Strategy optimization for virtual power plant complied with power to gas operation model

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Abstract. Virtual power plant (VPP) is an integrated class of integrated power plant composed of energy management system and small and micro distributed energy resources controlled by it. Its distributed energy sources can be distributed generator sets, distributed energy storage equipment or demand response resources distributed among many demand-side users. Its concept emphasizes more on the function and effect presented to the outside world, updating the operation concept and produce social and economic benefits, in line with the needs and direction of China's power development. Given the uncertainty in renewable energy output and demand response, the VPP market of gas networks, Power to Gas (P2G) equipment, flexible loads and other resources are introduced. Furthermore, VPP's optimal scheduling strategy includes considering power and gas scheduling for both power and gas flows, and studies the optimization model considering the dual energy market to maximize the profits of VPP. Through example studies, the economics and scheduling strategies of the proposed VPP are analyzed. Simulation results show that the VPP proposed in this paper can effectively reduce the proportion of renewable energy emissions reduction by selling power or P2G equipment. Moreover, it is conducive to maintaining the pressure stability and safe operation of the natural gas power grid. VPP can reduce the cost of unbalanced punishment and reduce the impact of uncertainty.

1. INTRODUCTION
With the growing depletion of fossil energy sources and the increasing emergence of environmental pollution and climate change problems, the vigorous development of new energy sources and realizing the low-carbon utilization of various energy sources has become the theme of today's energy revolution [1, 2]. The proportion of large-scale new energy power such as wind power and solar power generation in the power system is constantly increasing, which fundamentally changes the structure, form and operation control mode of the traditional power system. Virtual power plant (VPP) which was proposed by Shimon Awerbuch in 1997 [3] is one of the important technologies to solve grid balance with renewable generators and make distribution grid more intelligent. VPP aggregated of distributed generators (DG), controllable loads (CL) and energy storage systems (ESS) installed in distribution network, participates in the electricity market as a special agglomeration [4, 5].

VPP is a remarkable solution for reliable supply of power with highest quality and coordinates the contradiction between smart grid and distributed energy [6, 7]. The typical characteristics of VPP is to make power consumers become an active participant in the power system, which could balance the
supply and demand by replacing the traditional energy generation at the peak period and have rapid application in practice projects [3]. The concept of virtual power plant is similar to microgrid, which also could integrate DG, CL and ESS. The review of the stochastic modeling for a microgrid is provided in reference [8] to optimize microgrid for efficient, reliable and economic operation. References [9] describes the characteristics of internet of energy and compares the VPP management and optimization strategies with traditional grid. Moreover, the factors which affect VPP efficiency are identified. A considerable amount of literature has been published on the research of VPP, which include bidding strategies [10-14], and stochastic problems [15]. Moreover, the tools which is used to solve the problems of VPP with uncertainties and the demonstration projects are introduced. The aggregated resources of VPP focus on electric vehicle [16] and renewable energy [17, 18]. Overall, there are less VPP study involve natural gas station which has lower emission and higher efficiency in city energy system. Moreover, the power-to-gas (P2G) system is deployed as an efficient means to reduce renewable energy curtailments through bi-directional energy conversion between electricity network and natural gas network [19]. Obviously, the P2G technology has the potential to adjust the balance the supply of electricity and gas to gain more economic or social benefits, and at the same time to enhance the reliability of electricity and gas network [20]. The P2G has high investment costs, low full-load operating hours, and high electricity costs at current stage, but this situation could be changed rapidly as the new support mechanisms and big scale application [21]. Therefore, an VPP which aggregated P2G considering the constraints of natural gas network is required to depth research.

The internal structure of the virtual power plant (VPP) with P2G is shown in the following figure, in which photovoltaic and wind turbine are the renewable energy units with partially controllable output to reduce carbon dioxide emissions. However, the volatility and uncertainty of renewable energy output will challenge the operation of virtual power plant. The traditional power stations are the stable power supply, and the flexible power loads can partially adjust the power demands. Fuel cell plant and electric-gas transfer technology (P2G) are the coupling nodes of power grid and hydrogen storage/network, which are used to balance the energy network. The virtual power plant with P2G realizes the bilateral switching of hydrogen and electricity, and could participate in the power market to obtain the benefits according to the difference of energy prices in the same period.

![Fig. 1 The structure of Virtual Power Plant with P2G](image_url)

Although many studies have been done in the field of the VPP optimization problem, they have not paid much attention to the P2G, natural gas network and gas market. In this paper, an optimized scheduling model is proposed for the VPP which includes power and gas dispatching in electricity market and natural gas market considering the uncertainties of renewable energy outputs and demand responses.

2. VPP with P2G operation model
The objective function to optimize the operation scheduling of virtual power plant is the minimum of total cost of the system which is shown as follows:
3. Case study
The virtual power plant includes resources: distributed photovoltaic (20MW), distributed wind power (30MW) and traditional thermal power station (60MW). The price of electricity sold is a certain proportion of the price of electricity purchased from the power grid on account of no relevant practices of VPP participating in the electricity market. Five scenarios are established as shown in the following table, and then the operation law of virtual power plant is analyzed.

| Scenario | Electricity market | With P2G | Hydrogen network constraints |
|----------|-------------------|----------|----------------------------|
| 1        | ×                 | ×        | ×                          |
| 2        | √                 | ×        | ×                          |
| 3        | ×                 | √        | ×                          |
| 4        | √                 | √        | ×                          |
| 5        | √                 | √        | √                          |

Because of the large wind power output and less load demand at night, the rate of abandoning renewable energy in virtual power plant is higher. Discard renewable energy could be solved when virtual power plant can sell electricity to power grid and contain P2G equipment. According to the
table, the cost savings of virtual power plant can only be sold to power grid, which is much higher than that of virtual power plant only containing P2G equipment.

| Scenario | Abandoned renewable energy rates | Cost of virtual power plants (10^4 Yuan) | Cost saving proportion |
|----------|----------------------------------|------------------------------------------|------------------------|
| Scenario1 | 21%                              | 71                                       | -                      |
| Scenario2 | 0                                | 64.1                                     | 9.7%                   |
| Scenario3 | 0                                | 68.2                                     | 3.9%                   |
| Scenario4 | 0                                | 63.8                                     | 10.1%                  |
| Scenario5 | 0                                | 63.8                                     | 10.1%                  |

In the scenario1, when the night wind resources of the virtual power plant are redundant and the load demand is low, the basic load of the traditional thermal power station is running, the peak-shaving gas power station is out of operation, and there is a large amount of abandoned wind power which are shown in Fig. 2.

4. Conclusions
In this study, the principle of P2G technology is analyzed and the structure frame of virtual power plant with P2G is established. Moreover, the optimal scheduling strategy model of virtual power plant consists of natural gas network, P2G equipment, flexible load and other resources is introduced in dual energy markets. The virtual power plant could store a certain amount of natural gas at night which can supply to gas network at daytime. Therefore, it is beneficial to maintain pressure stability and security operation of natural gas network by the proposed VPP.

Conflicts of Interest
The authors declare no conflict of interests

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