced information and communication technology to realize DERs (distributed energy storage system, controllable load, electric vehicle, etc.). resources) for integrated and coordinated optimization.As a special power plant to participate in the power market and grid operation of power coordination management system, is considered to be the ultimate configuration of energy Internet. The Energy Internet is a new energy system mainly composed of renewable energy and supported by information and communication technology. It has the characteristics of decentralization, intelligence, interconnection, and efficiency, and can achieve large-scale application and sustainable development of clean energy.

As an important component of the energy internet, virtual power plants can integrate dispersed distributed energy resources to form a virtual power plant, participate in transactions in the electricity market, and achieve large-scale application of clean energy. At the same time, they can also bring more intelligent and efficient management methods to the operation and management of the power grid, providing strong support for the construction and development of the energy internet.

Virtual power plant integrates various DERs together to realize the stability and reliability of its overall output and provide efficient electric energy for the grid, so as to ensure the stability and safety of grid-connection. According to operation control mode, virtual power plants can be divided into three types: centralized central-decentralized and fully decentralized. The centralized architecture not only has high requirements for communication system, but also is difficult to cope with the management of numerous fit and forget distributed energy sources. Therefore, in order to better realize the management of DERs, the scheduling strategy of virtual power plant has been transformed from traditional centralized to distributed. Distributed virtual power plant has gained more attention and has better scalability and openness. In distributed virtual power plants, the multi-agent technology is usually used to realize the distributed communication of DERs. Through the information interaction between the agent and the neighbor node, it realizes self-regulation and eventually tends to the consistent variable. However, because multi-agent technology cannot obtain global information efficiently and accurately, it needs to approach consistent results through continuous iteration, which has problems such as inaccurate calculation and low efficiency [4,5].

To solve this problem, some optimization methods can be adopted, such as hierarchical control, local information sharing, predictive control, etc. These methods can help multi-agent system achieve consistent results more quickly and reduce computing and communication overhead.

Relevant scholars have studied the application of blockchain technology in the decentralized trading mechanism of distribution network, automatic demand response system, energy Internet, multi-module collaborative autonomous mode, distribution network, power trading and other fields. Blockchain and distributed virtual power plant are consistent in decentralized decentralized collaborative regional autonomy and other aspects. For example, in the distributed virtual power plant, there is no central control mechanism, and each DERs obtains global information through direct data exchange and then completes the regulation and operation of its own node independently [6,7].

To sum up as a whole, for distributing all virtual power plants, according to their status with blockchain in point-to-point cooperation and fair cooperation, this paper proposes to use blockchain technology to realize the time division of virtual power plants. Based on the constant consumption micro-increment rate criterion, the optimal economic dispatch of the virtual power plant is realized by using the micro-increment characteristic as a consistent variable. Combined with the blockchain recommendation algorithm, each power distribution node independently calculates the new power of each unit, and stores the new power information of the chain, while maintaining the global relationship of small features, to realize the reasonable distribution of load among units [8].

3. Method.

3.1. VPP distributed scheduling model. The VPP (Virtual Power Plant) distributed scheduling model is an energy management model based on virtual power plants. It integrates multiple distributed energy devices (such as solar, wind, energy storage, etc.) into a virtual power plant, and achieves centralized management and scheduling of these devices through communication methods such as the Internet, thereby achieving participation in the electricity market and energy trading.

This paper takes the optimal distribution of active power load as an example. The so-called optimal distribution is to make the power generation equipment consume the least amount of energy per unit time in the process of generating electric energy on the premise of satisfying the continuous power supply of a certain amount of load. It usually adopts the principle of constant consumption rate increase to distribute load among units. In order to simplify the description, the optimal active power allocation scheme without network loss is adopted [9,10].

The implementation of optimal allocation can effectively improve the efficiency and reliability of the power system, reduce energy consumption and operating costs, and also reduce environmental pollution and carbon emissions, achieving sustainable utilization of clean energy. Therefore, optimal allocation is one of the important means for the operation and management of the power system, which is of great significance for achieving energy transformation and building a sustainable energy system.

