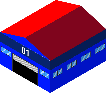
Planning of virtual power plant considering dispatchable load under uncertainty

**ABSTRACT:** Virtual power plants (VPP) are expected to be important components of the new intelligent energy. In this study, a two-stage stochastic optimization model is developed for the planning electric power systems included VPP under uncertainty.The support vector regression technique is applied to the prediction of power demand. The prediction result is then used in the planning model peak load constraints.The model systematically reflects the complexity of the renewable energy management system and improves the applicability of the modeling process. The resulting solution provides the desired energy resource/service allocation plan with minimized system costs, maximized system reliability, and maximized energy security. And thus the trade-off between system costs and energy security will balance. The results show that the dispatchable load of the virtual power station can effectively alleviate the power generation pressure caused by the shortage of renewable energy due to weather and other factors. In detail, this study aims to provide: (a) adjustment or justification of the pattern of distribution of renewable energy resources and services in the context of Intelligent Energy; (b) decision support of local policies on energy use, economic development and energy structures under various energy supply and policy interventions; (c) analysis of the interaction between economic costs, system reliability and energy supply shortages.

**KEYWORDS:** Virtual power plant, Uncertainty, Electric power systems, Interval, Support vector regression

## Introduction

China is the world's largest consumer of energy and electricity. The overall power supply is abundant in China. Nevertheless, due to uneven development, the electricity shortage still exists in some areas during the peak period of electricity consumption [1], whereas some capacity is idle at the low-load period in these areas. This phenomenon not only increases the power costs and pollution emissions in the peak-period but also caused the resource waste in the low-load period. On the other hand, China's government is actively adjusting the structure of energy, optimizing the power production structure and further improving the proportion of non-fossil energy generation. The installed power generation capacities of hydro, wind and solar in China rank the first around the world [2]. The intermittent and unpredictable nature of clean energy generation, such as wind power and photovoltaic power generation, increases the cost and risk of renewable energy grid-connected. How to improve the stability of renewable energy grid-connected? How to deal with the problems of energy shortage, environmental pollution? How to adjust the user's power consumption, reduce the peak and valley difference, and ensure the safe and stable supply of electricity for the power system? Solve those urgent problems are vital for China and the world to move forward with a clean, efficient, safe and sustainable energy development. Under the above background, VPP is proposed as a new technology for smart energy in the power market. VPP refers to heterogeneous power plants, which usually include heterogeneous distributed energy resources (DERs), traditional fossil fuel power plants, energy storage facilities and dispatchable loads. As shown in Figure 1. According to the characteristic of the service region, its concrete composing form is various. The VPP can effectively integrate, aggregate and manage traditional and renewable energy power plants, including distributed generators, energy storage systems and dispachable loads [3]**,** in order to increase the power generating, reduce the instability of wind and solar power generation, shave peak load to cope with power shortage during rush hour.



**Dispatchable loads**



**PV**



**Hydropower**



**Wind power**



**ESS**



**EVs**

√



**Cloud computing**

**Utility Grid**



**CHP**



**Ice storage**

**Fig.1.** **The composition of heterogeneous VPP**

In Europe, there are many demonstration projects of VPP, shown in table 1. For instance, the Danish *EDISON VPP(EVPP)* project [4] collects historical data and real-time data on the operation of electric vehicles, and aggregates them to form the market resources, and then participates the market transactions through the retailers. The European Union's *FENIX-VPP* project [5] is a combination of traditional generator sets and cogeneration of wind turbine generator to form VPP, coordinated and controlled through technical means, and then involved in the electricity market through trading software. The EU's *WEB2-ENERGY-VPP* project [6] attempted the transmission of the electricity communication protocol IEC61850 in a wide area network. End users and power supplies can be accessed via the Internet into the control center of the VPP, and through the CIM-61850 converter is converted into an electric public information model to participate in market transactions. The Netherlands *Power Matcher(PM)*[7]architecture is a kind of agent concept, that is, the VPP can assume a centralized agent, auction agent, and other different agent functions, in the market to gain profits. In Germany, there are several VPP projects such as the *vpp-intelligent-energy*, etelligence, and *RegModHarz*[8]. The smart grid pilot project *eTelligence*, which combines large ice storage as a dispatchable load and wind power plants to form a VPP. By adopting the policy of combination of segmented electricity price and dynamic electricity price, the load of the two ice storages will be adjusted automatically with the power fluctuation of electricity price and wind power. The standard of OPENIEC61850 communication protocol based on *etelligence* project design has been recognized by the German industry. The *PREMIO* project is used to optimize the effect of module access such as distributed energy, storage and demand response in power grids [9]. The "large-scale and friendly interactive system" in Suzhou, China, can carry out millisecond control on several interruptible loads, and by cutting off some unimportant small power supply, the priority to ensure the important load will not be affected when the instantaneous power outage of the power grid.

