A Game-Theoretic Pricing Model for Energy Internet in Day-Ahead Trading Market Considering Distributed Generations Uncertainty

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Abstract—**This paper designs a distributed trading mechanism for Energy Internet in which the uncertainty of distributed generations (DGs) is considered. In order to match up Energy Internet, the new energy frame, a novel energy accessing mode called We-Energy (WE) is proposed for the convenience of energy regulation, energy trading and information interaction. First, multiple interconnected WEs are considered in a region where, at a given time, some WEs have superfluous energy for sale to make profits called Surplus-WEs, but some WEs need to buy additional energy to meet local demands called Short-WEs. Under the trading mechanism, the market clearing price (MCP) is determined by supplies as well as demands. Then, a Bayesian game model considering distributed generations (DGs) uncertainty is established to analyze the strategies among WEs, which are assumed as the bidding supplies and demands. A unique Bayesian-Nash equilibrium among Surplus-WEs and Short-WEs are proved respectively according to hessian matrix, and solved by using the Karush-Kuhn-Tucker (KKT) conditions. Numerical results show that the designed MPC can reflect the relationship of supply and demand better, and maximize the utility of all the WEs.**

Keywords—Bayesian game; Distributed generations uncertainty; Energy Trading; Energy Internet; We-Energy

I. INTRODUCTION

Energy Internet is an integration of energy technology and internet information technology, referring to various subjects and fields. Realizing the vision of Energy Internet is contingent upon not only an architecture and framework, but also the key facilities and advanced technologies. Around Energy Internet, related researches have been widely studied in [1-5], which could be mainly divided into four parts: framework structure, information and control technology, economy of energy market and policy mechanism.

Energy market, an important part of Energy Internet, plays a role in regulating the balance between energy supply and demand. Day-Ahead trading, as an important part of energy market, with the premise that players have ability to predict their demands or supply accurately, organizes energy market one day in advance to form a trading plan, which includes MPC, the quantity of demand and supply [6].

Previous studies on energy market mainly focus on designing the energy response mechanisms that energy market regulates energy supply and demand by MPC. In the studies, MPC is determined by the strategies of one side, the sellers or buyers, and the strategies of another side will change in response. A structure of market-retailer-consumers is established as two-stage two-level model, where consumers adjust their demands according to retail's bidding price [7]. But as the leader in Stackelberg model, if the demands of consumers are necessary in daily life or company operation, the retailer's monopoly position has not changed. An inverse load demand curve is designed to calculate the retail electricity price, where the more demands are, the lower MPC is in the pricing mechanism [8, 9]. However, the pricing mechanism is likely to lose the peak shaving and valley filling, and result in electricity shortage under the heavy loads. In the [10], the allocating supplies for buyers are determined by the bidding price of buyers, where the higher bidding price of buyer is, the more allocating supply is. The trading mechanism is essentially a supply response that the sellers decide the supply in response to the MPC. Although the buyers have the initiative [7-9], the power of sellers on regulating energy market is weakening to a large extent.

However, with DGs participating widely, some terminal users have the ability to generate energy, and even to sell energy. Considering the condition, the terminal users in the future will no longer receive energy from the unified energy suppliers passively, and the buyers and sellers have the same status. Therefore, the top-down mode of traditional market trading will be no longer applicable to the future energy trading in which the terminal users will be not only the consumers of energy but also the energy producers [11]. The trading mechanism of double auction, which can be used in Energy Internet, is adopted in [12, 13], in which a step function of energy quantity-price is used to adjust bidding prices of buyers and sellers, and the trading will be successful when and only when the bidding price of buyers is equal or greater than the bidding price of sellers. The double auction release the initiative to both of buyers and sellers greatly, but the scheme of bidding price adjustment is not sound yet for the players in trading failure.

Moreover, the participation of DGs in the energy production can bring a considerable environmental benefit, whereas the uncertainty of DGs makes it difficult for energy management and control [14, 15], but also energy trading.

Reference [16] proposes a model to maximize the total profits of wind and conventional power producers. Reference [17] proposes a combined energy and regulation reserve market model to encourage wind producers to regulate their short-term outputs. It's worth noting that the players containing DGs are always the sellers instead of buyers. In Energy Internet, for a small region, when the demands are more than the output of DGs, the region containing DGs acts as a buyer.