Assuming that the cost function of the generator set in DERs is quadratic, the minimum generation cost of VPP can be achieved by expressing the cost function:

$$minF = min\sum_{i=1}^{n} F_i(P_i) \tag{3.1}$$

n indicates the number of group DERs in VPP, P_i represents the output power of unit i. The total cost of VPP is denoted as F, $F_i(P_i) = a_iP_i^2 + b_iP_i + c_i, a_i, b_i$ and c_i represents the coefficient of the cost function.

All the DERs units inside the VPP meet the active power balance of the whole system when running, without considering the network loss, namely

$$\sum_{i=0}^{n} P_i = P_{LD} \tag{3.2}$$

P_{LD} represents the total load demand of all users.

According to the principle of constant consumption micro increase rate, the load is distributed among units.

$$\lambda = \frac{dF_i}{dP_i} = 2a_iP_i + b_i \tag{3.3}$$

As a result, λ can be used as a consistent variable between nodes in the blockchain, adjusting as the load changes, but remaining consistent across the network [11].

3.2. Consensus mechanism in alliance chain. The private chain is controlled by a single organization and is open only to its own organization; Consortiums are between public and private chains, open to a specific industry organization, and require that each new node be verified and audited. The alliance chain can adapt to the situation containing a small number of faulty or evil nodes and has certain fault tolerance characteristics [12].

Generally, different types of blockchain adopt different consensus mechanisms, and Byzantine Fault Tolerance (BFT) is one of the core issues to be solved in blockchain consensus algorithms. Bitcoin's POW and Ethereum's POS are public chain algorithms, which solve the BFT in the case of numerous consensus nodes. Compared with POW POS of the public chain,PBFT adopts the mechanism of each node voting to reach consensus, which can solve the bifurcation problem and improve efficiency. The operating environment of the PBFT requires a relatively closed cluster, and each consensus requires multiple p2-node communication. The traffic volume is $O(n^2)$, and n is the number of nodes in the cluster[13]. PBFT is suitable for alliance chain dominated by industry and government, and is an ideal choice for a system with limited number of nodes and no need for virtual currency incentive mechanism. Based on the operation characteristics of virtual power plant, this paper chooses alliance chain and adopts PBFT consensus algorithm [14].

The premise of PBFT algorithm is to ensure that message communication between nodes is immutable through cryptography technology. PBFT has certain fault tolerance characteristics, assuming that the total number of nodes in the system is $|n| = 3f + 1$, f is Number of tolerated PBFT faulty or malicious nodes.So in order for the whole system to work properly, you need to have 2f+1 normal nodes. The classic representative project in the consortium chain is the Fabric project under the IBM Hyperledger organization, with Fabric0.6 using the PBFT algorithm [15].

Table 3.1: Blockchain and virtual power plant characteristics comparison

Feature	blockchain technology	Virtual Power Plant
Decentration	All nodes have equal rights and obligations	All power generation and power consumption subjects are equal, dispersed and coordinated
Cooperative autonomy	Using the consensus mechanism, all nodes jointly maintain	Each DERs realizes collaborative scheduling and supply-demand balance through data interaction
Credit system	No third party trust mechanism is required	Each DERs uses communication network to realize point-to–point direct interaction
Smart contract	The ability to automatically execute contracts	The power of each unit should be set reasonably according to the control command