**Tab.1.** **The structure and function of demonstration projects of VPP**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Project | VPP members | | | | | | | | Function |
| PV | WPP | PSH | CPP | CHP | ESS | EV | DL | &mode |
| EDISON |  | √ |  |  | √ |  | √ |  | PBDR+FR |
| Power Matcher |  |  |  |  | √ |  |  |  | PS |
| FENIX | √ | √ |  | √ | √ |  |  | √ | PBDR+PS+FR |
| WEB2ENERGY | √ | √ | √ |  | √ |  |  | √ | PBDR+IRC+FR |
| eTelligence | √ | √ |  |  | √ |  |  | √ | PBDR+IBDR+PSFR |
| vpp-intelligent-energy | √ | √ |  |  | √ |  |  | √ | FR |
| RegModHarz | √ | √ | √ |  | √ |  | √ |  | PBDR+PS |
| PREMIO | √ |  |  |  |  | √ |  | √ | PS |

Note: Pumped-storage hydroelectricity (PSH); Conventional power plants(CPP); Wind power plants (WPPs);Photovoltaic units (PVs); Energy storage system (ESS); Dispatchable loads(DLs); Electric vehicles (EVs); Combined heat and power(CHP);Frequency regulation(FR);Price-based demand response (PBDR); Incentive-based demand response(IBDR); Peak-shaving(PS); Inter-regional cooperation(IRC);

In addition to the above-mentioned practical demonstration projects, scholars have carried out a lot of research work on the technical feasibility, economic feasibility, and reliability of the VPP. In[10],the authors put forward a technique of dispatching and optimizing operation, integrating the data center into Intelligent Power network to participate in the intelligent demand response, and the simulation results verify the feasibility of the technology. A distributed VPP scheduling method without centralized control center is proposed in [11]. The authors in [12] analyze selected communication quality of service parameters—in particular, latency, packet loss, retransmissions, bandwidth, amount of traffic, and message patterns of the IEC 60870-5-104 protocol. Authors of [13] proposed a VPP routing algorithm for data communication, which supports centralized, decentralized, or fully distributed control. These studies provide technical support for the participation of VPP in the flexible response of power market transactions. LI et al. [14] discussed the feasibility and incentive mechanism of a VPP based on the case of Chongming in China. The results show that the optimal combination ratio of wind energy and photovoltaic power stations is conducive to raising the self-sufficiency rate of Chongming Electric Power. In [15] the authors conclude that explores the development of Germany's future energy system, and the simulation results show that the heterogeneous VPP composed of fossil power plant, renewable energy, and cogeneration equipment can bring some economic benefits. Based on the bid information of Korea Electric Exchange, authors of [16] puts forward a demand response method of the VPP, and tests and validates the method in IEEE Reliability Test System (IEEE RTS-24). The results show that the method can bring down the total operating cost. A method of VPP scheduling management optimization model for maximizing the profit is presented in [17]. The operator can select the best demand response loads program for each VPP in a scheduling procedure, and the reliability of the model is also tested in IEEE RTS. In [18] takes the VPP as the production/the consumer to participate in the market transaction independently, also takes the VPP profit maximization as the goal, proposed the two-stage stochastic mixed integer linear programming model under electric power market planning. In [19-21] establishes the optimal dispatching model in the power market environment in which traditional power plants, renewable energy power plants and VPP coexist. The problem of the cooperation between neighboring VPP is discussed in [22], to maximize the expansion of VPP's energy trade opportunities. Authors of [23] take Genco as an example to establish the optimal operation scheme of risk avoidance in the VPP is established. These studies further confirm the feasibility of the VPP participating in energy trading and distribution issues. In addition, there are a few studies on the involvement of smaller energy efficiency units in the power market. In [24] author constructs a virtual energy storage system that stores and releases energy by coordinating the demand response of the city's household refrigerators to achieve the goal of reducing carbon emissions by replacing the rotational reserve capacity of fossil-fueled generators. The study of the VPP or energy-efficient power plant provides a new direction for solving the problem of power supply shortage, energy supply security and energy integration. In particular, the rapid development of smart grid technology promotes reasonable resource configuration and provides solid support for VPP operation.

