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Determining the Optimal Strategy of Multi Virtual Power Plants using GA-GT

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ABSTRACT: In the present work, determining the optimal strategy of multi virtual power plants (VPPs) as well as the objective of maximizing profit through the multi-level control of VPPs are discussed by the micro-grid utilization center including virtual power plants. VPPs include renewable resources such as wind farms, photovoltaic, and conventional resources such as fuel cell, micro turbine, hybrid heat and power include gas and also waste heat boiler integrated with electrical resources and energy storage devices such as batteries. During the market competition process, the method of biding for each VPP is determined according to the optimal generation capacity of each VPP.

In order to reduce the effects of uncertainty and unpredictability of the output power of wind farms, a more precise method for predicting using wavelet transform and artificial neural network as well as genetic algorithm method has been provided.

Two operational models are described in this paper: 1) specify the optimal independent strategy of each VPP; and 2) The game theory model to specify the optimized strategy of 9-bus IEEE system including multiple virtual power plants as well as a model of load response according to pricing mechanism for time use and also removable electrical loads.

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1. INTRODUCTION

Nowadays the power sector has globally experienced a significant progress in the deployment of scattered renewable energies due to their environmentally-friendly nature and energy shortage crisis [1]. Despite the fact that these resources can bring substantial benefits for power systems, nevertheless, their small size and alternating essence are among the most important challenges which have encountered for lack of participation in the liberalized electricity markets [2]. These clean resources have usually been traded at zero marginal cost as well as their progressive influence leads to lower market prices. [3]. To do so, the persistent and consistent trend towards a more competitive electricity market and the fast upward infiltration of distributed energy resources require proper platform and policies to handle both emerging technical and economic challenges for real-time operation condition. To overcome these problems and also reduce the complexity of small-scale distributed energy resources management by independent system operator, decentralized management of distributed energy resources that are integrated with each other seems to be beneficial and cost-effective [4]. Virtual power plants (VPPs) can aggregate capacity of different type of distributed energy resources and demand entities which may be dispersed in different points of network to make contracts in the power market and to bid services to the independent system operator. With regards to the concept of VPP and given the significant progress and developing of advanced metering infrastructure over smart power grids, it is possible to integrate and combine heterogeneous energy resourse and dispatch-able demands as a single entity, while covering the risk associated with the uncertainty in the VPP coalition [5]. The integrated coordination of disparate resourse under the VPP concept will generate surplus profits relative to the manner in which these resources are individually participated in the business interactions [6]. So, the VPP provides an opportunity for owners of small-scale resources to participate in the energy market at an acceptable risk level [7]. Under this context, developing an effective strategy for VPP participation in the power markets is among top priorities for private sector. VPPs are not only used to allow energy resourses for marketing energy trading but also play as an autonomous part in improving the power system flexibility [8]. In previous literature, for example, commercial VPPs have usually used for economic targets through participation in energy markets [9,10] and ancillary services such as reserve markets [11]. In [12], an integrated strategy for day-ahead offering and real-time operation of wind farm-energy storage has been proposed to maximize its overall profit. Besides, providing an appropriate platform that authorizes demand response resources to contribute in the electricity markets can significantly improve both VPP business and power

*Corresponding author’s email: jafari@iauln.ac.ir system flexibility under different operating situations [13]. Tremendous efforts have been devoted to utilize demand response (DR) programs to achieve different goals like minimizing operating costs, harnessing the risk of market participation, decreasing market price spike, mitigating of renewables fluctuating and curtailments [14,15].

Scholars [16] have utilized an optimized approach for decreasing network compression and misbalance among generation and load. In this approach, a big number of loads can be integrated to straight control within a micro grid (MG). Moreover, the load released is improved upon a specified control time space [14]. In Ref. [17], it is stated that the MG consists a gas power plant, wind, and solar can block profit-sharing agreements using close of bilateral agreements, and the problem is solved by planning integer linear. In Ref. [18], scholars stated that a proposed approach along with a VPP in the energy as well as reserve future markets are cached section, which is solved objective function including load and supply balance limitations, constraints of dispersed resource and distribution network security. As stated in [19], commonly planning consists a MG including of alternative renewable resources and a traditional power plant as well as a storage approach. The issue of optimized distribution was formulated in the form of a linear complex integer linear planning model that maximize the weekly gaining of a VPP along with considering long-term bilateral agreements as well as technical constraints. The wind power uncertainty along with solar power generation has been solved using a pump-storage unit for flexible function and also having a usual power plant as a backup production. In the Ref. [20], it is stated that the MG changes electricity in future and equilibrium markets and searches to maximize envisaged profits. Uncertain factors, consisting the power output from distributed generation as well as market price are modeled via design according to Historical information. As stated in [21], an eventual price related unit comment approach is utilized for modeling uncertainties at market prices along with generation resources for suggesting a VPP for the future electricity market. Scholars [22] have proposed a method for solving the integration issues of large-scale divided generation resources according to optimized power control approaches.

The pricing approach of energy resources has been suggested in the case of association in energy and reserve markets [23]. Researchers [24] have expanded a novel approach to analyze reliability tasks and a VPP is suggested for modeling carbon monoxide to renewable resources, and the power plant validity is studied. After that the method of Monte Carlo has been utilized for analyzing the validity of active dispensation approaches with attending various operational modes at one and sometimes more events. The outcomes indicated that utilizing this model reduced the cost by around 50%. In the Ref. [25] modeling and also examining of a VPP has been done for the power system. The aim of this work was to design the access of maximum income for the market. In the Ref. [26], by utilizing a multistage modeling, a set of resources including CHP is designed in real-time market of electricity.

In this approach, real-time decision making around heat and also power is commonly adopted. The purpose of this work is to obtain superlative power. An approach in the case of dividing interests in VPPs that is consisting demand response loads is done in balance market using the game theory (GT) approach [27]. In this method, different uncertainties are existed in market price, consumption and losses as well as renewable generations are attended. In the Ref. [28] an approach has been introduced for indicating the optimized propose a VPP consisting a CHP and sources of renewable energy as well as loads of demand response. Three different procedure are studied. Moreover, their outcomes demonstrate, which the real-time pricing approach is mutable and possess a proper efficiency. In the Ref. [29], an approach for sketching a unit of VPP, consisting renewable resources along with loads to non-elastic properties in the electricity market are shown. The outcomes indicated that with adding flexible resources to loads and also renewable resources, performance of apparatus enhances and the mathematical predicted cost reduces.

