Exploration on Optimal Dispatching of Rural Virtual Power Plant for Power Carbon Emission Based on LMDI Decomposition Method

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Abstract: With the technological innovation of virtual power plant (VPP), the objective demand for optimal dispatching is also constantly improving. The research on optimal dispatching of rural VPP based on LMDI (Logarithmic Mean Division Index) decomposition method for electricity carbon emissions is becoming more and more important. In the construction of the optimal dispatching model of the entire VPP, how to improve the market yield of the improved model and improve the carbon emissions of the system is the key problem that needs to be solved urgently at present. In this paper, based on the relevant research on the optimal scheduling of traditional VPP, the application of LMDI decomposition method in VPP and the analysis of algorithm process steps, combined with the composition structure of rural VPP with carbon emissions, and according to the data results, the following conclusions were drawn: six regional samples were selected through simulation experiments, and the application of LMDI based VPP scheduling model improved the market profitability compared with the traditional scheme; the overall average increase was about 5%. At the same time, there were also improvements in carbon emissions, and the overall average decrease was about 11.2%. This showed that the optimal dispatch model of rural VPP based on LMDI decomposition method has a good effect in practical application. Finally, the improved VPP optimal scheduling model proposed in this paper provides convenience for resource allocation in the current electrical field, and has certain reference value.

Keywords: Virtual Power Plant, LMDI Decomposition, Optimal Dispatching, Power Carbon Emissions

1. Introduction

At present, with the continuous development of statistical analysis and decomposition methods, the technology update speed of VPP is gaining momentum, and people are researching and talking about it in new ways. This paper's major goal is to calculate the composition structural constraints of rural VPP with carbon emissions in order to

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enhance the optimum dispatching model of VPP. Therefore, it is very important to build a VPP dispatching model based on LMDI.

There are many theories about the optimal dispatch of rural VPP with different electricity carbon emissions As carbon neutral policies and multi energy systems are widely concerned in developed countries, Alabi T. M. suggested an optimisation model and deep learning technique to get the optimal day-ahead scheduling of zero carbon multienergy system VPP. He employed automated encoders for scene restoration and established a clean energy marketing approach in technology. Finally, the model was validated by an example in a region of the United States, and the results showed that the sustainable reliability of the system's practical application was high [1]. In the context of power carbon self-scheduling and market participation under the uncertainty of wind speed and electricity price, A R M L solved the optimization scheduling decision-making problem of VPPs. In order to assess the quality of finding solutions, this problem is modelled using random programming formulae, which also provide a framework for comprehending and quantifying the effect of sample size on the variability of outcomes. Numerical experience showed that the obtained scheduling method approaches the optimal solution [2]. A single controllable configuration file, which was used for the application of VPP in distribution networks, was summarised by Sharma H. based on the growing popularity of small-scale distributed energy resources (DER), which have supplanted traditional power plants. Sharma H. proposed an improved multi-objective optimisation method based on Particle Swarm Optimisation Algorithm in conjunction with Power Generation Coordination, such as energy cost minimization and power carbon optimal scheduling. At the same time, he conducted a case study on State Power Corporation of China and found that the proposed technology is relatively more cost-effective than other technologies [3]. Ozge P analyzed the optimal day ahead scheduling of a VPP composed of wind power plants, pure heat generating units and battery energy storage systems, aiming to adjust the power generation system to obtain maximum profits and minimum carbon emissions, and used the general algebraic modeling system for modeling and analysis of five application cases. The research results showed that the profits of VPP can be increased while the carbon emissions can be reduced [4]. Tan Z F examined the value of VPP in assisting the grid in connecting dispersed energy resources in light of the rising installed capacity of solar photovoltaic and wind power generation. He created a single VPP operation scheduling model and a profit distribution model in order to research the economic scheduling of distributed energy resources in VPP. Ultimately, the case study confirmed that the suggested methodology is workable and efficient. [5].

The combination of LMDI decomposition method and the development of VPP optimal dispatching model has prompted the energy and electrical fields to re optimize the dispatching scheme of rural VPP for carbon emissions [6]. Although there is a dearth of study on carbon emissions, the use of the numerous research ideas and methodologies mentioned above can successfully boost market returns.