In order to simplify energy regulation, trading and information interaction and ensure a fair competition between energy customers and energy producers, a novel energy accessing mode for the Energy Internet, named “We-Energy” (WE), is proposed which is characterized by producer-consumer integration, coupling and complementarity, openness, and regionalization. WE is an aggregation of energy production devices, energy storage devices and user loads, proposed in this paper which differs from traditional energy supply mode dominated by traditional energy supply companies. Thus, a complete trading mechanism for WE is studied to set a reasonable price in the paper.

The rest of the paper is organized as follows. A novel energy accessing mode for Energy Internet, WE is defined and the trading model of WEs is proposed to find the reasonable trading value between the Surplus-We-Energy (Surplus-WE) and Short-We-Energy (Short-WE) in section II. Section III considers a trading mechanism with multiple interconnected WEs. Under the mechanism, the market clearing price (MCP) is determined by supplies as well as demands. A Bayesian game model considering DGs uncertainty is established to analyze the strategies among WEs in section IV. In section V, several simulation cases are given to show the effectiveness of the proposed price adjustment and bidding strategy. We conclude this paper in section VI.

II. ENERGY TRADING MODEL OF WE-ENERGY

Recent years, with the influence of the traditional energy suppliers weakening gradually, terminal users no longer receive energy from the unified energy suppliers passively, but have some right, such as energy production and sale. The openness, sharing, peer-to-peer and plug-and-play of the Energy Internet, will provide ultimate users with an energy interaction platform. However, energy quality will be affected by the fluctuations which are generated by energy storage devices and energy production devices. And the total fluctuation will increase or offset when several fluctuations superpose together. For Energy Internet, if energy terminal users can accept energy fluctuations by themselves, it is unnecessary to regulate all of the energy quality in outputs and inputs, but the energy quality in points of common coupling (PCCs). In some small regions, if they can market their own products, and meanwhile have possibility to supply energy for Energy Internet, energy quality Energy Internet really concerned is the output part. Similarly, what Energy Internet needs to guarantee is the energy quality of PCCs or inputs of some small regions. Inspired by the transmission of information, We-Media, from the Internet, including blog, WeChat, post bar and Bulletin Board System (BBS), which characterized by diversity, openness and popularization, a novel energy accessing mode for Energy Internet, We-Energy, is proposed to simplify energy regulation, trading and information interaction in this paper. There are some similar properties that We-Media and We-Energy are not only receivers but suppliers and mainly come from grassroots level. However, the loss and block are inevitable in energy, while information can be copied infinitely.

As an accessing mode of energy production devices, energy storage devices and user loads, WE is not only energy consumer but also energy producer, which trade energy with others by the advanced communication, electronic conversion and automatic control technology in Energy Internet. For the scale, a personal energy entity, villa, enterprise and community, which are provided with energy production devices or energy storage devices (e.g. DGs, electricity/heat storage devices, CCHP (Combined Cooling Heating and Power)), can be accessed by WE. Here, a note about this accessing mode is that the devices contained in a WE are as a unity to participate in energy trading. According to the definition, what makes WE different from traditional energy accessing mode is that WE is no long a passive consumer, but also a potential energy supplier in the energy interaction, which trades energy with others in the principle of ‘peer-to-peer’ instead of ‘peer-to-plane’. The main features of the WE are given as follows:

1) Producer-Consumer Integration: the traditional energy supply mode is broken by WEs which can not only market their own products but trade with Energy Internet. Common energy terminal can participate in energy trades and transmissions, and the energy transmission is changed as bi-directional transmission. Therefore, the ability of energy production, transmission, storage and consumption can be integrated by WEs in the energy internet;

2) Energy Coupling and Complementarity: compared with the traditional energy accessing mode that different energies are supplied independently, WEs have the capacity to transform various type of energy into the desired energy. According to energy pricing, peak shaving can be realized by transforming energy under meeting demand response. The strong coupling and complementarity of the energy production and the energy demand contribute to achieving the energy balance among WEs, reducing the cost of energy transmission, and improving the utility efficiency of renewable energy;