In the literature [30], operational approaches about a collection of VPPs have been provided. In suggested model, the management of multi-VPP, which is interdepend, has been tested; and income release among units was analyzed by utilizing theory of game. In many studies like [31] the utilizing industrial flexible load as well as its designing in the case of power system are studied and different approaches of this designing are examined. In addition, in Ref. [32], the combine heat and power (CHP) sketching as well as renewable resources in a dispensation approach is studied. In this way, the planning issue became a multipurpose planning issue and the aim of the planning is to reduce costs and pollutants. In the Ref. [33], by utilizing a two-stage planning approach, an optimized model of out-of-risk offer in the case of a VPP in the energy along with spinning tasks market has been provided. Therefore, a risk amount is taken into consideration to control the proper profit along with the renewable resources uncertainty is selected and the uncertainty made using the load demands and reserves, has been attended in reserve, balance market price, and uncertainties. VPPs planning is considered due to maximize the benefit of various markets. Industrial VPP as well as its management are investigated in the Ref. [34]. The content of this paper is organized as follows. Sections II establish three mathematical models for multi-VPP system, aiming at minimizing operation cost, and hunting for optimal bidding strategy. In Section III, multi-time scale rolling scheduling strategy and the process of solving problem is studied. Case study and analytic results are presented in Section IV. Finally, the conclusion is drawn in Section V.

Novelties, in this paper, can be shortly explained as follows:

- VPPs include Comprehensive energy resources used in the power system. In previous studies, energy resourses such as wind farm (WF), photovotaic(PV), CHP, fuell cell(FC) and energy storage devices(ESD) are not optimized concurrently.
- Prediction of WF power generation through wavelet transform- artificial neural network- genetic algorithm (WT-

ANN-GA). According to the previous studies, prediction of WF power generation using proposed method has the less error of prediction than the other methods, and this means to generate the scenarios closer to reality and causes the optimal programming.

- Maximize the profit of VPPs in two stages.
- First stage, Reduce the generation cost of each VPPs by optimizing the objective function.
- Second stage, Reduce the variance of multi-VPPs (four VPPs) profits to prevent players from leaving the market through genetic algorithm- game theory (GA-GT). In previous studies it is assumed that the power system consists of two players (VPPs) while this assumption is incorrect in practice.

2. MG MODEL

A.Demand Response (DR) Model

The DR model is related to consumable behavior in market-based electricity networks. This means that users reply to the market price and system of incentive. Moreover, users can change their regular patterns of electricity consumption. DR in the electricity market may be classified into two types based on the US Department of Energy, in various modes of users' response as follows [31]:

(i): price-based DR and (ii): incentive-based DR.

The t is time-of-use (TOU) known as a price-based DR and a mechanism which can effectively shows the difference in electricity costs at different times. Due to the characteristics of the load on the power grid, the hours of the day are classified into peak courses, valley courses and flat courses. To achieve goals such as dropping load peak, filling the valley (low load hours) and balancing load, in the valley courses, the price of energy is reduced, and in peak courses prices will increase, so that power consumption is changed on demand side and part of the load is transferred from peak courses to valley courses. In this situation, the new load balance is expressed as:

$$D_t = d_t + d_{t,up} - d_{t,do} \tag{1}$$

$$d_{t,up} . d_{t,do} = 0 \tag{2}$$

$$\sum_t d_{t,up} = \sum_t d_{t,do} \tag{3}$$

d_t stands for the load amount at the time of t, where D_t stand for the load amount after the executing of TOU pricing ; $d_{t,\, up}$ is the enhanced load, and $d_{t,do}$ is the load dropped at the time of t. The load may increase or decrease over time, but in total, remains unchanged. Similarly, the load settings have a certain range and only a part of the load involved in price incentives.

In these relationships, $B_{t,up}$, and $B_{t,do}$ are the maximum value of load variation that determine the over limit of the load transfer; ε_{up} as well as ε_{do} are load factor coefficients that determine the lower limit of the load transfer. Pr_t stands for the power exchange tariff and also Pr_{ref} is the reference tariff. According to (2), only one of the inequalities (6) and (7) can be used at any time.

where interruptible load(IL) stands for an Incentive-based DR model. Under the agreement signed between supply and demand departments, IL implementation institutes, send the request signal to users in peak courses. After responding to these signals, the supply a part of power is suspended. For users who are not very sensitive to the power supply reliability, the power company may cut or stop power supply for peak courses, and pays damages to the consumer due to power outages [30].

$$B_{t,up} . d_t \geq d_{t,up} \geq 0 \tag{4}$$

$$B_{t,do} . d_t \geq d_{t,do} \geq 0 \tag{5}$$

$$d_{t,up} \geq \varepsilon_{up} . d_t . \left(1 - \frac{Pr_t}{Pr_{ref}} \right) \tag{6}$$

$$d_{t,do} \geq \varepsilon_{do} . d_t . \left(\frac{Pr_t}{Pr_{ref}} - 1 \right) \tag{7}$$

In peak courses or in courses where the power system will be faulty, interrupting the load can reduce demand and increase the capacity of power generation. As a result, IL is commonly considered as a particular reserve capacity that may enhance load side flexibility and reduce standby values and optimal power distribution. IL costs consist two parts namely (i): the cost of compensating capacity and (ii): the cost of withdrawn capacity. The first part is based on the capacity that can be utilized using the user to participate in the IL and the second part is related to the actual amount of network dropped [30]. The cost of compensation and IL can be expressed as:

$$C^C_{t,j} = \beta_{t,j} . Q^C_{t,j} \tag{8}$$

$$C^{IL}_{t,j} = \gamma_{t,j} . Q^{IL}_{t,j} \tag{9}$$

In these relations, $C^C_{t,j}$ is the compensating capacity cost, $Q^C_{t,j}$ is the capacity of compensation, $\beta_{t,j}$ is the price of compensation, $C^{IL}_{t,j}$ is the IL cost, $Q^{IL}_{t,j}$ is the IL amount, and $\gamma_{t,j}$ is the cost of the delayed load.

B. VPP Distribution Model

The VPP distribution model is related to optimizing the power of the virtual power plant, which consists various types of DGs, energy storage devices and loads. Total required power of loads is provided by using units inside the system. In addition, DR provides more flexibility in planning. For VPP, it is difficult to maintain real-time power and load balances, especially when failing or supplying units. As a result, IL is defined as a standby source. Like the capacity of the reservation, the IL may enhance flexibility on the side along with lower standby costs as well as distribution of optimal power.