This study primarily focuses on the application analysis of the LMDI decomposition method in VPP optimum dispatching. The objective of this paper's design study was to increase market income and reduce carbon emissions. To this end, relevant research on the best scheduling of traditional VPP was consulted, along with the analysis of simulation trials. The final findings demonstrated the effectiveness of the VPP scheduling model based on LMDI in real-world applications.

2. Relevant Methods and Exploration of VPP Dispatching

2.1 Optimized Dispatching of VPP

VPP is a management system that utilizes intelligent communication technology and software control systems to achieve spatial range coordination and optimization of energy storage processes. It serves as a special power plant in the field of electrical engineering to participate in power market power coordination [7-8]. With the rapid development of distribution network and transmission network, VPP is used in rural power carbon emissions to achieve reasonable allocation of resources, laying a stable foundation for the next VPP security model [9-10]. According to the relevant knowledge and theoretical achievements of VPP at home and abroad, the relevant research and specific contents of optimal dispatching of VPP are shown in Table 1.

Table 1. Exploration on Optimal Dispatching of VPP

Research		Specifics
Technical VPP	Optimize the power output of each internal power supply	Make aggregated resources available to system operators to maintain system balance at minimal cost
		Leveraging its aggregated resources as well as conventional units to serve the transmission system
Commercial VPP	Regulating each resource to optimize economic goals	Connect wind power, photovoltaic, electric vehicles, etc. to the grid and control the dispatch of each resource with the economic optimum
		Aggregate and dispatch small distributed energy sources scattered in different areas

It can be seen from Table 1 that the optimal dispatching of VPP mainly includes two aspects: technical and commercial. The commercial VPP mainly adjusts the output of various resources to optimize the economic objectives, which can effectively solve the unified dispatching of distributed energy and grid connection optimization. Moreover, the commercial VPP is the mainstream direction of current research [11-12]. In technical VPP, optimizing the output of various internal power sources and providing supporting services for the safe operation of the local distribution network are the main goals to achieve the lowest cost of maintaining system balance [13-14]. Therefore, based on the traditional rural VPP of electricity carbon emissions, the introduction of LMDI decomposition method is of great significance for day ahead scheduling optimization.

2.2 Application of LMDI Decomposition Method in VPP

The LMDI model is a technique for breaking down variations in energy usage. Its fundamental idea is to break down variations in energy consumption into the contributions of different elements in order to have a better understanding of the trends and factors that influence energy consumption. LMDI does not have unexplained residuals after decomposing objects, and can use relatively simple conversion expressions for addition decomposition and multiplication decomposition [15-16]. In the application of optimal dispatch of rural VPP for carbon emissions of electricity, based on the LMDI Logarithmic mean decomposition method, carbon emissions can be decomposed into three parts: structural effect, intensity effect and combined effect, so as to improve the effect and accuracy of the entire model [17-18]. The specific process of LMDI decomposition method applied in VPP is shown in Figure 1.

To sum up, determining the factors and time period to be decomposed is the first step of LMDI's day ahead scheduling in VPP. Next, by determining the proportion of important factors related to electricity carbon emissions in rural VPP in the time period, the logarithmic difference and the contribution rate of each factor are calculated and normalized to the percentage form, so as to achieve the verification of carbon emissions results [19-20]. Based on the steps of the whole LMDI algorithm, the total energy consumption can be divided into the contributions of various factors. Combined with the analysis of the components of the VPP below, it is conducive to in-depth understanding of the structural changes of carbon emissions.