3) Openness of energy trading: compared with the traditional energy monopolist, most of WEs are converted from terminal users, with make the energy trading more peer-to-peer, more renewable and less utilitarian, promoting the development of the non-fossil energy;

4) Regionalization of Energy Consumption: the regional self-sufficient energy supply can be realized by increasing the amount of WEs, due to the broader renewable energy resources and other clean energy resources. Then the advantage of long-distance transmission of the traditional fossil energy is weakened greatly. As the energy production and the energy consumption of WEs are more convenient and flexible for the common users than that of the professional and large-scale traditional major energy suppliers, the development of the WE can gradually change the structure of the traditional energy consumption and reduce the dependence on the fossil energy.

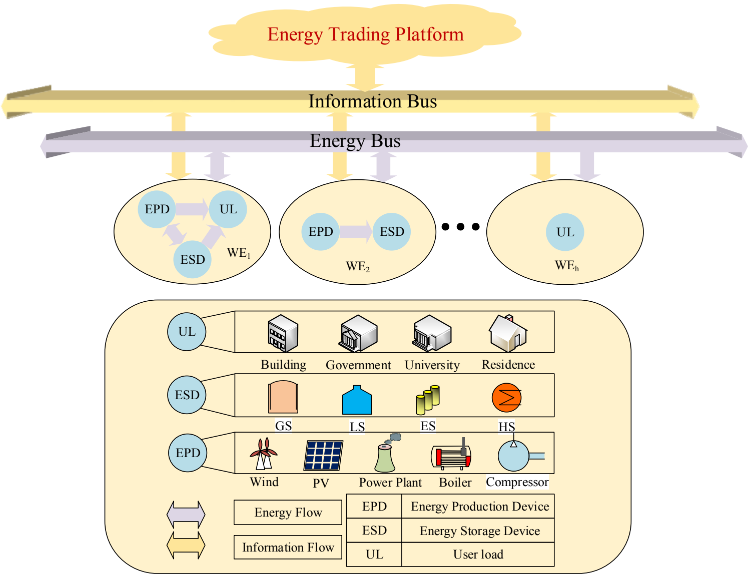

Fig. 1. Energy trading model of WEs in Energy Internet.

In Energy Internet, if a number of WEs need to participate in trading, those WEs can represent random combinations of energy production devices, energy storage devices and user loads, which can be expressed as $\mathrm{WE}=\{\mathrm{WE}_1,\mathrm{WE}_2,\cdots,\mathrm{WE}_\mathrm{H}\}$. As shown in Fig. 1, we consider that ULs are supplied by EPDs which include wind farms, photovoltaic stations, traditional power plants, boilers, and compressors. Meanwhile, surplus energy produced by EPDs can also be stored by Energy Storage Devices (ESDs) which include gas storages (GSs), liquid storages (LSs), electronic storages (ESs), heat storages (HSs) and so forth.

For single type energy, due to the uni-direction of energy transmission in the traditional energy grid, the participant is only one of the three: supplier, demander and balancer at one point. While the heterogeneity and diversity of energy lead to the different market supply-demand situations in Energy Internet. Therefore, there are the possibility of a two-way flow of energy.

In the energy of the Internet, due to the heterogeneity of the energy and diversity, the participants own structure heterogeneity will lead to energy supply and demand condition differ in thousands ways, the diversity of energy will lead to a variety of market price is different, so at the same time, different kinds of energy exists the possibility of energy flow in the opposite direction, participants may act as buyers and sellers at the same time two roles. At the same time, because the energy highly coupled, exist in energy interface between various energy conversions.

In order to describe WE more visually, Surplus-WE, Short-WE and Balance-WE are defined as supplier, demander and balancer in Energy Internet respectively.