At present, the research on the VPP focuses on the operational frame, optimal dispatch, technology realization and operation control. However, many economic, environmental and policy factors have had a significant impact on the energy management process, leading to various uncertainty in decision-making. Dozens of system parameters (such as renewable resource availability, facility capacity, production efficiency and allocation target, as well as their interrelationships) may appear uncertain and may be presented in fuzzy, probabilistic and/or interval formats. Previous research on VPP rarely considered these uncertainties. Also, for VPP that contain controlled loads, decision-makers may need to know the following issues. What impact does a VPP with a controlled load have on a region's CO2 emissions? What kinds of power generation technologies are needed to meet these needs if the electric demands during peak periods are not shaved? In 2015, the growth rate of thermal power in China dropped by 2.6%, but in 2016, it increased by 3.6%. Can the peak load regulation by the VPP reduce the electric generating of fossil fuel power plants? What is the effect of load shifting? There are few reports about the mid-term effects brought by the VPP. Decision-makers need to comprehensively assess the combined impact of a VPP when formulating regional development plans.

Therefore, in this study, we will discuss the energy planning problem considering large ice storages as dispatchable loads incorporated with renewable energy power plants to form VPP. A power planning model based on the cost minimization strategy is proposed. The economic and emission reduction benefits of the energy substitution scheme, which is provided by using the intelligent incentive control mechanism in the smart grid, are analyzed.

## Modeling formulation

This study will discuss the energy planning of VPP composed of dispatchable loads (such as large ice storage) and wind power generation, photovoltaic power generation and hydropower. Large-scale ice storages, freezers in supermarkets, or refrigerators and freezers in private homes can be viewed as a storage electrical power facility that store electricity in cold form. Hot-Spring convalescent facilities using cogeneration systems store electricity in hot form, and electric cars in cities can also be used as energy storage devices in the Smart Grid. These facilities all have sponge-like properties, they can play a role of energy storage when the power load is at a low point (i.e., the generating capacity is higher than the load), absorb and store electricity, and when the load is at a peak period (i.e., the generating capacity is less than the load), it is like energy storage device that begins to release electricity. Such as ice storage even if the power cut-off, the temperature drop is very slow, in a certain temperature and time range, and will not lead to the deterioration of the quality of storage goods. Therefore, can be opened according to load demand, low-load operation or shutdown. When the wind power is strong, solar energy is abundant and electricity market price is low, the smart control system can start the ice storage or reduce the set temperature of refrigerated in operation, to store a certain amount of electricity in 'cold' form. In the period of electricity shortage, lack of wind or solar energy and high price in the electricity market, smart system can suspend the operation of ice storage, run the frequency converter or increase the set temperature, to reduce the power consumption and play the role of peak load shifting. The traditional energy-efficient power plant and energy efficiency demonstration project are through the implementation of a package of the energy-saving plan, access to demand-side savings of power resources. A VPP with dispatchable load type is different, these "virtual power units" with their spongy properties do not reduce their demand for electricity or even increase the demand for electricity due to frequent start-up and shutdown of equipment. It only reduces peak electricity demand in the form of load transfer. In the power gap period, the "VPP" in some special areas can play an active role in regulating, such as areas where high reliance on renewable energy sources, port cities with many large-scale ice storages bases, and hot spring convalescent facilities using CHP systems.The framework of VPP participating in energy market transaction is put forward, as shown in Fig.2. The large-scale ice storage in the VPP can serve as the peak shaving function.