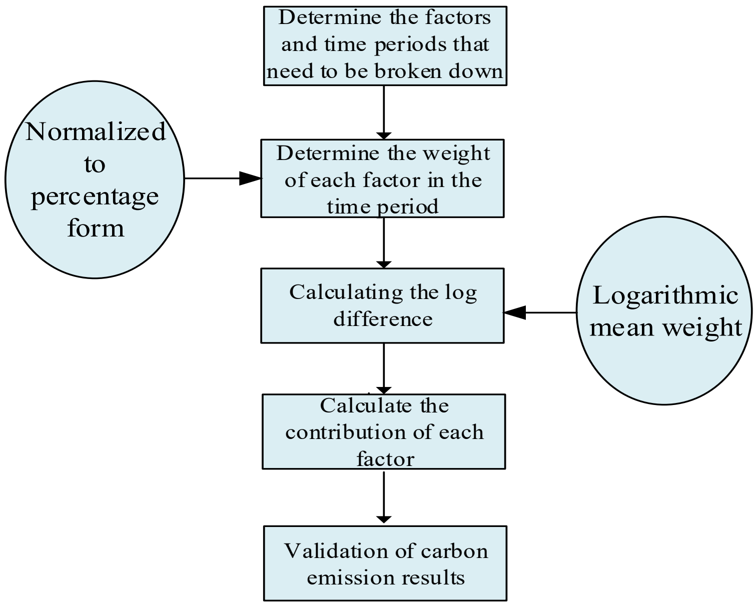

Fig.1 Flow chart of LMDI application in VPP

3. Model Construction of VPP Optimal Scheduling

3.1 Components of Rural VPP for Electricity Carbon Emission

After a research discussion on the theory related to the optimal scheduling of The study of the rural VPP component of power carbon emissions is pursued, along with the use of the LMDI decomposition method in VPPs. The intelligent placement of distributed generation in the power market based on prediction data for conventional power plants, renewable energy sources, and other sources is referred to as the optimal dispatching of VPP. energy storage equipment and load demand, and the generation of appropriate operation schemes to achieve the safe and stable operation of VPP. The analysis of VPP components is the basis of optimal dispatching. Therefore, the composition and content of rural VPP related to carbon emission of electricity are shown in Table 2.

Table 2. Components of Rural VPP for Electricity Carbon Emission

Structure	Description
Photovoltaic Power Generation	The output power of photovoltaic cells is proportional to solar radiation and basically obeys the Beta distribution.
Wind Turbine Power Generation	The output power of wind power is closely related to the wind speed, and often adopts the two-parameter Weibull distribution.
Gas Turbine	Consists of a micro gas turbine, a permanent magnet generator and a filter
Energy Storage System	Electricity is purchased from the grid during the low price period and supplied to customers during the peak price period
Flexible Load	Flexible loads are divided into three main categories: base loads, transferable loads and curtailable loads

It can be seen from the above composition structure of the rural VPP for electricity carbon emissions that the entire VPP consists of five parts: photovoltaic power generation, wind turbine power generation, gas turbine, energy storage system and flexible load. These structures have important reference value for realizing the dispatching model of VPP based on LMDI. When scheduling optimization of VPP system is involved, it often needs to be solved at the same time, so its scheduling flexibility needs to be considered when building the scheduling model.

3.2 Dispatching Model of VPP Based on LMDI

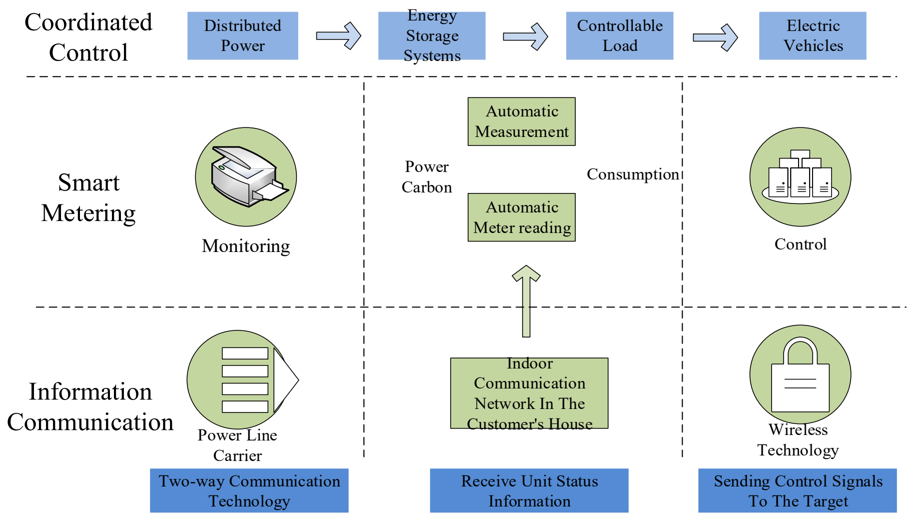

Fig.2 LMDI based optimal dispatching model of VPP

According to the relevant research on the optimal dispatching of traditional VPP, combined with the application and process of LMDI decomposition method in VPP, the optimal dispatching model of VPP based on LMDI decomposition method is divided into coordination control module, intelligent metering module and information communication module according to the key technology by virtue of the composition structure of rural VPP with electricity carbon emissions. Therefore, the optimal dispatching model design of VPP based on LMDI is shown in Figure 2.