III. TRADING MECHANISM

A. Problem Description

A two-level energy market structure is designed in this paper shown as Fig.2. In the energy trading system, it is considered that there are N Surplus-WEs and M Short-WEs, and $\Omega_{Surplus-WEs}=\{1,2,\cdots,N\}$ denotes index set of Surplus-WEs and $\Omega_{Short-WEs}=\{1,2,\cdots,M\}$ denotes index set of Short-WEs. In a given time period, each Surplus-WEs $i\in\Omega_{Surplus-WEs}$ is able to generate a total energy $\Delta P_{i,t}$ and each Short-WEs $j\in\Omega_{Short-WEs}$ requires a total demand $\Delta D_{j,t}$.

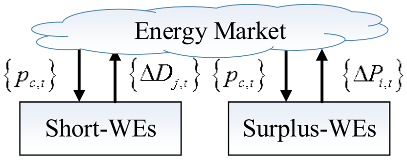

Fig. 2. Structure of energy market.

In this energy market, Surplus-WEs and Short-WEs report supply profile $\{\Delta P_{i,t}\}$ and demand profile $\{\Delta D_{j,t}\}$ to the Energy Market Administration (EMA), and then a clearing price $\{p_{c,t}\}$ is formulated in EMA according to (1):

$$p_{c,t}=-\theta\sum_{i=1,j=1}^{n,m}\left(\Delta P_{i,t}-\Delta D_{j,t}\right)+\delta \tag{1}$$

where θ, δ are the energy supply coefficients.

Compared with the inverse load demand curve [8], the MPC curve in this paper can better reflect the relationship of supply and demand, and achieve the purpose of peak shaving and valley filling.

Imbalance of supply and demand among WEs is inevitable in this trading mechanism. Therefore, the Energy Internet needs to play a role in keeping balance between energy supply and demand. When the energy supply provided by Surplus-WEs is more than the demand required by Short-WEs, the difference between supply and demand will be absorbed by Energy Internet with a lower price thanks to a greater energy supply $\Delta P_{i,t}$. Similarly, Energy Internet will provide energy by a higher price when the energy supply is less than the demand. And in the future, there will be few of WEs which mainly generate energy in the Energy Internet, like solar power station and thermal power plant, but most of WEs will be the intelligent buildings, which are the demanders under heavy loads but suppliers under light loads, such as office buildings and schools.

Considering the uncertainty of DGs, a linear probability distribution of DGs output $\xi_{DG,t}$ is assumed as follows:

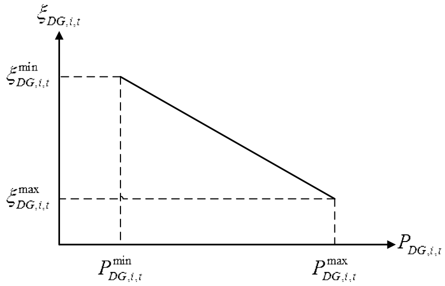

Fig. 3. Probability Distribution of DGs.

$$\xi_{DG,t} = k_{DG,t}\left(P_{DG,t} - P_{DG,t}^{\min}\right) + \xi_{DG,t}^{\min} \tag{2.1}$$

$$k_{DG,i,t} = \frac{\xi_{DG,i,t}^{\max} - \xi_{DG,i,t}^{\min}}{P_{DG,i,t}^{\max} - P_{DG,i,t}^{\min}} \tag{2.2}$$

where $P_{DG,t}^{\max}$ and $P_{DG,t}^{\min}$ are respectively the maximum and minimum DGs output of a WE during the period t, $\xi_{DG,t}^{\max}$ and $\xi_{DG,t}^{\min}$ are respectively probability of maximum and minimum DGs output, the $P_{DG,t}$ is the forecast output of DGs in a WE.

B. Utility Function of Surplus-WE

In this paper, the utility function of Surplus-WE $U_{sur,i,t}$ is an expected profit of Surplus-WE considering the uncertainty of DGs. The marginal cost of DGs is ignored and the marginal cost of energy generators is assumed as a quadratic function of generated energy. Therefore, the utility function of Surplus-WE can be expressed as:

$$U_{sur,i,t} = p_c \Delta P_{i,t} - c_{G,i.t} \tag{3.1}$$

where $c_{G,i.t}$ is the marginal cost function of DGs. $\Delta P_{i,t}$ and $c_{G,i.t}$ are shown as:

$$\Delta P_{i,t} = P_{i,t}^{\min} + \xi_{DG,i,t}\left(P_{DG,i,t} - P_{DG,i,t}^{\min}\right) - L_{i,t} \tag{3.2}$$

$$c_{G,i,t} = \alpha_{G,i} P_{G,i,t}^2 + \beta_{G,i} P_{G,i,t} + \gamma_{G,i} \tag{3.3}$$

where $\alpha_{G,i}$, $\beta_{G,i}$, $\gamma_{G,i}$ are coefficients of small generator cost, L is the local load.
subject to

$$P_{DG,i,t}^{\min} \le P_{DG,i,t} \le P_{DG,i,t}^{\max},\ P_{G,i,t} \le P_{G,i}^{\max} \tag{3.4}$$

C. Utility Function of Short-WE

For the Short-WE j, the utility function $U_{short,j,t}$ is assumed as expenditure for load, which can be expressed as:

$$U_{short,j,t} = -p_c \Delta D_{j,t} - c_{G,j,t} \tag{4.1}$$

$$\Delta D_{j,t} = L_{j,t} - P_{j,t}^{\min} - \xi_{DG,j,t}\left(P_{DG,j,t} - P_{DG,j,t}^{\min}\right) \tag{4.3}$$

IV. BAYESIAN-NASH EQUILIBRIUM ANALYSIS

A. Bayesian Game

Bayesian game is a static non-cooperative game whose the strategies of players in are stochastic. In this paper, $\left\{\Delta P_{i.t}\right\}$ and $\left\{\Delta D_{j.t}\right\}$ are the strategy spaces of Surplus-WEs and Short-WEs respectively, which can be divided as $\left\{P_{G,i,t}, P_{DG,i,t}\right\}$ and $\left\{P_{G,j,t}, P_{DG,j,t}\right\}$ in detail. Surplus-WE and Short-WE are the type space of players which can be regarded as seller and buyer in this Bayesian game. $\left\{\xi_{DG,t}\right\}$ is belief of a WE described as the uncertainty of $\left\{P_{DG,t}\right\}$ in a WE about the types of the other WEs. One has to specify that each belief is the probability of the other WEs having particular types, given the type of the player with that belief. Therefore, the utility function is 2-place function of strategy profiles and types. If a WE has utility function $U_{sur,i,t}\left(\Delta P_{i.t}, \xi_{DG,t}\right)$, the utility the WE receives is $U_{sur,i,t}\left(\Delta P_{i.t}^{*}, \xi_{DG,t}\right)$. And the best response function $B_{i,t}\left(P_{G,i,t}, P_{DG,i,t}\right)$ of Surplus-WE i is the best strategy for Surplus-WE i given the other Surplus-WEs' strategies $\left(P_{G,-i,t}, P_{DG,-i,t}\right)$ and the market clearing price $p_{c,t}$, which is shown as:

$$\begin{aligned} B_{i,t}\left(P_{G,i,t}, P_{DG,i,t}\right) &= \arg\max_{\Delta P_{i.t}} U_{sur,i,t}\left(\Delta P_{i.t}, p_{c,t}\right) \\ &= \arg\max_{\Delta P_{i.t}} U_{sur,i,t}\left(\Delta P_{i.t}, \Delta P_{-i.t}, \Delta D_{j,t}\right) \end{aligned} \tag{5.1}$$

and it is similar with Short-WEs:

$$\begin{aligned} B_{j,t}\left(P_{G,j,t}, P_{DG,j,t}\right) &= \arg\max_{\Delta D_{j.t}} U_{short,j,t}\left(\Delta D_{j.t}, p_{c,t}\right) \\ &= \arg\max_{\Delta D_{j.t}} U_{short,j,t}\left(\Delta D_{j.t}, \Delta D_{-j.t}, \Delta P_{i.t}\right) \end{aligned} \tag{5.2}$$

B. Existence of Bayesian-Nash Equilibrium

Definition 1: Let f be a function of many variables with continuous partial derivatives and cross partial derivatives on the convex open set S and denote the Hessian of f at the point x by $H(x)$. Then [18]

- f is concave if and only if $H(x)$ is negative semidefinite for all $x \in S$
- if $H(x)$ is negative definite for all $x \in S$ then f is strictly concave
- f is convex if and only if $H(x)$ is positive semidefinite for all $x \in S$
- if $H(x)$ is positive definite for all $x \in S$ then f is strictly convex.