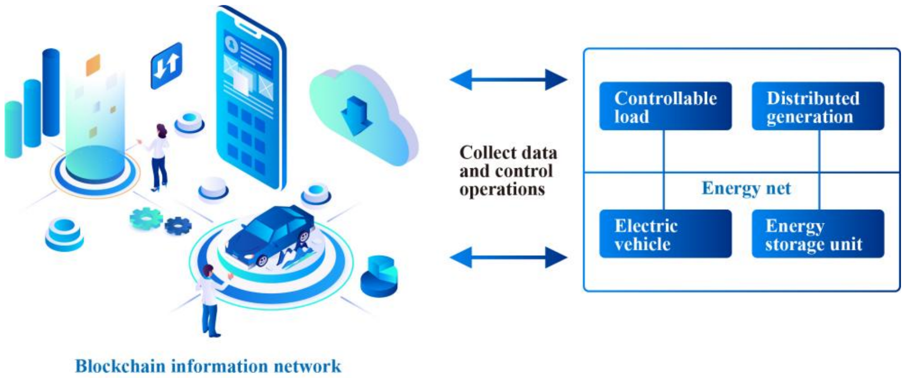

Fig. 3.1: Blockchain builds the underlying information architecture of decentralized virtual power plants

3.3. Blockchain distributed scheduling model. Blockchain distributed scheduling model is an energy management model based on blockchain technology, which realizes the security and reliability of the power market participation and energy transaction through the establishment of a distributed account. In the blockchain distributed scheduling model, each distributed energy device is regarded as a node in the network, and each node has an account and some data. These data include the equipment's production capacity, storage capacity, energy consumption, and so on. Data from all nodes is encrypted and stored on the blockchain, with each node having access to and modify its own data. In a completely decentralized virtual power plant, there is no centralized control mechanism, and the decision-making process is completed through direct interaction and multiple iterations of each power generation and power consumption unit. Based on the consistency of the two sides' ideas and needs, blockchain is expected to become one of the underlying architectures for building decentralized virtual power plants, and realize the regulation and operation of virtual power plants. The comparison of characteristics between virtual power plants and blockchain technology is shown in Table 3.1.

Based on the coincidence between blockchain and virtual power plant, blockchain can be used to build the underlying information architecture of decentralized virtual power plant. Each DERs forms a blockchain network, which can realize point-to-point communication. The consensus mechanism is used to calculate the consistency variables. The specific structure of decision control through intelligent contract execution is shown in Figure 3.1.

As shown in Figure 3.1, it consists of a physical energy transmission network and a blockchain information network, where the energy network is responsible for power transmission and connects each DERs. Each DERs

Fig. 3.2: Data stored on the chain

unit corresponds to a node in the blockchain information network. Data and control signals can be transmitted between blockchain nodes and DER, and a point-to-point network is formed between nodes. The control strategy of the entire virtual power plant is calculated by the blockchain network and delivered to the physical network for execution.

3.4. Distributed scheduling policy execution process.

3.4.1. On-chain data. When the optimal operation configuration is reached, the micro increment characteristic λ value of all units is the same. Therefore, λ is selected as the state information of the blockchain platform, and the calculation is completed through the consensus mechanism, and the consistency is maintained.

According to the characteristics of blockchain data storage, each node saves a complete backup of global status data and keeps synchronization with other node data.According to the scheduling policy, each generator set needs to save the power information of all the units P_i(unit:kW) in the whole network and the cost function coefficient of the corresponding unit(a_i, b_i, c_i). Usually, the cost function remains inconvenient. After each power adjustment, the new power on-link storage makes use of blockchain technology so that each unit can accurately obtain the global state information. The data storage structure of each node is roughly shown in Figure 3.2 [16].

3.4.2. Distributed scheduling execution process. According to the PBFT consensus execution process, combined with the isobaric micro-increment criterion, the distributed scheduling calculation process is shown in Figure 3.3. When the total load demand changes, the power adjustment demand broadcast to all units, after PBFT consensus, each unit separately calculate the new power and λ, and adjust the power of the unit and broadcast λ at the same time all units of the new power on the chain storage for the next adjustment application.