According to the optimal dispatching model of VPP built in Figure 2, the entire VPP provides management and auxiliary services for distribution network and transmission network. Subsequently, the model constraint conditions are calculated, and the supply-demand balance constraint conditions of electricity carbon are calculated as follows in Formula (1):

$$C_{gt}(t)+C_{gb}(t)=C_{gtp}(t)+C_{ex}(t) \tag{1}$$

Among them, $C_{gt}(t)$ and $C_{gtp}(t)$ are respectively the free quota and actual carbon emissions of gas turbine in the VPP through allocation of t period; $C_{gb}(t)$ is the amount of carbon dioxide absorbed by the Power-to-gas equipment during operation in period t; $C_{ex}(t)$ is the carbon emission quota size of VPP trading with other participants in the carbon emission trading market at time t. Therefore, the optimization scheduling problem model is calculated as Formula (2):

$$\min \alpha$$

$$s.t.\ \alpha \geq \sum_{t=1}^{T}(f_a(t)+f_b(t)-f_c(t)) \tag{2}$$

Among them, α is the intermediate variable; $f_a(t)$, $f_b(t)$ and $f_c(t)$ respectively represent the market income of electric heating energy, the market income of Carbon emission trading and the operating cost of Power-to-gas equipment.

4. Simulation Experiment Results

Following the completion of the design of the best dispatching model for rural VPP based on the LMDI decomposition approach for electricity carbon emissions, simulation tests were used to evaluate the model's real performance in various scenarios.

Six regions—Region A, Region B, Region C, Region D, Region E, and Region F—were chosen as sample parameters for this experiment, and they were trained and evaluated as datasets. The market returns and carbon emissions of the VPP optimal scheduling model based on LMDI decomposition method in six regional samples were obtained after 100 rounds of data testing and analysis using the Monte Carlo method within a certain amount of time, and were compared with the outcomes of the traditional VPP scheduling method. Figure displays the outcomes of using both conventional techniques and the enhanced scheduling model to market returns 3.