Definition 2: A function f of many variables defined on the convex set S is concave if and only if the set of points on or below its graph is convex:

$$\{(x,y): x \in S \text{ and } y \le f(x)\} \tag{6.1}$$

A function f of many variables defined on the convex set S is convex if and only if the set of points on or above its graph is convex:

$$\{(x,y): x \in S \text{ and } y \ge f(x)\} \tag{6.2}$$

Proposition 1: The Bayes model among the Surplus-WEs has a unique Bayesian-Nash equilibrium, and Bayes model among the Short-WEs has a unique Bayesian-Nash equilibrium.

Proof: Hessian matrixes of (3.1) and (4.1) are given as (7.1) and (7.2) at the end of the next page. $H_{sur,i,t}(x)$ is negative semidefinite for all $(P_{D,i,t}, P_{DG,i,t}) \in \Omega_i$. According to the Definition 1 and Definition 2, $U_{sur,i,t}$ is concave and the Bayes model among the Surplus-WEs has a unique Nash equilibrium. And $H_{short,j,t}(x)$ is negative semidefinite for all $(P_{D,j,t}, P_{DG,j,t}) \in \Omega_j$. According to the Definition 1 and Definition 2, $U_{short,j,t}$ is strictly concave and the Bayes model among the Short-WEs has a unique Nash equilibrium.

The KKT conditions [19] are used to find the Nash equilibrium of utility function in this paper. The KKT conditions of Surplus-WEs and Short-WEs can be deduced as (8.1) and (8.2).

$$\begin{cases} 2\alpha_{G,i}P_{G.i.t} + \beta_{G,i} + \theta\Delta P_{i,t} - p_{c,t} + \mu_{i,1} = 0 \\ 2\left(\theta\Delta P_{i,t} - p_{c,t}\right)\left(\xi_{DG,i,t} - \dfrac{\xi_{DG,i,t}^{\min}}{2}\right) + \mu_{i,2} - \mu_{i,3} = 0 \\ \mu_{i,1}(P_{G,i,t} - P_{G,i}^{\max}) = 0 \\ \mu_{i,2}\left(P_{DG,i,t} - P_{DG,i,t}^{\max}\right) = 0 \\ \mu_{i,3}\left(P_{DG,i,t}^{\min} - P_{DG,i,t}\right) = 0 \end{cases}$$

$$\mu_{i,r} \ge 0\left(r = 1, 2, 3\right) \tag{8.1}$$

$$\begin{cases} -p_{c,t} + 2\alpha_{G,j}P_{G.j.t} + \beta_{G,j} + \mu_{j,1} = 0 \\ -2p_{c,t}\left(\xi_{DG,j,t} - \dfrac{\xi_{DG,j,t}^{\min}}{2}\right) + \mu_{j,2} - \mu_{j,3} = 0 \\ \mu_{j,1}(P_{G,j,t} - P_{G,j}^{\max}) = 0 \\ \mu_{j,2}\left(P_{DG,j,t} - P_{DG,j,t}^{\max}\right) = 0 \\ \mu_{j,3}\left(P_{DG,j,t}^{\min} - P_{DG,j,t}\right) = 0 \end{cases}$$

$$\mu_{j,r} \ge 0\left(r = 1, 2, 3\right) \tag{8.2}$$

V. NUMERICAL RESULTS

In this section, the detailed numerical results are provided for illustrating the Bayesian-Nash equilibrium behavior with 7 WEs interconnected system covering 3 communities, 2 factories, a university and a small photovoltaic power station (PVPS). WE_1, WE_2 and WE_3 are assumed as communities installing PV panels whose capacities are $700\,KW$, $800\,KW$ and $900\,KW$ respectively. WE_4 is assumed as a university with $30\,KW$ wind turbines and $1050\,KW$ PV panels. WE_5 and WE_6 which are 2 factories install PV panels with $500\,KW$ and $700\,KW$ respectively. WE_7 is a PVPS with $3000\,KW$ PV panels. Small generations of $200\,KW$ are installed on WE_1 to WE_6. And $\theta = 5\times10^{-5}$, $\delta = 0.7$ are assumed in this paper. The detailed parameters of the system is shown as Table 1:

$$H_{sur,i,t}(x) = \begin{bmatrix} -2\theta - 2\alpha_{G,i} & -4\theta\left(\xi_{DG,i,t} - \dfrac{\xi_{DG,i,t}^{\min}}{2}\right) \\ -4\theta\left(\xi_{DG,i,t} - \dfrac{\xi_{DG,i,t}^{\min}}{2}\right) & 2k_{DG,i,t}\left(p_{c,t} - \theta\Delta P_{i,t}\right) - 8\theta\left(\xi_{DG,i,t} - \dfrac{\xi_{DG,i,t}^{\min}}{2}\right)^2 \end{bmatrix} \tag{7.1}$$

$$H_{short,j,t}(x) = \begin{bmatrix} -2\theta - 2\alpha_{G,j} & -4\theta\left(\xi_{DG,j,t} - \dfrac{\xi_{DG,j,t}^{\min}}{2}\right) \\ -4\theta\left(\xi_{DG,j,t} - \dfrac{\xi_{DG,j,t}^{\min}}{2}\right) & -2k_{DG,j,t}\left(p_{c,t} + \theta\Delta D_{j,t}\right) + 8\theta\left(\xi_{DG,j,t} - \dfrac{\xi_{DG,j,t}^{\min}}{2}\right)^2 \end{bmatrix} \tag{7.2}$$

TABLE I. THE PARAMETER OF 7 WES

Parameter	WE₁	WE₂	WE₃	WE₄	WE₅	WE₆	WE₇
$\sum_{t=0}^{23} L_{i,t}$	12314	9204	9278	10220	7456	8153	1229
$P_G^{\max}$	200	200	200	200	200	200	0
$\sum_{t=0}^{23} P_{DG}^{\max}$	4992	6680	6492	9930	4166	5723	20335
$\sum_{t=0}^{23} P_{DG}^{\min}$	2610	3150	3036	4821	2120	2544	8525
$\alpha_G\left(10^{-3}\right)$	8	6	7	7	9	6	0
β_G	0.4	0.6	0.5	0.4	0.3	0.5	0
γ_G	0	0	0	0	0	0	0

Fig. 4 illustrates the Bayesian-Nash equilibrium of small generators' output from WE_1 to WE_6. Due to no generator in WE_7, there is no output of WE_7 in Fig. 4. In this system, the total capacity of wind turbine is less than the PV capacity and small generators. Therefore, the small generators mainly shoulder the responsibility of adjusting MPC at night, and decrease gradually in day due to the increasing PV power. The peaks of generators are resulted by a mass of demand consumed by communities and university, which are shown as $P_{G,peak} = \{38.6, 34.8, 37.0, 44.2, 39.9, 43.2\}\, KW \bullet h$. Fig. 5 is the output of DGs, which includes the output of PVPS. Combining Fig. 4 and Fig. 5, the whole strategy of Bayesian-Nash equilibrium is exhibited for us.

Considering that MPC is an inverse proportion to supply and there is a probability of DGs' output in this paper, cthe bidding outputs of DGs are always less than the predicted maxium. The character of PV output creates a peak of DGs' output and a valley of generators' output during 13 to 14 o'clock.

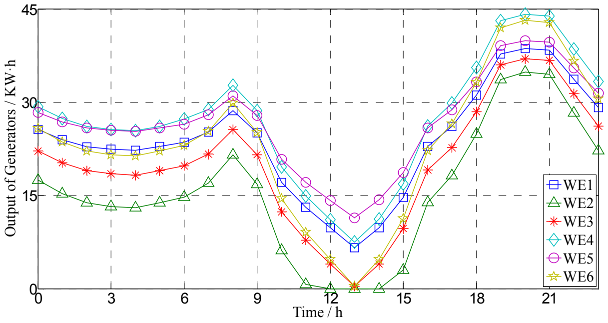

Fig. 4. The generators' output of WEs in a day.