The specific process is as follows

1. When the total load changes, the power calculation request operation of primary node DER1 is activated, and the primary node selection is completed according to the agreed algorithm rules of PBFT.
2. After receiving the request, the primary node broadcasts the request to each DERs node in the network according to the three-phase protocol rules.
   Different requests have different ordinals. A pre-prepare message is constructed using the ordinals and request operations and broadcast to each DERs node. In this stage, the PLD and the power calculation request of the total change load are sent to each node.
   Then there is the interaction phase, where each DERs node receives the pre-prepare message and each node broadcasts the prepare message to other DERs nodes If a node receives messages from 2f different nodes, it means that the prepare phase of the node has been completed and each node has obtained the total load PLD after the change .Conditions are available to calculate the new power.
   Finally, there is the sequence number confirmation stage. After each node verifies the request and order in the view, if the node receives 2f+1 commit message, it means that most nodes have entered the commit stage and a consensus has been reached in this stage. The following takes the calculation process of the I-th node in the blockchain as an example to illustrate the calculation process of power allocation according to the constant consumption micro-increment criterion.
   According to the distributed scheduling criterion, all nodes are required to have the same λ, that is, the formula 3.4 is satisfied

$$\lambda = 2a_1P_1 + b_1 = \cdots = 2a_iP_i + b_i \tag{3.4}$$

The power of all nodes is expressed in P_i

$$\begin{cases} P_1 = ((2a_iP_i + b_i) - b_1)/2a_1 \\ P_2 = ((2a_iP_i + b_i) - b_2)/2a_2 \\ \cdots \\ P_n = ((2a_iP_i + b_i) - b_n)/2a_n \end{cases} \tag{3.5}$$

Substitute formula 3.5 into formula 3.2 to get formula 3.6

$$\begin{aligned} P_{LD} =& ((2a_iP_i + b_i) - b_1)/2a_1 + \\ & ((2a_iP_i + b_i) - b_2)/2a_2 + \cdots + \\ & ((2a_iP_i + b_i) - b_n)/2a_n \end{aligned} \tag{3.6}$$

As P_{LD} is known, P_i^* of DERsi's new power can be calculated, then, P_i^* is substituted into formula 3.5 to obtain the new power value of all nodes and update the new value to the blockchain;The value λ is calculated at the same time and sent to the task initiator node; The drive DERs unit works according to the new power value [17].

3. The task initiator receives responses from different nodes. If there are 2f+1 responses with the same λ value, the response is the result calculated for this request and is the consistent variable of the whole network. The distributed power distribution adjustment is completed to achieve optimal economic scheduling.
   Specifically, the task initiator will perform the following actions:
   Collect responses: Wait for responses from different nodes and collect them into a list.
   Verify Response: For each response, verify its completeness and correctness. Ensure that the response is sent by the correct node and that the calculation results in the response are correct.
   Select Response: For each request, select with the same λ 2f+1 response of the value. If there is not enough response, wait for more responses until sufficient responses are received.
   Calculation result: Use the selected response to calculate the final result. This will include the optimal economic dispatch values calculated for each node, thereby achieving optimal economic dispatch for distributed distribution adjustment.
   Distribute Results: Distribute the results to all nodes so that they can update their local status and perform the next calculation.

Because the distributed energy can be added or withdrawn at any time, when a new node is added, the node broadcasts its own parameters and the current power value, requesting that the new node be added and the power redistribution be completed. Based on the PBFT mechanism, each node adds new node parameters to the on-chain storage, and adjusts the power based on the criteria to ensure that the system runs in the optimal state. When a node exits, similar operations are adopted to update the data on the chain and adjust the power [18].

The execution process of distributed scheduling is a dynamic and real-time process that requires continuous monitoring and adjustment to adapt to the complex and ever-changing operating environment of the power system.

3.5. Experimental verification. To verify the effectiveness of the proposed algorithm, an experimental simulation is conducted to verify that four DERs are distributed in a VPP system of the type Micro Gas Generators (MGGs), which are connected through a blockchain network.Each MGG is a node in the network. It is assumed that the network has a certain network delay, but the operation parameters and initial power of the point-to-point direct communication unit are guaranteed as shown in Table 3.2.