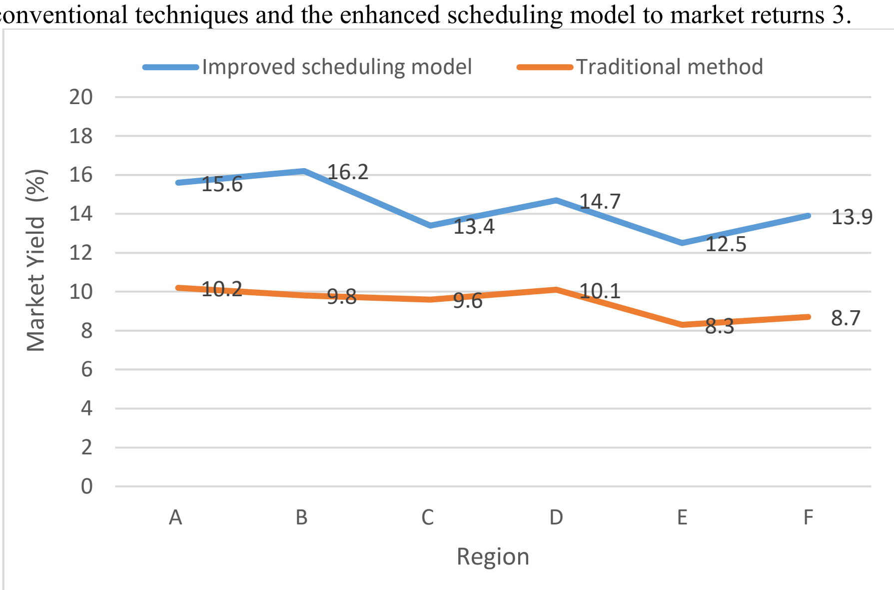

Fig.3 Market yield of improved scheduling model and traditional methods

In Figure 3, the blue line represents the market return rate of the optimized dispatching model of rural VPP based on LMDI for electricity carbon emissions, and the orange line represents the market return rate of the traditional dispatching model of VPP. It can be seen that the market return rate of the improved LMDI algorithm model in region B had the best effect, increasing from 9.8% to 16.2%, with an increase of 6.4%. The market return rate of the sample in other regions increased from left to right by 5.4%, 3.8%, 4.6%, 4.2% and 5.2%, respectively. It can be seen that the comprehensive average increase of the market return rate of the improved and optimized dispatching model of VPP was about 5%. This showed that the optimal dispatching model of VPP based on LMDI decomposition method was an improved scheme in terms of market revenue.

Following a discussion of the aforementioned market return findings, more simulation tests were conducted. Analysis was done on the carbon emissions of the rural VPP optimum dispatching model as well as the model's decrease in carbon emissions. based on LMDI decomposition method compared with traditional methods is shown in Figure 4.

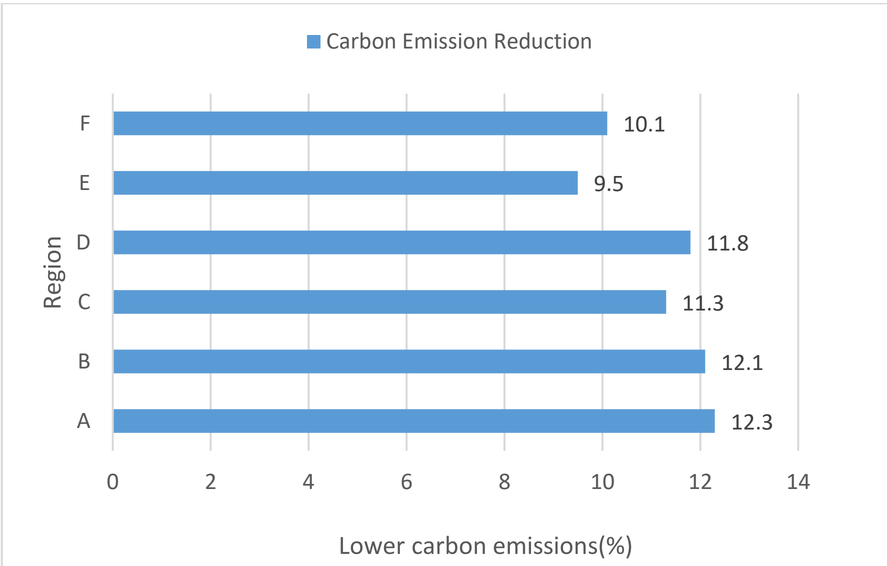

Fig.4 Improved scheduling model for reducing carbon emissions

In Figure 4, the blue column showed the reduction of carbon emissions in the optimal scheduling model of VPP based on LMDI decomposition method. The carbon emissions of VPP in each regional sample were reduced. The reduction ranges of different sample groups from bottom to top were 12.3%, 12.1%, 11.3%, 11.8%, 9.5% and 10.1% respectively. It can be seen that the comprehensive average reduction of the improved optimal dispatching model was about 11.2%. This showed that the application of the optimal scheduling model of VPP based on LMDI decomposition method had a good application effect in carbon emissions.

5. Conclusions

A rural VPP optimum dispatching model based on the LMDI decomposition approach may be widely employed in the power market and distribution network system due to the quick advancement of science, technology, and statistical analysis techniques. The pertinent study on the best scheduling for conventional VPP is the foundation of this work. Through the analysis of the application of LMDI decomposition method in VPP and the algorithm process steps, and with the help of the composition structure of rural VPP with electricity carbon emissions and simulation experiments, it was concluded that the improved model of optimal scheduling of rural VPP based on LMDI decomposition method has a good application effect on market profitability and carbon emissions. This paper expected that through theoretical and empirical research, it can provide the optimal dispatching model design of rural VPP based on LMDI decomposition method for China. The number of regional samples selected is too small, and the analysis of the composition and structure of rural VPP with carbon emissions is not perfect. The optimal scheduling model of VPP designed in this paper has many defects and deficiencies, which would be further improved in the future research.

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