Local Autonomous Optimization based Virtual Power Plant Dispatch Strategy

Jianli Zhao¹, Shaodi Zhang², Ciwei Gao²*, Sisi Ma³, Siya Wei⁴, and Hongjuan Zheng⁵

¹State Grid Shanghai Electric Power Company, Shanghai, 200030, China
²Shanghai Electrical Science Research Institute (Group) Co. LTD, Shanghai, 200063, China
³School of Electrical Engineering, Southeast University, Nanjing, Jiangsu, 210000, China
⁴NARI Technology Development CO., LTD, Nanjing, Jiangsu, 210061, China
⁵NARI Control System Co. LTD, Nanjing, Jiangsu, 211106, China
*Corresponding author’s e-mail: ciwei.gao@seu.edu.cn

Abstract. The load of central air conditioning can be transferred or reduced through reasonable control and has become an effective alternative resource for the adjustable capacity of power grid. In the demand response mode, the central air-conditioning load can be aggregated to form a virtual power plant to participate in the unified grid dispatching operation. In this paper, the virtual energy storage model of the central air-conditioning system is built based on the integrated thermal inertia. The paper also proposed the internal coordination control mechanism based on multiple agents. Furthermore, the regulatory potential of the central air-conditioning system is evaluated from the perspectives of adjustable power and sustainable time according to the virtual energy storage characteristics. The virtual power generation unit is constructed by means of comprehensive coordinated control so as to realize the standardized unified modeling of central air conditioning system. Finally, This paper proposes the strategy of virtual generating unit dispatch based on local autonomous optimization and the operation strategy of virtual power plant participating in grid peak regulation. Through the strategy the distributed optimal control of power generation resources is realized in virtual power plant and the pressure on virtual power plant operators is released. This paper has guiding significance for virtual power plant to participate in the actual dispatching operation of power network.

1. Introduction

In recent years, the national power load and the peak-valley difference remain increasing with the development of social economy, making the power system load difficult to regulate. The huge urban air-conditioning power consumers are the main cause of peak load in summer. The building equipped with air-conditioners is capable of converting electricity to heat for storage. Reasonable regulation can realize load transfer or reduction. Therefore, the central air-conditioning load has the power regulatory potential within the comfort range that users can bear. On account of small volume and scattered location of air-conditioning unit, virtual power plant is adopted to aggregate many distributed resources to participate in unified grid dispatch as a whole through various technologies. In actual system, the power
of refrigerating machine is often regulated by adjusting the outlet temperature of the refrigerating water or changing the on and off state of the refrigerating machine; the power of the heat or water pump is regulated by changing the working frequency; and the power of terminal fan is regulated by changing the air volume of fan.

From the perspective of control architecture, Trcka divided the control of central air conditioning system into two levels: global control and local control. As for the participation of air conditioning load in demand response, current scholars mostly start from the thermal inertia of air conditioning room, building building body and additional cold storage unit to explore their regulation potential. Virtual power plant realizes the complementary coordination and optimization control among internal multiple power generation resources internally, and provides external power or power auxiliary services to the power grid.

Therefore, this paper proposes a virtual power plant operation method based on local autonomous optimization of central air conditioning, where air-conditioning cluster is aggregated into a virtual power plant to participate in power grid peak regulation. The method makes full use of the thermal inertia of the central air-conditioning system to provide adjustable capacity for the power grid and encapsulate the whole system into a virtual generation unit to provide continuous and stable output. The method not only realizes the standardized modeling of central air-conditioning system, but also alleviates release the operation pressure during peak load by fully exploiting the potential of demand-side resources.

2. Analysis of virtual energy storage characteristics of central air-conditioning system

2.1. Thermal inertia analysis of central air-conditioning system

Figure 1 shows the heat transfer process of central air-conditioning system. The response time scale of electric power and cooling capacity in central air-conditioning system is quite different. The thermal and electrical energy can be decoupled via the energy buffer of the chilled water system to provide effective user-side adjustable capacity for power system.

![Diagram of central air-conditioning system heat transfer process](image1)

Figure.1  Diagram of central air-conditioning system heat transfer process

2.2. Modeling of virtual energy storage for central air-conditioning system

Figure 2 shows a virtual energy storage model of central air-conditioning system constructed by analogy with traditional energy storage circuit.