The present research focuses on the economic distribution model and modeling the minimal operating cost of a VPP. The objective function is as Eqs (10)-(13) [35]:

$$\min C^{VPP} = F^{G} + F^{DR} + F^{ES} + C_{gas} \\ .(P^{FC}/\eta_{FC} + P^{FC}/\eta_{B}) + P^{FC}.C_{FC} + P^{FC}R_{FC}.\eta_{WB}.C_{WB} \tag{10}$$

$$F^{G} = \sum_{t\hat{o}T}\sum_{i\hat{o}N}\left(aP_{t,i}^{2} + bP_{t,i} + c\right) \tag{11}$$

$$F^{DR} = \sum_{t\hat{o}T}\left(C_{t}^{C} + C_{t}^{IL}\right) \tag{12}$$

$$F^{ES} = \sum_{t\hat{o}T}\left(\frac{1}{2}.e.\left|P_{t}^{ES}\right|\right) \tag{13}$$

In this relationship, C^{VPP} represents the operating cost VPP; F^{G} shows the cost of producing a controllable unit; F^{DR} is the DR's cost, the term F^{ES} is the energy storage cost; where T is the time periods summation and N is the controlled VPP units numbers; $P_{t,i}$ is the active power provided using the unit of control i is generated; a, b and c are related to the fuel cost coefficients of term i; P_{t}^{ES} is also the power amount of the energy storage terms. In addition, the term P_{t}^{ES} is more than zero, the energy storage elements release and release the so-called energy. The value of P_{t}^{ES} smaller than zero also indicates the energy absorption or charge of energy storage. e is the energy storage utility and indicates the energy efficiency; C^{gas} , C_{FC} and C_{WB} are natural gas price, operational cost of FC and waste heat boiler respectively; P^{FC} and P^{B} are output power FC and gas boiler; η is the efficiency of resources; R_{FC} is ratio of heat to electricity of FC.

The relations (14) - (17) are the balance of power and constraints, respectively. In this relations, is the electrical load.

$$P_{t}^{VPP} = D_{t}^{VPP} - Q_{t}^{IL} \tag{14}$$

$$P_{t}^{VPP} = P_{t}^{WF} + P_{t}^{PV} + P_{t}^{ES} + P_{t}^{FC} - P_{t}^{ED} \tag{15}$$

$$P_{t,max}^{VPP} - \left(D_{t}^{VPP} - Q_{t}^{IL}\right) \geq R_{t}^{VPP} \tag{16}$$

$$R_{t}^{VPP} = r_{1}.D_{t}^{VPP} + r_{2}.P_{t}^{WF} + r_{3}.P_{t}^{PV} \tag{17}$$

In this relationship, P_{t}^{VPP}, P_{t}^{WF}, P_{t}^{PV} and P_{t}^{FC} are the output power of VPP, the predicted power of WF, the predicted value of PV and output power of FC respectively; $P_{t.\max}^{VPP}$ is the maximum output power; R_{t}^{VPP} is also the capacity of the reserve. The r1, r2 and r3 parameters are load factors, PV and WF, respectively, which represent the maximum possible error in the predicted values. The constraints of controllable units of power generation are as Eqs (18)-(20):

$$P_{i,min} \leq P_{t,i} \leq P_{i\ ,max} \tag{18}$$

$$P_{t,i} - P_{t-1,i} \leq \Delta UP_{i} \tag{19}$$

$$P_{t-1,i} - P_{t,i} \leq \Delta DP_{i} \tag{20}$$

where $P_{i,\min}$ and $P_{i,\max}$ are the least and peak outputs of unit i, respectively. Eq (19) represents the maximum capacity limit for increasing units. Eq (19) is an index that represents the maximum power of units that can be reduced. ΔDP_{i} and ΔUP_{i} are respectively the lowest and highest unit power changes.

Eqs (21) - (23) are clauses for energy storage elements, including charging-discharging equilibrium, capacity holds, and charge-discharge constraints.

$$\sum_{t\in T} P_{t}^{ES}.\Delta t = 0 \tag{21}$$

$$E_{min} \leq E_{0} - \sum_{i=1}^{t} P_{t}^{ES}.\Delta t \leq E_{max}, t = 1, \ldots T \tag{22}$$

$$-P_{max}^{charge} \leq P_{t}^{ES} \leq P_{max}^{discharge} \tag{23}$$

In these relationships, t is the load distribution period; $E_{\min}$ and $E_{\max}$ have least and peak storage capacity of energy storage systems, and E_{0} stands for the initial capacity of these storage devices; $P_{\max}^{charge}$ and $P_{\max}^{discharge}$ are also the peak charge-discharge of power of storage systems.

The thermal load balance constraint has also been added as Eq (24) [35]:

$$P^{FC}R_{FC}.\eta_{WB} + P^{B} - P^{TD} = 0 \tag{24}$$

In this regard, $P^{FC}R_{FC}.\eta_{WB}$ is the thermal power of waste heat boiler. P^{TD} is also thermal load. The min/max production capacity of the gas and waste heat boiler are as Eq (25) and Eq (26) respectively [35].

$$P_{\min}^{B} \leq P^{B} \leq P_{\max}^{B} \tag{25}$$

$$P_{\min}^{WB} \leq P^{FC}R_{FC}.\eta_{WB} \leq P_{\max}^{WB} \tag{26}$$

The minimum production power is zero and is achieved by the definition of P^{B} as a positive variable.

C. Distribution model of multiple virtual power plants based on GT

After completing the VPP distribution, each VPP must declare its cost-effective power output for the operation center. Also, all considered VPP offers its pricing strategy with a price range and then decides on the VPP according to the proposed the VPP price.

The GT model used to distribute multiple VPPs is of unlimited repetitive games type [19]. If the VPP manager is patient enough, it will make a reasonable profit on the VPP balance point. However, VPP is competing for the most profit. It is assumed that "argmax g (•)" is a proper subset of a defined domain that can maximize the function g (•).

$$\begin{cases} p_1^* \epsilon \arg max\left[\left(p_1 - c_1\right).S_1\left(p_1, p_2^*, \ldots p_n^*\right)\right] \\ p_2^* \epsilon \arg max\left[\left(p_2 - c_2\right).S_2\left(p_1, p_2^*, \ldots p_n^*\right)\right] \\ \vdots \\ p_n^* \epsilon \arg max\left[\left(p_n - c_n\right).S_n\left(p_1^*, p_2^*, \ldots, p_n\right)\right] \end{cases} \tag{27}$$

$$c_j = F_j^G - / M_j \tag{28}$$

In these relations, ρ_j is the $j-th$ VPP bidding strategy and ρ_j^* represents the optimal bidding strategy for $j-th$ VPP. $(\rho_1, \rho_2, \ldots. \rho_n)$ is a set of bidding strategies for VPPs and is the $n-th$ VPP value based on its pricing strategy. c_j is the maximum cost per kilowatt-hour of energy and F_j^G is the electricity cost sold by the $j-th$ VPP. M_j is the maximum power that the $j-th$ VPP can feed.