**Smart Demand Response**

**Energy allocation using VPP adjustment**

**Start adjusting device**

**Weather data**

**Comprehensive impact analysis**

**Risk Management**

**Load Forecast Data**

**…**

**Device Reliability Data**

**To achieve the level of risk control?**

**Economic operation analysis of VPP**

**Need to take action?**

**Decision Management**

**Incentive Policy**

**No action**

**No**

**Yes**

**Yes**

**Flexible operation mode**

**Constant operation mode**

**Smart Grid Scheduling**

As volatility and uncertainty increase dramatically because of more renewable energy grid-connected. In the power system planning, many data obtained will be biased, and the probability distribution and membership function of these data are not easy to obtain. ILP is an effective method to deal with uncertainties existing as interval values without distribution information [25,35-37].

**Fig.2.** **Operation process of VPP**

There is an uncertain deviation between the actual output and the planned output of the power system dispatching wind power, PV, and hydropower with renewable energy. If the failure to achieve the planned output due to weather or other factors occurs, there will be a deviation penalty cost. At the same time, the power system also needs to arrange standby fossil fuel generating unit to generate electricity to meet the demand. The large ice storage, commercial buildings and other interruptible loads can be used as a part of the reduction of the output deviation of the renewable generations. Also, it can combinate with the renewable energy generation to form a VPP. The start-up and stopping of large ice storages will result in some economic losses. Thus, it is necessary to include the compensation cost of the deviation penalty cost and interruptible load into the objective function.

 (1)

(1) The total cost for purchasing primary energy

 (2)

(2) Fixed and variable generation costs for traditional power plants (3)

(3) Operating costs of a VPP

 (4)

(4) Penalty for excess CO2 emission

 (5)

s.t.

Electricity demand constraints:

 (6)

(2) Capacity limitation constraint for power-generation facilities:

 (7)

CO2 emission constraints:

 (8)

Electricity peak load demand constraints:

 (9)

Renewable Energy availability constraints:

 (10)

Electricity generated from solar energy equal to or less than its total availability

 (11)

Electricity generated from wind energy equal to or less than its total availability

 (12)

Electricity generated from hydropower equal to or less than its total availability

1. Dispatchable load Regulation Constraints

(13)

1. Electricity deficiency equal to or less than the predefined targets

 (14)

1. Energy availability constraints:

 (15)

 (16)

Boundary constraints for primary energy sources

1. Non-negativity constraints:

(17)

The annual power demand forecast is an important part of power system planning, which is influenced by economic and social uncertainties. Also, annual historical data is less. Support-Vector-Machine（SVM） is a machine learning method based on the principle of structural risk minimization. The basic idea is to transform the input space into a high-dimensional space by using the nonlinear transform defined by the inner product function and to find the exact description of the non-linear relation between the input variables and the output variables in this high-dimensional space. Support-Vector-Regression（SVR）can be applied to the prediction problem in the case of finite samples. Thus, SVR can be used for predicting electricity demand.

 (18)

