Intermittent energy station coordination control based on cooperative game

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Abstract. Aiming at the uncertainty output of intermittent energy stations in new ecological energy towns, this paper proposes a risk trading scheme based on the cooperative game mode of multi-energy station main interests. Combining wind power and photovoltaic power generation through the risky electricity trading between different energy stations and take full advantage of the natural complementarity between wind and solar energy in time and region, which is expected to reduce the risk of wind power and PV forecast deviation. At the same time, in view of the different load characteristics of cold/heat/electricity and play the coordination and complementary capabilities, which can realize coordinated control of new ecological energy stations. Finally, the proposed method are verified by simulation.

1. Introduction

The current urban energy supply pressure and environmental pollution caused by traditional energy structure and consumption patterns have become the bottleneck restricting urban development. How to reduce the environmental pollution caused by energy use while ensuring the sustainable supply of urban energy is a hot spot of urban development[1-3]. In the energy town, the load exists in various forms such as cold, heat, electricity, gas, etc. But simultaneously the uncertainty of the cold/heat/electric load and the intermittent energy output Significant instability poses a challenge to the coordinated control of the energy town system. The intermittent energy station(IES) in the new eco-energy town is difficult to adapt to the traditional day-ahead scheduling mode. Therefore, an operational model for the characteristics of intermittent energy stations is urgently needed.

At present, there are few studies on the optimization of the risk of intermittent energy stations with
cold/heat/electric load. Most of them are the short-term trading and long-term trading risk assessment of microgrid, and some involve the volatility of wind and light storage and the internal response of load [4-5]. The literature [6] deals with multiple energy generators in a cooperative mode and proposes to maximize profits, but does not involve risk optimization.

From the perspective of the intermittent energy power stations’ revenue, this paper proposes an energy risk trading scheme based on the cooperative game mode to coordinate the control of the intermittent energy station in the park, which effectively reduces the loss of revenue caused by the uncertainty of intermittent energy output by trading multiple sources of risk at the energy station.

2. The concept and characteristics of a new ecological energy town

The new type of ecological energy town is characterized by the efficient use of micro-integrated energy systems. In the energy town, on the one hand, energy can be utilized in cascades; on the other hand, through the utilization of the coupling mechanism between different energy systems, the comprehensive management and coordination and complementarity of multiple energy sources can be realized. This paper makes full use of the characteristics of intermittent power supply, including high energy grade and rapid response, to establish a cooperative relationship between different energy stations and achieve better coordinated control of multi-energy flow. Fig.1 is a schematic diagram of coordinated control of multi-energy flow in a new type of ecological energy town.

![Figure 1. coordinated control of multi-energy flow Schematic diagram](image)

3. Intermittent energy station model in non-cooperative mode

3.1. Without considering the output plan under the uncertainty of intermittent energy output

The uncertainty of the output of intermittent energy causes that its actual output is inconsistent with the predicted value. The actual benefit of a batch energy station in this case can be expressed as:

\[
F = \sum_{r=1}^{T} \left( P_{pre}^{r} \alpha - \Delta P_{r} \cdot k \left( \Delta P_{r}, t \right) \right)
\]

In the above formula, \( F \) represents the IES income, which consists of the day-ahead market income and the intraday bias penalty. The first part on the right side of the equation represents IES’s sale proceeds after the day-ahead forecast of intermittent power generation. Specifically, \( P_{pre}^{r} \) represents the predicted value of power generation and \( \alpha \) represents day-ahead electricity price of electricity market. The second part is the penalty for the power market's deviation from the output of the IES.
\( k(\Delta P, t) \) is the power deviation price which is the function of power deviation and time. \( T \) is the scheduling period of the day.

3.2. Consider the output plan under the uncertainty of intermittent energy output

The uncertainty of intermittent energy output often causes a large loss to IES. In the day-ahead market, the consideration of the intermittent energy output uncertainty can effectively reduce the penalty of intraday output deviation. Similar to the IES sales plan without considering uncertainty, the sales revenue after considering the uncertainty of intermittent energy output can be expressed as follows:

\[
\begin{align*}
\text{max} & \quad \mathcal{F} \\
\text{s.t.} & \quad \Pr \left\{ \sum_{i=1}^{T} (P^i_{tt} - \Delta P^i k(\Delta P^i, t)) \leq \mathcal{F} \right\} \geq a
\end{align*}
\]

Among them, \( \mathcal{F} \) is the optimistic value of the objective function \( F \) and \( a \) is the confidence level set by the decision maker. \( P^i_{tt} \) is the output after considering the randomness for the \( t \)-th scheduling period.

4. IESs cooperative game risk trading

4.1. Principle of cooperative game

The game is mainly composed of three elements: decision maker, decision space and income. In the IESs cooperative game risk trading, the decision makers are intermittent energy stations. \( N \) different participants are represented by \( \text{IESN} (N=A, B, \ldots, N) \). The strategies are electricity and electricity prices of their respective risk transactions when IESs play a game.

4.2. IESs risk trading

The output deviations of different IESs are usually not the same, by trading a certain amount of intermittent energy output between different IESs, the risk can be reduced from the perspective of probability, thus reducing the power deviation penalty.