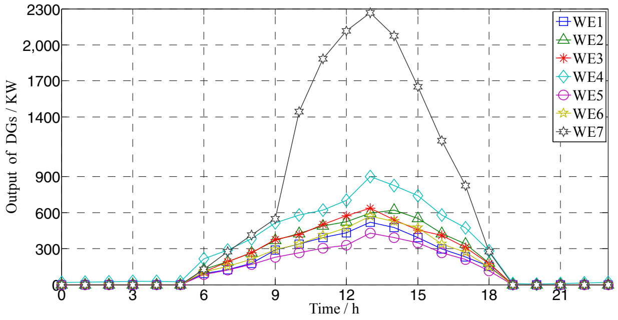

Fig. 5. The DGs' output of WEs in a day.

Accoding to the strategies of $\{P_G\}$ and $\{P_{DG}\}$, MPC can be calculated from (1), which is shown as Fig. 6. When the demands are more than supplies, the MPC dereases. On the contray, when the demands are less than suppies, the MPC increases. The maximum of MPC is $0.86\, Yuan / KW \bullet h$ during 20 to 21 o'clock. The minimum of MPC is $0.54\, Yuan / KW \bullet h$ during 13 to 14 o'clock.

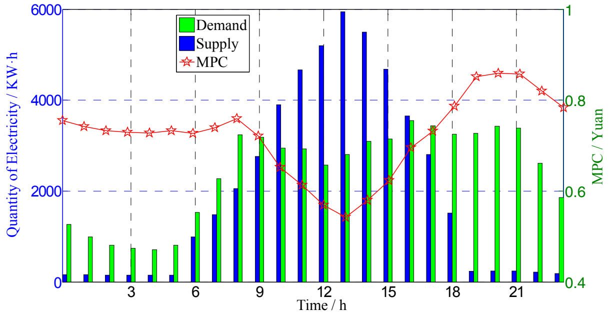

Fig. 6. MPC curve of demand and supply in a day.

Fig. 7 shows the total payout and payoff among WEs in a day. The maximum payout is 7039.60 Yuan appearing at WE_1, and the minimum payoff is 3305.03 Yuan appearing at WE_5. The WE_7 earns 6957.79 Yuan as a PVPS in a day. And an expectation profit of Energy Internet can be calculated as 18640 Yuan, in return for balancing the supply and demand in a day.

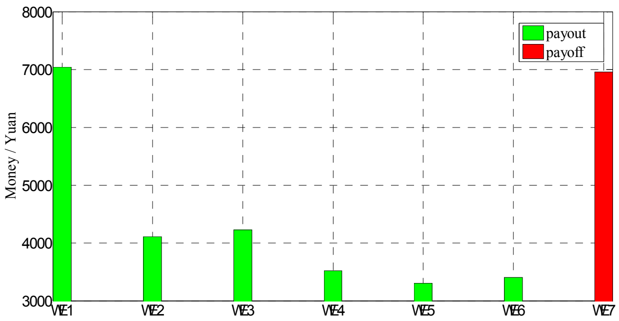

Fig. 7. The total payout and payoff among WEs in a day

VI. CONCLUSION

In this paper, we have addressed a problem in which several regions interact by trading energy to maximize their utilities that the utility of buyer is designed as a payout function, and the utility of seller is designed as a payoff function. In order to simplify energy regulation, trading and information interaction, which match up Energy Internet, a novel energy accessing mode called WE is proposed in this paper. A Bayesian game model considering DGs uncertainty, under two-level energy market structure, is established to analyze the strategies among WEs. According to hessian matrix, we have proved that the Bayes model among the Surplus-WEs has a unique Bayesian-Nash equilibrium, and Bayes model among the Short-WEs has a unique Bayesian-Nash equilibrium. Numerical results have shown that the designed MPC, which fluctuates at [0.54, 0.86] $Yuan/KW \bullet h$, can reflect the relationship of supply and demand better, and maximize the utility of all the WEs. As a role of balancing the supply and demand among WEs, the profit of Energy Internet is calculated as 18640 Yuan in a day.

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