![Schematic diagram of central air-conditioning virtual energy storage model](image2)

Figure.2  Schematic diagram of central air-conditioning virtual energy storage model

The power of the refrigerator rising is equivalent to charging the water heat capacity. When the refrigerating machine power drops, the refrigerating water and heat capacity starts to discharge to the
user component, so that the refrigeration power transferred to the user can maintain stable. The virtual energy storage of the central air-conditioning system can be modeled in three perspectives: charge-discharge power, changes in virtual storage of energy and state of charge of virtual energy storage. The specific formulas are left out here.

3. Assessment method of regulating potential of central air-conditioning system under integrated control

We apply centralized-decentralized control architecture to regulate the internal central air-conditioning resources of virtual power plants participating in grid peak regulation. We combined the global and local control to adjust the cooling source temperature and the terminal air flow at the same time so as to regulate the central air-conditioning system power. The assessment method evaluates the demand response characteristics of the central air-conditioning system with two indicators of adjustable capacity and sustainable time. Due to space constraints, the detailed modeling process is not shown in this article.

4. Operation strategy of virtual power plant based on the normalized dispatch of generation unit

This section takes the virtual power plant participating in power grid peak clipping based on the demand response of central air-conditioning as an example and focuses on the combined control of each central air-conditioning load during the process of virtual power generation which lasts for a period of time.

4.1. Construction method of central air-conditioning virtual power generation unit

We encapsulate each central air-conditioning system into independent Virtual Generation Unit (VGU) through local autonomous optimization to present unified form of virtual generation parameters to the outside and realize standardized modeling for complex central air-conditioning system.

4.1.1. Central air-conditioning virtual generation unit

Through combination and regulation of internal power equipment, the system can maintain continuous and stable virtual generation power externally, in which case the whole central air-conditioning system is called as virtual generation unit, as shown in the red rectangle in the Figure 3.

4.1.2. Calculation of user's cooling demand

Take account of the relationship between the amount of cooling required and the indoor temperature, local controller can calculate the minimum cooling demand of the region according to maximum tolerable room temperature $T_{r,i,\text{min}}$ and minimum fresh air volume $M_{f,i,\text{min}}$ provided by the users of each area. Afterward, refrigeration system agent will receive the data and calculate the minimum cooling volume required for all air-conditioning users $Q_{t,\text{HVAC, min}}$ in this area. The specific calculation formula is not given for the space limit.
4.1.3. Construction method of virtual generation unit of central air conditioning system

First, the adjustable power gap of the refrigerator and the maximum adjustable power provided by the terminal fan cluster are calculated as shown in equation (1) and (2).

\[
\Delta E = \left( P_0 - P_i \right) T^* - E_{e,ch} \tag{1}
\]

\[
E_{e,f} = \sum_{i \in L} \left( P_i^{f,\text{sum}} - P_i^{f,\text{sum}^*} \right) \tau_i^* \tag{2}
\]

According to the relationship of \( E_{e,f} \) and \( \Delta E \), there are two cases of the construction of virtual generation unit. Both case conducts a optimization in order to maximum power reduction of the system \( \Delta P_{\text{max}} \).

To sum up, the control center of the central air-conditioning system performs local autonomous optimization and generates virtual generation unit with sustainable duration \( T^* \), then it reports the maximum power reduction of the system \( \Delta P_{\text{max}} \) (hereafter referred to \( P_{\text{VGU}}^* \)) to VPPO for unified peak cutting regulation and management.

4.2. A virtual generation unit dispatch strategy based on local autonomous optimization

After receiving the virtual generation unit dispatch information issued by VPPO, the central air-conditioning system control center of each user generates the optimal control instructions of each power equipment in the system according to the virtual generation unit dispatch strategy. The dispatch strategy of virtual generation unit is divided into two parts: pre-setting of cold source temperature and real-time adjustment of terminal air volume, namely global primary and secondary optimization problem.

4.3. The strategy for virtual power plant participating in the power grid peak regulation

The operation control architecture of virtual power plant is divided into three layers: dispatching layer, management layer and user layer. Each two adjacent layers can conduct a two-way information interaction.