where are the Lagrangian multipliers.is called the kernel function, whose value equals the inner product of two vectors (such as  and ) in the feature space. is constant. SVM aims at minimizing the empirical risk. Selecting and determining the parameters of the kernel function requires knowledge based on the application domain and reflects the distribution of the input training data as much as possible. There are many kernel functions commonly used, such as polynomial kernel function, Gaussian radial basis function (RBF) kernel function and the Sigmoid kernel function. RBF kernel is easier to implement and capable to non-linearly map the training data into an infinite dimensional space, and it is suitable to deal with non-linear relationship problems [26]. Thus, this study used RBF kernel to predict the electricity demand. Radial basis function (RBF) with a width of . SVR generalization performance depends on a good setting of regularization constant, precision parameterand the kernel parameters.[27] In this study, the optimal value of parameters,,andare determined by employing a grid-search in a n-fold cross-validation approach which can prevent the over fitting problem[28,29]. The mean absolute percent error (MAPE) is a commonly used forecasting error metric for quantifying and assessing the accuracy of the predicted output values. Meanwhile, the average relative error strengthens the function of the large error term in the indicator. Therefore, this study adopts the average relative error as the judgment basis of each prediction result. Three kinds of accuracy criteria (i.e. prediction accuracy: PA, Fitting accuracy: FA, and overall accuracy: OA) were used to assess the performance of the SVR model [30,31].

 (19)

 (20)

 (21)

is used to compare actual electricity consumption values and predicted electricity consumption values during the test period.  is used to compare the actual electricity consumption values and the predicted electricity consumption values of all the training points time periods. is used to compare actual electricity consumption values and to predict electricity consumption values over all time periods, including training and testing time periods.

The model needs to be able to cope with the peak load at different time periods of different seasons, so it needs to be constrained. Many traditional methods convert such constraint into deterministic scenarios and then verify the satisfaction of the solution to the model constraint under this deterministic scenario. Once the planning scheme does not meet the constraints requirements of the prescribed scenario, it is classified as an unworkable scheme and discarded. Therefore, this kind of constraint is "rigid constraint", and the optimal scheme must pay the "price" in some aspects, and it cannot adapt to the demand of the actual power production planning decision well. Therefore, this study adopts different processing principles, allowing the decision in some cases do not need to strictly satisfy the constraint conditions, but the probability of satisfying the constraints is not less than the specified confidence level. The constraint condition of the model in the optimization process is changed from "rigid satisfaction" to "flexible response", and the scheme can be flexible and operable while satisfying the optimization target. Such a scheme can help the decision-makers to weigh the system cost and the constraint violation risk, and improve the scientific and credibility of the program implementation effect while guaranteeing the safe operation of the power system.

Many parameters in the planning process are uncertain, and their probability distribution and the membership function are not easy to obtain or the data volume is huge. Some traditional processing methods will take the historical average as the parameter, which is convenient to planning, but it ignores the influence of the uncertainty from these parameters. Therefore, this study uses these uncertain parameters to be processed into the form of interval parameters. Depending on the expertise and experience of experts and stakeholders, these specific parameters are set to the upper and lower limits of the known interval but do not know their probability distribution of interval parameters. This not only reduces the requirement of the data quantity, but also can effectively solve the uncertainty of the coefficients in the objective function and the constraint, and obtain the stable and feasible interval solution when the variable probability distribution and membership function cannot be obtained. In addition, the planning decision goal is usually an economic goal (least cost or maximum profit). When making decisions, the most advantageous economic objectives are likely to have some negative impact on energy and the environment. Therefore, it provides the best optimal scheme and the worst optimal scheme interval based on the economic goal, so that the decision maker can adjust the value of the decision variable in the interval according to the actual situation, to obtain the satisfactory planning scheme and provide the scientific basis for the decision support.

(22)

(23)

 (24)

The availability of renewable energy, affected by the weather and other factors, is more difficult to determine. Here the availability of different renewable energy shortages in the planning period is treated according to discrete functions, and the probability level of renewable energy availability is divided into three kinds, high, medium and low.