4. Results and discussion. In the presence of network delay, the change of consistency variable λ is tested. As can be seen from Figure 4.1, when the initial t=1, the λ values of each unit are different, which does not meet the constant consumption micro rate increase criterion, and the system does not operate in the optimal state. After a PBFT consensus, λ variable reaches the same value at t=8, and the system reaches the optimal operating state[19].

Table 3.2: Unit operating parameters and initial power

electric generator	a_i	b_i	c_i	P_i/KW
MGG1	1.256	1.355	8.812	30
MGG2	1.099	1.293	4.876	35
MGG3	0.942	1.220	1.220	70
MGG4	1.079	1.276	8.831	40

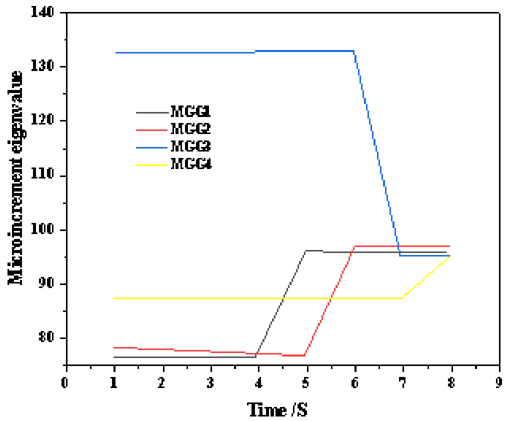

Fig. 4.1: The change of λ value of the microincrement feature

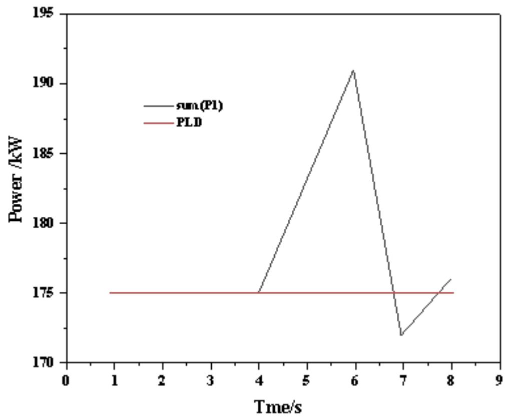

Fig. 4.2: Comparison of total load power and total generation power

Figure 4.1 shows the comparison between the total load power P_{LD} and the total power sum(P_i) of the generating unit in the process of consensus.

Figure 4.3 shows the power adjustment of each mgg unit, and the final power value remains stable in the working state[20].

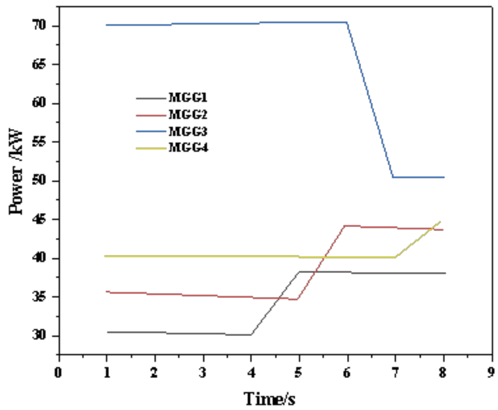

Fig. 4.3: Power variation of each unit

5. Conclusion. A research on distributed scheduling of virtual city power plants based on blockchain technology is proposed. The virtual power plant will be one of the last models of the future power of the internet, realize the reality of the agreement of resources in a wide range, and promote the use of electricity share. For the optimal operation of distributed virtual power plants, the fully distributed operation control of virtual power plants is realized by adopting the equal consumption and small increase principle and combining the distributed decentralized autonomous blockchain technology. In addition, the virtual power plant has some fault-tolerance capacity for situations such as node communication failure, which improves the safety level of the electric power. Specifically, virtual power plants typically adopt a distributed architecture, where multiple nodes form a network, and each node can transmit and process information. Therefore, in the event of a node failure or communication interruption, other nodes can still continue to operate and interact, thus ensuring the continuity and stability of the system.

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