To ensure the profit balance between VPPs, the return variance for each kilowatt-hour of energy is defined as the benchmark heading. In this regard, V is the profit margin for every kilowatt hour.

$$\min V = \sum_j \left(\bar{V} - V_j\right)^2 \tag{29}$$

$$\bar{V} = \frac{1}{n}\left(V_1 + V_2 + \ldots + V_n\right) \tag{30}$$

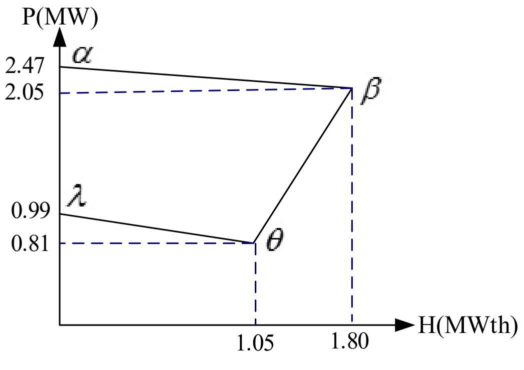


Fig. 1. The electrical-thermal characteristic of CHP units [36]

$$V_n = \frac{\sum_t \left[\left(p_n - c_n\right).S_n\left(p_1, p_2, \ldots, p_n\right)\right]}{\sum_t S_n\left(p_1, p_2, \ldots, p_n\right)} \tag{31}$$

D. Prediction of uncertainties

In order to predict the uncertainty, the WT-ANN-GA prediction method has been used based on the flowchart of Fig. 1.

1.Wavelet transformation

By using mathematical transformations, components and information properties can be extracted. WT is used to extract the components and characteristics of the time domain and the frequency of the information signal.

2.Neural network used to predict wind turbine output power

In the first stage, load forecasting is used from the neural network. ANN is set up to perform a specific task, such as identifying patterns and categorizing information, during a learning process. The simplest ANN is multilayer perceptron networks.

3.Genetic Algorithm

The GA is an optimization method which uses Darwin's principle of natural selection for finding the optimum formula. [36].

E. CHP Modeling

As observed in Fig. 1. The electrical power generations of CHP units are not independent of their thermal power and these two powers cannot be controlled in a separate manner [35]. The electrical-thermal characteristics of CHP units are shown Fig. 1. The operation constraints of CHP units can be extracted from Fig. 1. The area under $\alpha\beta$ curve is formulated through Eq. (32). Eqs. (33 and 34) represent the models for areas above $\beta\theta$ and $\theta\lambda$ curves, respectively. Both electrical and thermal powers are equal zero in the case of non-participating CHP units in energy generation according Eqs. (35 and 36) respectively.

$$P_{G,CHP}(t) - P_{G,CHP}(\alpha) - \frac{P_{G,CHP}(\alpha) - P_{G,CHP}(\beta)}{H_{G,CHP}(\alpha) - H_{G,CHP}(\beta)}(H_{G,CHP}(t) - H_{G,CHP}(\alpha) \leq 0 \tag{32}$$

$$P_{G,CHP}(t) - P_{G,CHP}(\beta) - \frac{P_{G,CHP}(\beta) - P_{G,CHP}(\theta)}{H_{G,CHP}(\beta) - H_{G,CHP}(\theta)}(H_{G,CHP}(t) - H_{G,CHP}(\beta) \geq -(1 - M(CHP,t) \times Y \tag{33}$$

$$P_{G,CHP}(t) - P_{G,CHP}(\theta) - \frac{P_{G,CHP}(\theta) - P_{G,CHP}(\lambda)}{H_{G,CHP}(\theta) - H_{G,CHP}(\lambda)} \\ (H_{G,CHP}(t) - H_{G,CHP}(\theta) \geq -(1 - M(CHP,t) \times Y \tag{34}$$

$$\leq H_{G\ CHP}\ t\ \leq H_{G\ CHP}\ \beta\ \times M\ CHP \tag{35}$$

$$0 \leq P_{G,CHP}(t) \leq P_{G,CHP}(\beta) \times M(CHP,t) \tag{36}$$

where, $\alpha, \beta, \theta, \lambda$ are four marginal points of the electrical-