According to the two-step method proposed by Huang [32-34], an ILP model can be transform into two sub-models. The sub-model (4) corresponding to the lower bound  should be first solved when the objective function is to minimize and can be formulated as follows:

(25)

Subject to:

 (26)

 (27)

 (28)

 (29)

 (30)

(31) (32)

 (33)

(34)

 (35)

 (36)

Correspondingly, the upper bound objective  can be presented as follows:

(37)

Subject to:

 (38)

 (39)

 (40)

 (41)

 (42)

(43) (44)

 (45)

(46)

 (47)

 (48)

## Case study and result analysis

The increasing power consumption in cities can be attributed to industrial development, economic improvement, and population growth. The first, second, tertiary industry and industrial products are the main factors determining the use of electricity. In addition, the population is another important parameter affecting electricity consumption. Gross domestic product (GDP) is a broad parameter that reveals the prosperity of the urban economy, which provides a quantitative indicator of the average living standard, indicating the capacity to produce and consume electricity. At present, coal-fired power generation is still the main power production technology, so coal consumption is also included in the influence parameters of electricity consumption. We refer to the historical data of an administrative area of Tianjin, China and establishes the analog input data of the model. As shown in Table 2.

Fig. 3 presents the observation, prediction and error of electricity consumption of the administrative district. Three kinds of accuracy criteria (i.e. PA, FA and OA) were used to assess the performance of the SVR model, and the SVR parameters can be searched by the grid-search method.

When the value of the parameters ,,andare27,2-7,1.0 respectively, the PA,FA and OA values of the SVR model are 95.42%, 91.36% and 93.53% respectively, and the predicted results are satisfactory. The predicting values of electricity demand are 263.34, 274.69 and 286.04(102 GWh) from 2017 to 2019.p- is prediction-. p+ is prediction+. The forecast results are used to set the interval of power demand. Table 3 provides the costs for electricity generation expressed as interval values.

**Tab.2. Seven attributes for SVR prediction.**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Resident population  (million) | GDP  (100 million $) | Primary industry  （100 million$） | Secondary industry | Tertiary industry | Industry | Coal consumption  (10,000 tons) | Electricity consumption (102GWh) |
| 2000 | 2.99 | 42.82 | 2.79 | 23.82 | 16.2 | 21.50 | 806.79 | 67.24 |
| 2001 | 3.00 | 78.19 | 3.39 | 39.69 | 35.12 | 36.11 | 838.11 | 70.97 |
| 2002 | 3.01 | 88.17 | 3.62 | 44.06 | 40.49 | 39.93 | 875.41 | 75.14 |
| 2003 | 3.02 | 98.81 | 3.87 | 49.12 | 45.83 | 44.49 | 906.65 | 84.30 |
| 2004 | 3.03 | 118.44 | 4.13 | 61.44 | 52.88 | 55.95 | 944.37 | 93.90 |
| 2005 | 3.07 | 142.92 | 4.84 | 77.45 | 60.63 | 71.19 | 1069.94 | 105.29 |
| 2006 | 3.13 | 179.43 | 5.16 | 98.09 | 76.18 | 89.95 | 1112.81 | 115.45 |
| 2007 | 3.23 | 205.03 | 4.75 | 112.88 | 87.40 | 103.90 | 1229.83 | 130.10 |
| 2008 | 3.35 | 241.32 | 5.06 | 132.89 | 103.37 | 122.29 | 1329.34 | 148.41 |
| 2009 | 3.53 | 308.68 | 5.63 | 170.44 | 132.62 | 157.07 | 1441.53 | 154.77 |
| 2010 | 3.68 | 345.57 | 5.92 | 183.21 | 156.44 | 166.41 | 1572.77 | 165.05 |
| 2011 | 3.90 | 423.79 | 6.69 | 222.37 | 194.73 | 202.64 | 1825.47 | 193.72 |
| 2012 | 4.06 | 519.48 | 7.34 | 272.36 | 239.78 | 249.50 | 2034.41 | 208.55 |
| 2013 | 4.24 | 592.37 | 7.88 | 306.15 | 278.34 | 281.30 | 2197.67 | 222.96 |
| 2014 | 4.42 | 663.49 | 8.66 | 335.75 | 319.09 | 307.19 | 2364.55 | 238.34 |
| 2015 | 4.55 | 722.52 | 9.18 | 355.22 | 358.12 | 325.23 | 2443.52 | 247.18 |
| 2016 | 4.64 | 759.79 | 9.59 | 353.95 | 396.26 | 320.80 | 2478.04 | 255.34 |