5. Data and analysis

5.1. An example of virtual power generation unit construction in central air-conditioning system

A case study of a small commercial building is conducted and the data are shown as in the following table 1.

| Parameter                                | Value     | Parameter                                | Value     |
|------------------------------------------|-----------|------------------------------------------|-----------|
| Specific heat capacity of Water kJ/(kg*℃) | 4.187     | Chilled water outlet temperature(℃)      | 8         |
| Specific heat capacity of air kJ/(kg*℃)  | 1.004     | Fan plate inlet temperature(℃)           | 8.4       |
| regional thermal resistance              | [0.15,0.30] | Chilled water flow(kg/s)                 | 27        |
| regional heat capacity                   | [10,30]   | Maximum air flow(kg/s)                   | 5.5       |
| User set temperature(℃)                 | [22,26]   | Indoor temperature deviation upper limit(℃) | 3         |
| outdoor temperature(℃)                  | 35        | Pipe loss coefficient                     | 0.1       |

First, evaluate the regulatory potential of the terminal fan cluster of the central air conditioning system in the commercial building. According to the assessment method mentioned in 1.2 and 2.2 section, it can be concluded that the adjustable power has a negative correlation with the minimum comfort requirement of the user in this area. The power reduction in the region is approximately proportional to the temperature change while the duration of each scene is inversely proportional to that. As is shown in Figure 4 and Figure 5.
5.2. An example of virtual power plant participating in peak load regulation of power grid

We conduct an example analysis using the operation strategy of the virtual power plant proposed above in the application scenario that virtual power plant participates in the peak-regulation of the power system in a small park between 12:00-14:00 of a certain day in summer.

First, VPPO adopts the strategy in Section 3.3 to select the virtual power generation units which participate in grid peak shifting. As a result, 35 virtual generation units will participate in this virtual generation event.

5.2.1. Optimization effect of local autonomy in central air-conditioning system

Take 1 virtual generation unit as an example. Figures 6 and 7 present three perspectives of the optimization of local autonomy.

According to the figures, it can be concluded that in the whole virtual generation period:

1) The deviation rate remains within ±2%, which suggests that the coordination and control have a good effect on the central air conditioning system;

2) The VSOC values are kept in the range [0, 1], which shows the virtual energy storage is fully utilized. The virtual generation will not influence the normal use.

6. Conclusion

In this paper, a virtual energy storage model is constructed based on the analysis of the integrated thermal inertia of the building body and water circulation in the central air-conditioning system. The paper also
proposed an assessment method for the internal coordination control mechanism and regulatory potential of central air-conditioning system from the perspectives of adjustable capacity and sustainable time. Afterward, the central air-conditioning system is encapsulated into a standardized virtual generation unit via the combined control of cooling source temperature and terminal air volume. Finally, the operation strategy of virtual power plant for peak load shaving is proposed, which solves the problem of power supply shortage during peak load period.

Acknowledgments
We would like to express our great gratitude to State Grid Shanghai electric power company’s scientific and technological innovation project(B3090D200001) who provides financial support for this project.

References
[1] Browne, M.W., Bansal, P.K. (2002) Transient simulation of vapour-compression packaged liquid chillers[J]. International Journal of Refrigeration, 25(5):597-610.
[2] Li, W.T. (2013) Study on optimal control of ground water Source heat Pump Air Conditioning System. XAUAT Publishing, XI’AN.
[3] Fei, W.S. (2016) Control method of variable Air volume system for central air conditioning[J]. Heilongjiang Science and Technology Information, 2016(02):43.
[4] Trcka, M.M., Hensen, J.J. (2010) Overview of HVAC system simulation[J]. Automation in Construction, 19(2): 93-99.
[5] Tian, A.N., Li, W.X., Liu, D.W. et al. (2019) Air conditioning load control strategy based on improved state space model[J]. Automation of Electric Power Systems, 43(08):124-137.
[6] Chen, H.H., Li, Z.N., Jiang, T. et al. (2019) The control strategy of flexibility of intelligent building energy use based on model predictive control[J]. Automation of Electric Power Systems, 43(16):116-129.
[7] Cheng, B., Huang, T.L., Wei, R.Z. (2019) Multi-time scale optimization of cold, heat and power supply microgrid with ice storage air conditioning[J]. Automation of Electric Power Systems, 43(05):30-40.
[8] Yavuz, L., Onen, A., Muyeen, S., et al. (2019) Transformation of Microgrid to Virtual Power Plant - A Comprehensive Review. IET Generation, Transmission & Distribution, 13(11):1994-2005.