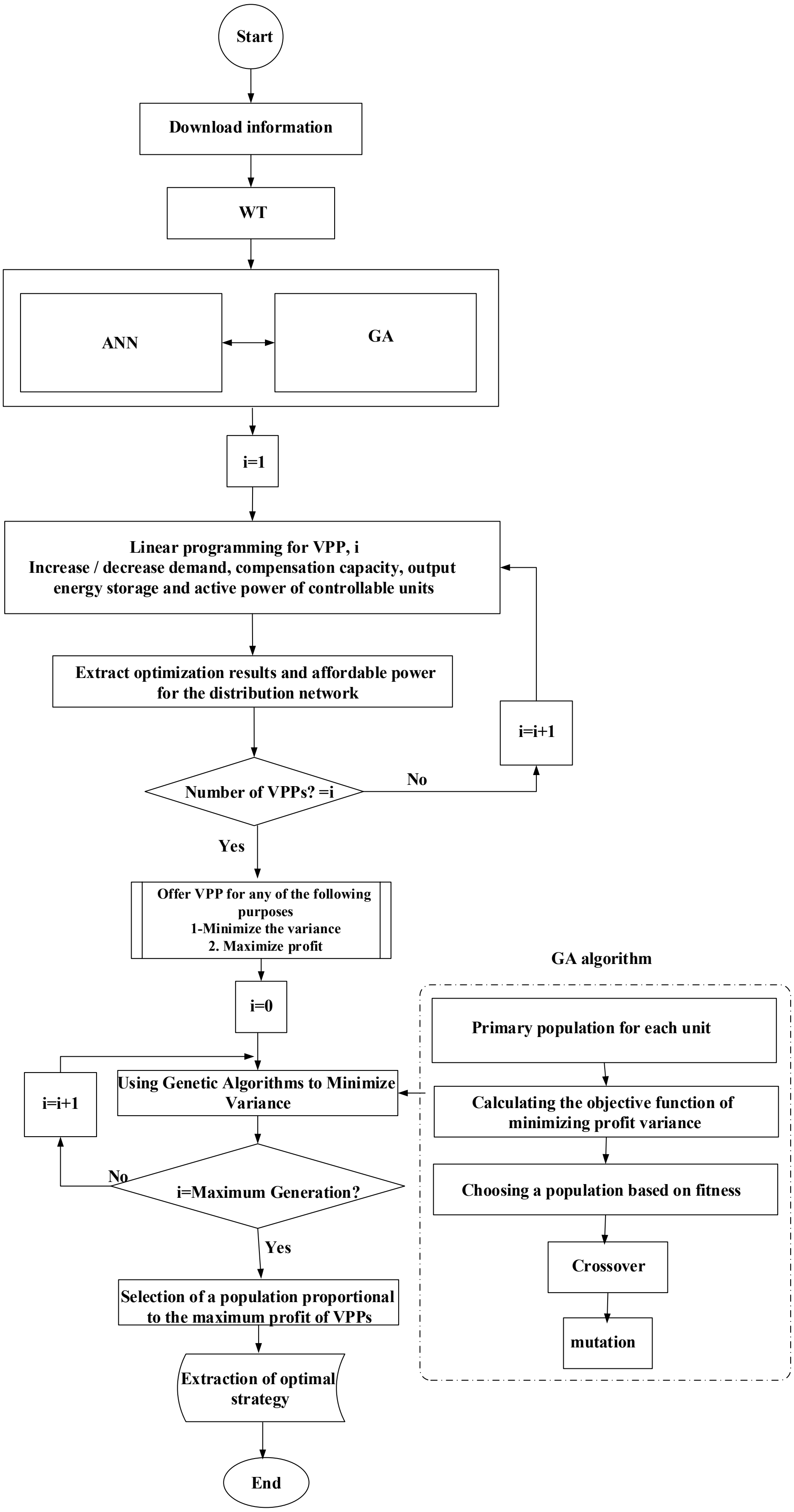


Fig. 2. Flowchart of day-ahead planning

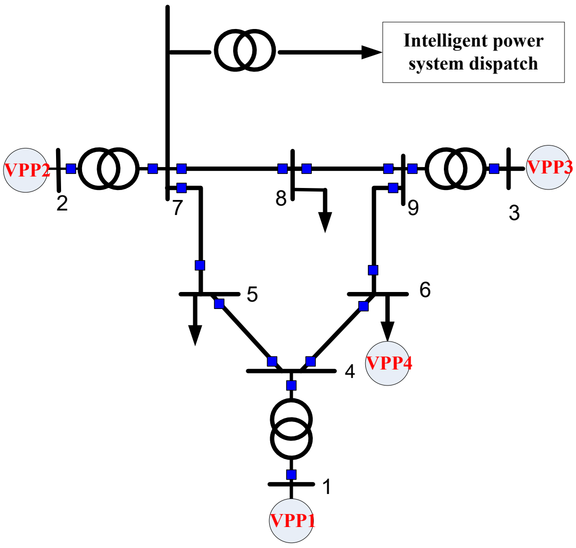


Fig. 3. Multi VPP systems

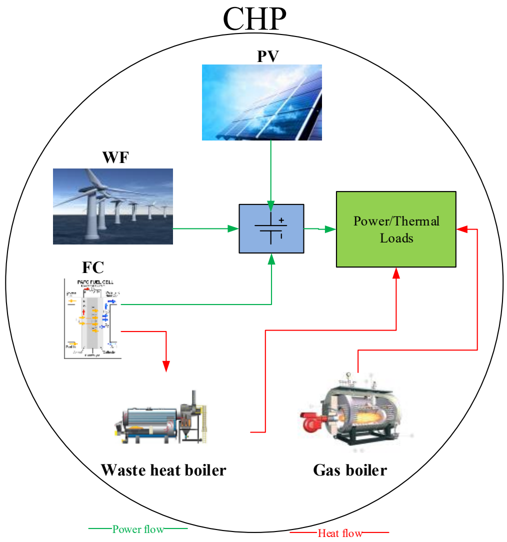


Fig. 4. combined heat and power configuration [37]

Table 1. Parameters of the MG [30]

type	Capacity (MW)	(VPP1/VPP2/VPP3/VPP4)	Upper generation limit(kW)	lower generation limit (kW)	cost (¥/kWh)
MT	30	6 4 6 -	180 120 180 -	--	0.56
BS	1.2	80 50 50 50	15 8 8 8	-15 -8 -8 -8	0.08

thermal characteristic of combined heat and power [37].

3-DAY-AHEAD MARKET ANALYSIS

Computational replays are classified into two sections: 1) the VPP distribution section; and 2) the multi-problems distribution VPP based on GT. This process is shown in Fig. 2.

A. VPP Distribution Division

Before predicting the issue, the MG factors, time interval and tariffs as well as the predicted values for uncertainties such as electrical and thermal load, PV and WF are given as inputs of the problem. Then, for each VPP, once the problem is solved by utilizing the linear programming algorithm. The variables of this problem include increasing / decreasing demand, output energy storage, and compensating capacity as well as active power of controlled units. Also, security along with integrity constrains were used, including Constrains (1), (3), (14), (15), (17) also inequalities (4) - (7), (16), (18) - (20) and (22). Finally, the outcomes of optimization and cost effective power are extracted as output. In this case, Eq (11) is linear based on the curve of price. Once i meets the max number of VPP, the algorithm moves forward to game theoretic multi-VPP dispatch mode.