**Fig.3. Comparison of the prediction and actual value with a SVR model**

**Tab.3 Cost for power generation**

|  |  |  |  |
| --- | --- | --- | --- |
|  | period1 | period2 | period3 |
| Cost for purchasing fossil fuels （103$/TJ） | | | |
| Coal | [0.32,0.38] | [0.30,0.36] | [0.28,0.34] |
| Natural gas | [0.35,0.42] | [0.33,0.40] | [0.31,0.38] |
| Variable cost for power generation (103$/GWh) | | | |
| Coal | [1.62,1.87] | [1.54,1.78] | [1.46,1.69] |
| Natural gas | [2.19,2.52] | [2.08,2.39] | [1.98,2.27] |
| Solar | [4.90,5.10] | [4.66,4.84] | [4.42,4.60] |
| Wind | [8.64,9.19] | [8.21,8.68] | [7.8,8.19] |
| Hydro | [6.58,7.80] | [6.25,7.41] | [5.94,7.03] |

(a) Spring and Summer

(b) Autumn and Winter

**Fig.4 Power generation of various generating technologies in different periods (lower bound)**

Fig.4. shows the power generation of various generating technologies in different periods (lower bound). The power consumption of businesses and residents has changed a lot in 24 hours a day. According to the actual situation, we divide the day into four periods. d=1, for the trough period, a total of 8 hours (23:00-7:00). d=2, for the general period, 8 hours (7:00-8:00 and 11:00-18:00). d=3 (8:00-10:00,18：00-19:00 ,and 21:00-23:00),d=4(10:00-11:00 and 19:00-21:00), respectively, the high demand period and peak period, 4 hours. The overall average load during summer high demand period and peak period were 29.36% higher than the general period. With the carbon emission reduction policy, power generation arrangements will shift to more economical and environmentally friendly power plants. While meeting the power demand, the power generation of coal-fired power plants has been declining year by year, and the proportion of renewable energy power generation technologies has steadily risen. The peak of electricity consumption occurs in summer, and the average daily minimum electricity consumption appears in spring. In the autumn, renewables generate the most electricity. This is related to the climate of the area corresponding to the reference data. Autumn windy, abundant sunshine, and abundant water. Therefore, renewable energy generation arrangements have increased. On the other hand, with the decline of thermal power, in three planning periods, renewable energy generation proportion gradually increased, accounting for the total generation of 32.73%, 40.78%, and 42.67%.

a) lower bound

b) upper bound

note: ACS(dispatchable loads) GER(renewable energy)

**Fig.5 Dispatchable loads adjusting quantity under different energy availability level**

Fig. 5 shows the dispatchable loads regulation and the shortage of renewable energy under different power availability .t represents the planning period, p is the probability of three kinds of renewable energy shortage random events. The probability level of p1, p2, p3 is medium, high and low. ACS is a dispatchable load adjustment represented by ice storage in a VPP. When wind power, photovoltaic power generation and hydropower shortage due to the weather and the like fail to reach the target power generation capacity, the dispatchable load can play a positive regulatory role. The maximum ratio of dispatchable load regulation to power generation shortage during the three planning periods is 94.16%, the minimum is 15.01%, and the average is 39.13%.

note: BAU (business as usual) VC (VPP case)

**Fig.6 Carbon dioxide emissions in different scenarios**

Figure 6 shows a comparison of carbon dioxide emissions conventional from conventional power generation scenario and from dispatchable loads as alternatives scenario in VPP. Currently, common means for balancing electricity demand is to increase the electricity generation of conventional power plant when the scenario of insufficient renewable energy is taken place. However, as shown in Fig.6. result, ice storage as dispatchable load can effectively supplement the deficiency. It decreases the peak load for variable renewable energy deficiency or demand increasing, and transfer the load to low demand time periods with trivial additional cost. The optimal solution shows that, with unchanged total electricity demand, the CO2 emission of scenario BAU is a bit higher than VC.