![Figure 2. coordinated control of multi-energy flow Schematic diagram](image-url)
4.2.1. Trading method

For any two transactions between IES i and j, the transaction power $q_{ij}^t$ and transaction price $a_{ij}^t$ should be included. Where $q_{ij}^t$ is the selling power of IES i to IES j (in proportion to itself), and $a_{ij}^t$ is the selling price of IES i to IES j.

$$0 \leq q_{ij}^t \leq 1$$

(3)

4.2.2. Transaction price

In a stable risk trading system, the selling price of intermittent electricity in an IES unit for a certain period of time should be the same. Therefore, in the trading system with the number of N IES, the following formula is established:

$$a_{ij}^t = a_{ij}^{t+1} = \cdots = a_{ij}^{t+n}, \quad i = 1, \cdots, n$$

(4)

$a_{ij}^t$ is the intermittent power sale price of the i-th IES of the t-th scheduling period.

The best risk trading price is defined by:

$$a_{ij}^t = a_{ij}^* = \frac{q_{ij}^t \sigma_n}{\mu}, \quad i = 1, \cdots, n$$

(5)

among them, $r_i = \sum_{j=1}^T D_{ij}^t / \sum_{j=1}^T D_{ij}^t$, $\sigma_n = \sqrt{\sum_{j=1}^{N} D_{ij}^t}$, $r_i$ represents the risk factor, and $D_{ij}^t$ is the variance of the IESi predicted in the i-th time period. $\mu_i$ is the expectation of a random variable.

4.2.3. Sales revenue

For the i-th IES, the revenue from electricity sales considering the uncertain factors in the cooperative game mode is as follows

$$F_i = \sum_{t=1}^{T} \left[ P_i a_i - \Delta P_i k \left( \Delta P_i, t \right) \right]$$

(6)

The income consists of four items: IES's electricity sales to the grid, the grid's penalties for IES power deviations, IESi's risky electricity purchases, and risky electricity sales.

5. Simulation and verification

5.1. Basic data

![Figure 3. IES1-3 intermittent energy output prediction curve](image-url)
This article is formed by three IES alliances and conducts electricity trading in accordance with established rules. The IES1 area is a photovoltaic energy station with a PV peak of 500 kW and only electrical load demand. The IES2 area is a wind power station with a peak wind power of 300 kW and an electric/cool load demand. The IES3 area is a wind power station with a peak wind power of 300 kW and an electricity/heat load demand. The IES1-3 intermittent energy output prediction curve is shown in Fig.3.

**Figure 4.** The cold/heat/electric load data

The cold/heat/electric load data in the new eco-energy town is shown in Fig. 4. The time-varying electricity price curve used in this paper is shown in Fig.5 where the heat/heat load is equivalent to the unit heat value of 0.349 ¥ / (kW · h).

5.2. Simulation results and analysis

Simulate the scene where the intermittent energy generators participate independently in the electricity market and the transaction and form the alliance to participate in the market, the following comparison chart is obtained.

**Figure 5.** The time-varying price curve

**Figure 6.** IES1 Participation in risk trade and income analysis

**Figure 7.** IES2 Participation in trade

**Figure 8.** IES3 Participation in trade
Table 1. Three Scheme comparing

|                      | IES1    | IES2    | IES3    |
|----------------------|---------|---------|---------|
| Cooperation          | 3344.754 | 508.754 | 1888.013 |
| Non-cooperation      | 2584.684 | 364.2708 | 1395.155 |
| Income increase      | 760.0706 | 144.4832 | 492.8584 |
| Revenue growth percentage | 0.294067 | 0.396637 | 0.353264 |
| Risk increase income value | 578.23   | 122.05   | 441.61   |
| Risk optimization    | 0.223714 | 0.335053 | 0.316531 |

According to Fig. 5-8, it can be seen that each intermittent energy station increases in revenue, reduces its own risk and reduces the power deviation penalty after participating in the alliance. Since the power market allows for a certain forecast deviation, there is no penalty for a low power shortage, and no loss of revenue is caused under these circumstances. Taking the prediction error into account, the following table is obtained:

6. Conclusion

In this paper, based on the cooperative game, an innovative trading scheme is proposed for the intermittent energy station. According to the four factors, the sales revenue of each IES is determined. Based on the stability of the IESs risk trade, the simulation is concluded.

(1) When a batch energy station trades separately with the electricity market, the loss of revenue due to the volatility of the output forces it to join the alliance.

(2) Under the alliance form, the total revenue of each intermittent energy power producer increases, which improves the overall income of the alliance.

(3) Under the alliance form, the corresponding risk-return value also increases, and the risk that each of them bears after the alliance game is formed is reduced.

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References

[1] Jin H, Hong H, Wang B, et al. A new principle of synthetic cascade utilization of chemical energy and physical energy[J]. Science in China, 2005, 48(2):163-179.

[2] Wang, Hantao, Zhang, Huiming, Gu, Chenghong. Optimal design and operation of CHPs and energy hub with multi objectives for a local energy system[J]. Energy Procedia, 142:1615-1621.

[3] Sun Hongbin, Guo Qinglai, Pan Zhaoguang, et al. Energy Internet: driving force, review and prospect [J]. Grid technology, 2015, 39(11):3005-3013.

[4] Jia Hongjie, Wang Dan, Xu Xiandong, et al. Research on several problems of regional integrated energy system [J]. Automation of power system, 2015(7):198-207.

[5] Wang Chengshan, Hong Bowen, Guo Li, et al. A general modeling method for optimal scheduling of micro-grid for cold and hot power supply [J]. Chinese journal of electrical engineering, 2013(31):5+56-63.

[6] Wang Rui, Gu Wei, Wu Zhi. Economic and Optimal Operation of a Combined Heat and Power Microgrid with Renewable Energy Resources[J]. Automation of Electric Power Systems, 2011, 35(8):22-27.