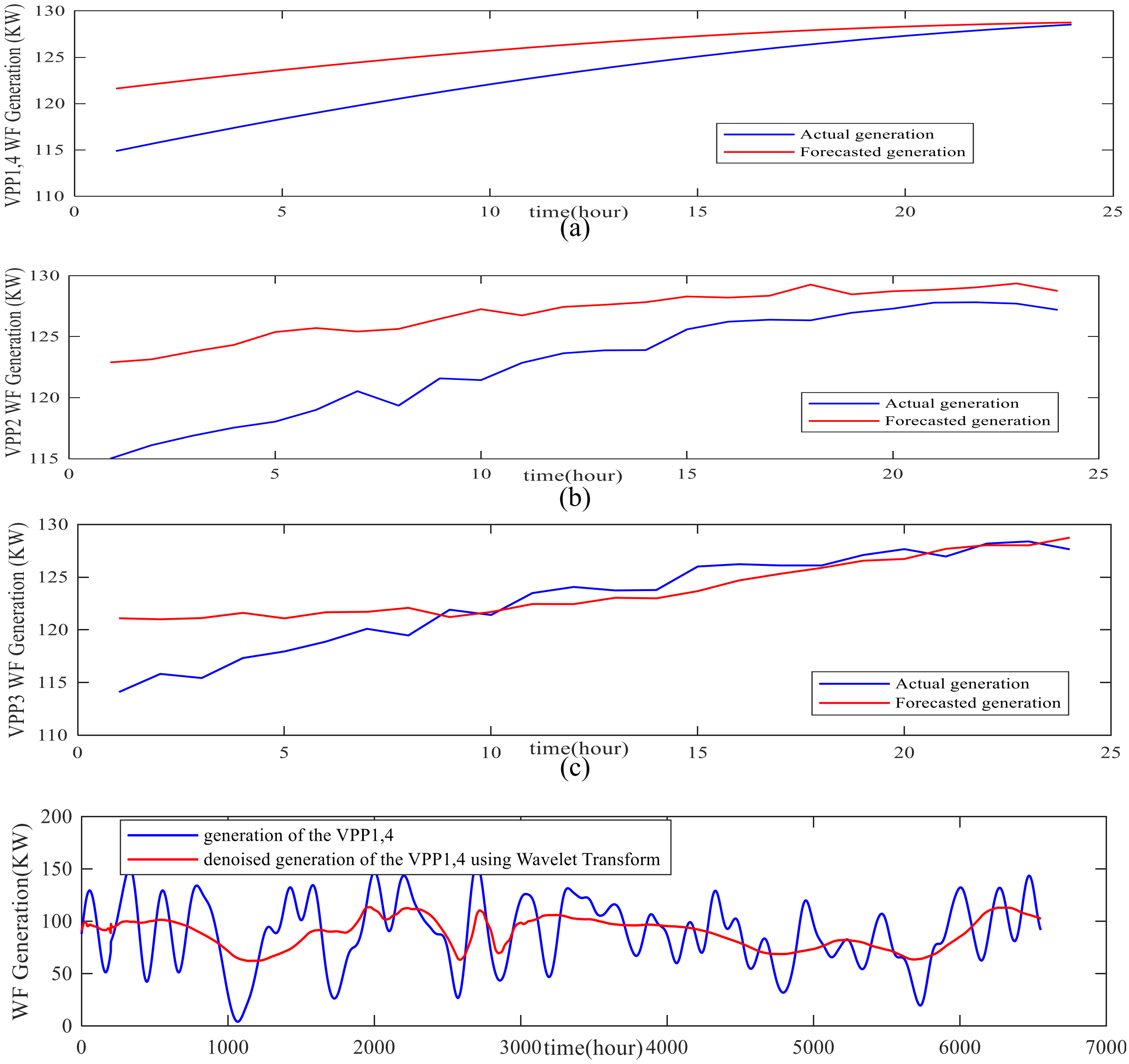
B. Multi-VPP distribution mode based GT

The price biding strategy offers the possibility for high-efficiency VPPs to rank in the top priority and maximize profits. Nevertheless, in a slight method, there are a lot of differences, and the best survival rule may not be utilized. Closed VPP will have the most power shortages. Hence, a sequenced classification method was suggested to avouch the security of system and also VPP profits. The purpose functions are considered to be at least [variance (profit / kWh)] as well as maximum (VPP gain) respectively. In the next step of optimization issue, a genetic algorithm is utilized to apply GT. The first step of this algorithm is to initialize the population.

The initial population of the primary parents is $(\rho_1, \rho_2, ...\rho_n)$. In the selection process, the fairest pricing method is chosen to realize the objective function 1, as well as the choice of roulette wheel method was used to generate a new population. The pricing strategy of a VPPs affects other VPPs, and this method is same to a crossover. Typically, a VPP changes the pricing strategy according to other VPPs. Some variations can be abnormal, and this method is identical to mutation. After generating the maximum number of population, the optimal number is obtained according to objective function 2 (maximizing VPP profits). Although the final population difference is not considerable, VPP profits can fluctuate strongly. Finally, the distribution network purchases

Table 2. time divisions and their tariffs [34]

Type	Peak	Flat	Valley
Time divisions	8-10 , 16-20	6,7,11-15,21	1-5 , 22-24
Price of energy (¥/kWh)	0.8789	0.6171	0.3819



(a)

(b)

(c)

(d)

Fig. 5. Estimated values for WF power generation. a: VPP1 and VPP4, b: VPP2, c: VPP3, d: denoised WF generation using WT

power from low to high price.

4-CASE STUDY

The proposed method of programming on a standard 9-base IEEE system (see Fig. 3) in general algebraic modeling system (GAMS) and MATLAB programs will be implemented by linking these two programs, and the GT in a four-player (four VPPs) Includes WF, PV, FC, CHP and ESD for the first time in this paper.