**Fig.7.** **Comparison of expected costs between two scenarios**

Figure 7 shows the cost comparisons in two scenarios. The power generation cost of the scenario including VPP(VC) is slightly lower than that of conventional power generation(BAU). In the optimal scheme of interval solution, the cost of the VC scenario decreased by 1.98%, the highest was 3.63%, and the average decreased by 2.34%. The cost decline is not obvious because the scale of the dispatchable loads in the case is limited. With the development of energy internet technology, the increase of the proportion of dispatchable loads is expecting to bring more cost reduction space for the VPP.

## Conclusions

Renewable energy integration and peak load shifting via VPP technology are useful tools for satisfying peak electricity demand with an environment-friendly way, which can effectively reduce the pollutant emissions and can improve the reliability of power demand-supply.

There will be more complex forms of VPP in the future, such as electric cars, because of their potential for agglomeration, electric vehicles are significant for renewable energy access to the grid. A single electric car can only store little energy, but when many electric vehicles are plugged into the grid, they may be used as a large energy storage device or be view as a VPP. With the increased share of fluctuation renewable energy in the power system, the demand for the peak-shaving and to assimilate instability of the intermittent renewable energy sources will grow. In our vision, with the development of smart grid and the expansion of ICT applications, the VPP will become an important component of the new Intelligent Energy infrastructure, which will mobilize the internal potential of the energy Internet to allow for maximum participation in the flow of energy, to use flexible products as a more cost-effective alternative scheme for the smart grid , to reduce reliance on import electricity or not clean energy, and reduce carbon dioxide emissions, to generate the stable power output, and improve the adaptability of energy systems.

There are many technical difficulties in the research of the VPP participating in the electric power transaction, which mainly focuses on the flexibility and reliability. There are a lot of problems that need to be solved in the future. such as, the stability of the smart composite system; The peak-shaving risk caused by the uncertainty of the forecast of wind power and PV power generation; The time response problem of electric electricity-shaving, the effect of price-based policy and the incentive policy on the flexible response of VPP, the integration of energy storage facilities and so on.

**Appendix A. Nomenclatures for parameters and variables**

 period (1 year)

 resource type, including coal and natural gas.

 Renewable energy generation type, include Solar, Wind power and Hydro.

 season, including Spring, Summer, Autumn, Winter.

Time.

 electricity conversion technology, including coal, natural gas, solar, hydro and wind power.

cost of purchasing primary energy k in period t (103$/TJ)

 the supply of fossil fuels k for the generation in period t (TJ)

 variable cost for generating electricity via electricity- generation technology i in period t (103$/GWh).

electricity-generation amount via electricity-generation technology i in period t season s time d. (GWh)

 maximum service time of electricity-generation technology i in period t

 carbon dioxide emission coefficient

 emission reduction efficiency

 emission reduction cost

 available resource k in period t

 energy consumption rate of electricity-conversion technology i

 total power demand in period t

 transmission loss in period t

 maximum allowed carbon dioxide emission in period t

 power factor of generating electricity via technology i in period t

peak-load electricity demand in period t under season s time d (GWh)

 average cost for renewable energy j based electricity production when energy is sufficient

the fixed target for electricity generation from renewable energy j that is determined at the first stage(GWh)

 average economic penalty for the shortage of electricity production from solar energy (103$)

 average economic penalty for the shortage of electricity production from hydropower (103$)

 average economic penalty for the shortage of electricity production from wind energy (103$)

 the amount of solar energy by which the target of AR is not met in period t (GWh)

 the amount of wind energy by which the target of AR is not met in period t (GWh)

 the amount of hydropower energy by which the target of AR is not met in period t (GWh)

 availability of hydropower in period t under probability level j (GWh)

 availability of photovoltaic in period t under probability level j(GWh)

 availability of wind power in period t under probability level j(GWh)

 compensation costs of dispatchable load (103$)

 The dispatchable loads of the ice storages (GWh)

cooling capacity of ice storage during period d of typical day in season s, (BTU/h)

Coefficient of performance of ice storage (BTU/GWh)

Average running time of ice storage(h)

 Maximum tolerated cooling deficiency rate

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