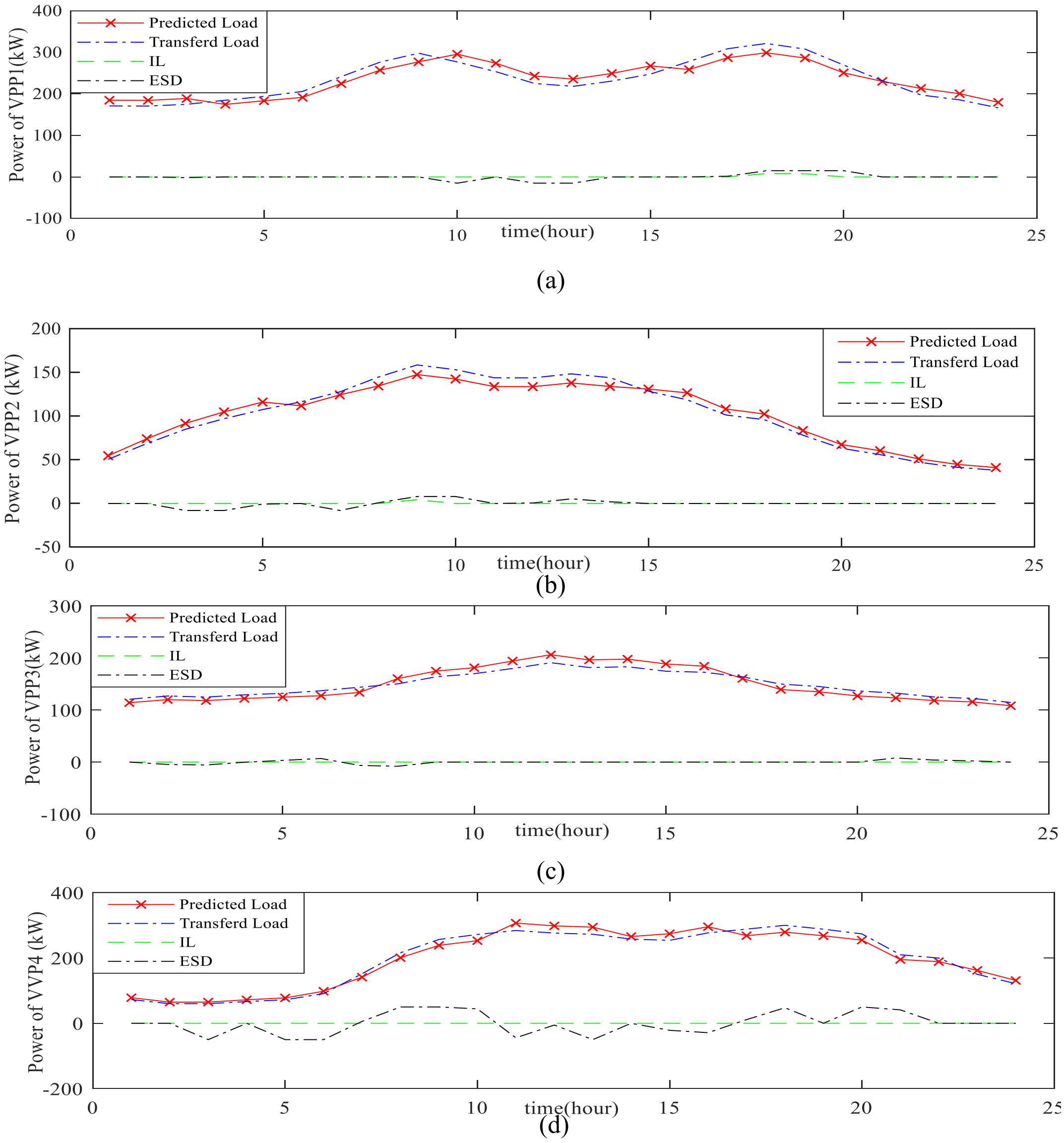
A. Parameters

The VPP Central Controller is a control and monitoring unit that is duo to for the communication, analyzing and control of each system. The MG parameters are tabulated in Table 1. The VPP4 is located at the 6th bus and includes a CHP and ESD. The demonstration of CHP is illustrated in Fig. 4.

The time divisions and their tariffs that is classified to peak, flat, and valley periods, are tabulated in Table 2. Load-bearing coefficients ε_{up} and ε_{do} are 4% and 3%, respectively. The reservation parameters r_1 , r_2 and r_3 were 0.05, 0.2 and 0.15, respectively. The compensating capacity cost as well as outage capacity are also 0.25 and 6 (per KWh), respectively.

Table 3. Computational Parameters [30]

Max generation	50	Number of variables	75
Population size	300	CPU	1.8GHz
Crossover probability	0.6	RAM	4GB
Mutation probability	0.1	software	Matlab2017b
Strategy limits		$(0.8 \sim 1.3)^{*}\,\mathbf{P}$	



(a)

(b)

(c)

(d)

Fig. 6. Distribution Planning and Load Changes in A: VPP1 B: VPP2 C: VPP3 D: VPP4

The price of standby unit and also network standby price were 0.25 (KWh). The calculated amount (24 hours) using WT-ANN-GA proposed method for WF in each of the VPPs are shown in Fig. 5. The uncertainty of electrical load demand, PV power generated and thermal load are extracted in [32] and [35] respectively. The computational parameters of the genetic algorithm are also given in Table 3.

B. Distribution Results VPP1

In the VPP dispatch model, considering interactive coordination between VPP and energy consumers, a demand response model based on TOU pricing mechanism and interruptible loads is employed. During the process of market competition, the bidding strategy of each VPP is determined by its affordable power output and fuel cost. In general, a VPP can guarantee safe and continuous nutrition. But unusual cases may occur during unit repairs or errors. For example, for VPP1, in optimal distribution mode, VPP1 cannot provide the required amount of load. Therefore, DR is used for solving the problem and after definition of the TOU, the condition of the courier is improved and some of the loads are transmitted. Due to the stability of uncontrollable micro-grids, the

Table 4. Affordable Capacity

Time	VPP1	VPP2	VPP3	VPP4
0	95.597	184.54	60.165	247.69
1	89.523	163.63	53.971	216.22
2	72.293	139.66	56.056	260.87
3	82.462	117.46	51.679	303.08
4	53.125	102.13	48.89	274.35
5	40.065	109.21	46.151	180.37
6	27.173	69.597	83.198	103.42
7	21.496	56.932	122.72	31.605
8	26.404	32.174	133.51	0
9	77.076	32.57	140.6	45.269
10	75.632	32.687	146.15	115.32
11	107.17	34.611	141.46	88.236
12	115.47	42.503	162.03	147.68
13	92.25	58.179	165.31	99.689
14	62.515	86.287	162.98	105.15
15	28.709	79.654	157.09	124.8
16	1.5096	103.15	166.6	17.946
17	0	103.09	163.09	0
18	0	118.31	107.2	0
19	4.4262	141.25	80.732	0
20	18.299	158.6	50.555	51.068
21	62.036	172.37	55.817	84.493
22	81.656	185.41	58.577	181.55
23	122.39	200.11	66.318	166.43

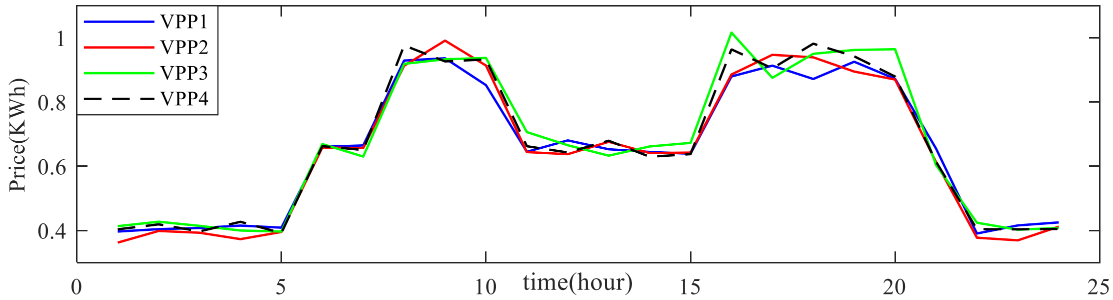


Fig. 7. Multi VPP distribution pricing method based on GT

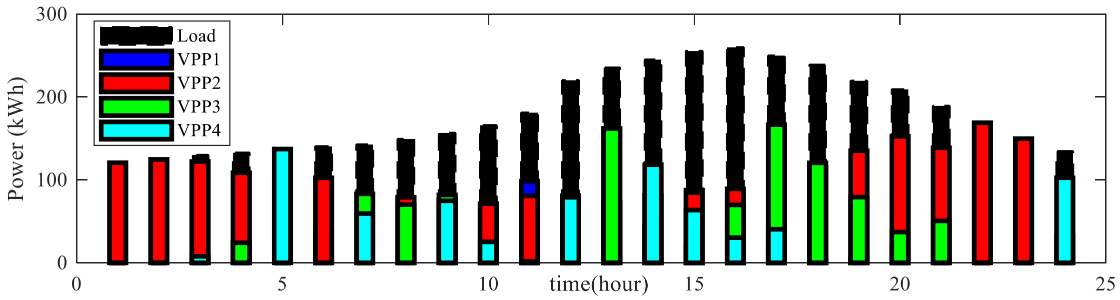


Fig. 8. Output results based on the optimal pricing method

whole power output of controlled VPP units is based on the variations in renewable resources. The ESD absorbs excess power at peak output power at PV and frees it at peak load. It is determined that combining the effects of the TOU and the energy storage device plays an effective role in changing the peak load and also power deficiency compensation in the first peak period (9:00). When we arrive at the another peak (18:00), the energy storage capacity devices are limited, so the IL is used as a protector (between 15:00 and 20:00) to avouch the system's validity. This is also shown in Fig. 6.

C. Distribution results based on GT for several VPPs

The optimal results of VPP dispatch model are applied in the game theoretic model for multi-VPP dispatch. Finally,

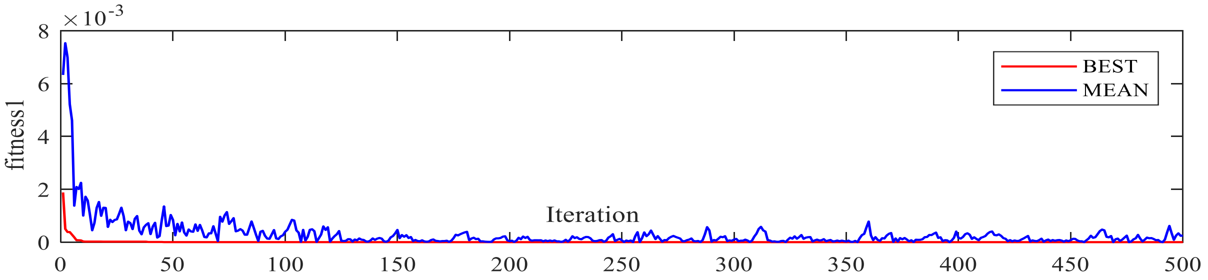


Fig. 9. Convergence of the objective function in the optimization algorithm

Table 5. Economic Analysis and Output of VPP

VPP	Energy Sales	Revenue from sales	Ratio of profit	Affordable capacity	Load Shifting
VPP1	432.49	88.244	0.20404	1357.4	96.942
VPP2	1492.3	308.8	0.20693	2524.1	44.148
VPP3	1333.1	273.97	0.20551	2480.9	58.484
VPP4	1098.7	227.81	0.20735	2845.2	84.402

taking the multi-VPP, which consists of various distributed generations and battery storage devices, as an example, variables including transferred load, compensation capacity, optimal bidding strategy, and profits for each VPP are obtained.

The cost-effective VPP capacity is shown in Table 4. During the second peak period, VPP1 uses IL as a backup, and therefore its cost-effective capacity is zero in these hours. In Table 4, the information in parentheses that indicates the output power of solar energy and also wind energy. Given that the VPP2 has WF, at night, it can provide overnight power. The VPP3 also has PV and may deliver at noon.

In the GT model for distributing multiple VPPs, as shown in Fig. 7, renewable resources are prioritized for sale. Solar energy and wind power provide lower prices than others. Given the wind power production at night (at 22: 00-1: 00), during these hours, VPP2 offered relatively modest prices.

However, although the VPP3 has plenty of solar power (PV), it is not necessary to use this strategy (Fig. 6). At noon (11: 00-15: 00), the amount of charge is high and solar energy can be used well. At the same time, the pricing strategy was additionally according to TOU, which offers relatively proper prices within peak periods and lower prices within the valley periods. The output of VPP is according to the optimized pricing strategy (Fig. 7). At first, a sequence of points is arranged between low and high prices. For each time period, the points near the circle center offer a lower price than the distances, and the related to VPPs have a higher priority for electricity sales. In Fig. 8, shows that much of the renewable energy is consumed by VPP2 and VPP2 gains more profit than other VPPs. Convergence of the objective function is shown in Fig. 9.

Finally, the output analysis and VPP economic efficiency are shown in Table 5. Since the VPP1 has more loads however less units, the load transfer capacity as well as its compensation capacity is higher. Additionally, the DR effect on load reduction in the peak period and filling the valley period in the distribution is well illustrated. Also, the energy sold by VPP is roughly proportional to its profit, which ensures equilibrium in the multi-VPP competition process. Therefore, this distribution method can be used on a regular basis.

CONCLUSION

In this paper, the DR-based Multi-Purpose Distribution Module and GT for a big number of VPPs linked to the Distribution Network are presented. The most important results are:

1. In view of the dual properties of VPP both as source and load, factors at the demand side are taken into consideration in power dispatch. During “the first dispatch,” TOU and IL pricing are studied. Then the GT is applied in “the second dispatch.” Compared with traditional dispatch models, the proposed mode is more flexible.

2. According to operation conditions, two models are presented in this paper, including VPP dispatch model and the game theoretic model for multi-VPP dispatch. Interaction performs well between VPP and operation center, VPP and energy consumers, VPP themselves.

In terms of model building, it is built step by step, which makes it more applicable. Moreover, multi-time scale rolling scheduling strategy is used to solve the problem of renewable generation fluctuations in VPP. This paper provides a new idea for multi-VPP dispatch system.

3. Trough prediction method of WT-ANN-GA, it was tried perdition more accurately and decreased the short-term prediction error of WF power generation. By this method, the scenarios closer to reality are generated with a greater probability, and WF optimal programming is done more accurately, and this will cause to increase the expected profit. Moreover, multi-time scale rolling scheduling strategy is suggested to solve the problem of renewable generation fluctuations in VPP.

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