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OPINION
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Concepts and Framework of Controllable Characteristic Evaluation and Bidirectional Interaction Technology of Flexible Load

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INTRODUCTION

At the power consumption side, with the emergence of energy storage, electric vehicles, microgrids with bidirectional regulation ability, and flexible loads such as translational load and interruptible load with certain response ability, more schedulable resources are provided for the power grid (Jiang et al., 2020). Through the interaction between the network and load and between the source and load, users give up the control of load to a certain extent. By dispatching this part of resources, the power grid reshapes the demand curve to match the supply curve, which is beneficial for ensuring the stable operation of the power grid, and provides a new means of support for stabilizing the volatility and peak shaving caused by large-scale clean energy access (Wang et al., 2021). However, the load-side resources are distributed in a large number, and the massive distributed schedulable resources are limited by communication, which makes it difficult to control accurately and directly, increasing the difficulty of power grid control. Nevertheless, with the rapid development of cloud computing (Geng et al., 2021), big data, Internet of Things (Cao, 2021), 5G mobile communication, and other technologies, the adjustable control characteristics of flexible load based on real-time data can be accurately predicted. Therefore, a large number of flexible loads are aggregated into one or more schedulable wholes according to certain criteria. Through sufficient real-time data mining (Xu et al., 2019), two-way interaction with the power grid is carried out, and active participation in power grid dispatching is carried out, which are beneficial for fully tapping the distributed resources, achieving higher economic benefits, and improving the stability of power grid operation. In this paper, the problems of flexible load controllability evaluation and bidirectional interaction technology based on real-time data are clarified, and some views on relevant technical elements are put forward.

FLEXIBLE LOAD CONTROLLABLE CHARACTERISTICS

In terms of the potential of flexible load response, Goldman et al. (2007) proposed a potential evaluation method for large industrial and commercial users to participate in demand response. The main steps include determining the research object and the type of demand response items, clustering analysis of user groups based on electricity characteristics, identification of the participation rate of the classified demand response items, calculation of price elasticity, and potential evaluation of demand response. The focus is on the calculation method of price elasticity applicable to subdivided user groups. Based on the above-mentioned assessment methodology, the Federal Energy Management Committee assessed the demand response potential of the United States for 2010 to 2020 from four scenarios: conventional operations, expanded operations, achievable participation, and full participation (Wang et al., 2014). Zhan et al. (2014) considered the electricity sales revenue of incentive load and the compensation cost of interruptible load and studied the participation of flexible load in load peak shaving. Based on the node marginal price, Sarkar and Khaparde (2013) analyzed the security constraint scheduling strategy of demand-side resources participating in reserve plans. Galus et al. (2011) carried out secondary frequency regulation of power systems through flexible load aggregation and used the load aggregation quotient to allocate control behavior. Yang et al. (2013) considered the joint scheduling of distributed generation and unidirectional flexible load to improve the operation efficiency of power systems. In summary, the current modes of flexible load participating in scheduling plans can be divided into three modes: participating in the scheduling plan, participating in the standby plan, and participating in frequency control (Tan et al., 2009; Gao et al., 2013; Jia et al., 2019). The scheduling architecture can be divided into centralized architecture, distributed architecture, and hierarchical architecture based on the load aggregator (Kurucz et al., 1996; Strbac and Kirschen, 1999; Ruiz et al., 2009). You et al. (2021) proposed an optimal control architecture of the flexible load aggregation control cloud platform-intelligent edge computing terminal-customer side energy information physics system. Second, referring to the architecture concept of cloud computing and edge computing collaboration (Xu and Dong, 2019), a set of flexible load aggregation control systems is designed based on the innovation of information and communication technology of the cloud intelligence-shifting chain (Zhang and Li, 2020) to realize the aggregation control of flexible load. Third, the flexible load aggregation control strategy is studied, and the multitype elastic load regulation algorithm based on cloud edge collaboration is constructed. You Feng et al. believed that the traditional centralized cloud computing model would encounter many limitations. On the one hand, adjustable potential computing relies on a large number of acquisition devices to run data. Data transmission from the end to the cloud has a high cost with respect to network bandwidth resources, and there is a network delay. On the other hand, the adjustable potential needs to be calculated in real time according to the equipment status, external environment, and other factors, and the computational power consumption is large. When massive load equipment is involved in load regulation, the cloud computing ability is required. Therefore, the cloud-side collaborative system architecture is constructed to sink a part of the computing power of load aggregation regulation to the edge end, complete the preprocessing and preanalysis of the collected data at the edge end, and solve some requirements at the edge end. It can reduce network overhead, reduce the load of the cloud, and bring lower delay and faster response.

In the aggregation regulation framework of flexible load, the user layer calculates the overall load adjustment potential according to the individual flexible load adjustment potential, the homogeneous load aggregation adjustment potential, and the heterogeneous load aggregation adjustment potential and reports this to the load aggregator. According to the adjustable potential of each user load, the load aggregator comprehensively evaluates the adjustable potential value, adjustment speed, adjustment cost, and complementarity of user load, completes the calculation of adjustable potential of user aggregation, and participates in market bidding. According to the scene requirements of peak regulation, frequency regulation, and clean energy consumption, the dispatching layer of the power grid generates day-ahead, day-in-day, and real-time regulation requirements based on the real-time operation status data of the power grid and the load storage prediction of the source grid and forms market information and releases it; according to the situation of load aggregators participating in market bidding, the load curve and flexible controllable margin reported by load aggregators are checked, and the market rules are precleared. The plan control target curve and baseline load curve of each load aggregator are issued. In addition, users perform autonomous control according to the control strategy and monitor and track the environment, operation parameters, and disturbance according to human behavior.

BIDIRECTIONAL INTERACTIVE NETWORK ARCHITECTURE

Based on real-time data of the power grid, flexible load can realize bidirectional interaction with the power grid. Li et al. (2016) proposed a bidirectional interactive network architecture between a smart park and a power grid system. The author believes that it can realize the interaction between the power grid and users, mainly in two aspects. The first aspect can use smart meters and implement dynamic real-time electricity price, and the power consumption period can be selected by the users themselves. The second aspect of the smart park power system allows users to have distributed power, including electric vehicles and energy storage devices to power the grid. The smart park grid system can make the energy flow and information flow between the grid and the load interact bidirectionally. The premise of realizing bidirectional interaction is to have a perfect power transmission and information communication system. Based on the traditional power transmission and distribution network, the construction of the smart grid should establish a powerful interconnected communication system that can realize communication between the power supply, power grid, and load. Ning et al. (2020) proposed a full process interaction system based on real-time data. The author divided the communication link between the dispatching automation system and the aggregator operating platform into uplink and downlink channels. The downlink data channel includes the control instruction and instruction time issued by dispatching, the day-ahead/day-in-day plan value, and the market clearing information. The uplink data channel is the real-time data of the aggregate total power, the number of load terminals, the power of load cells, the adjustable upper and lower limits, the AGC switching signal, the maximum step length of the acceptable instruction and other real-time data of the adjustable load cells sent by the aggregator, and the static model ledger information and market declaration information of the adjustable load cells.

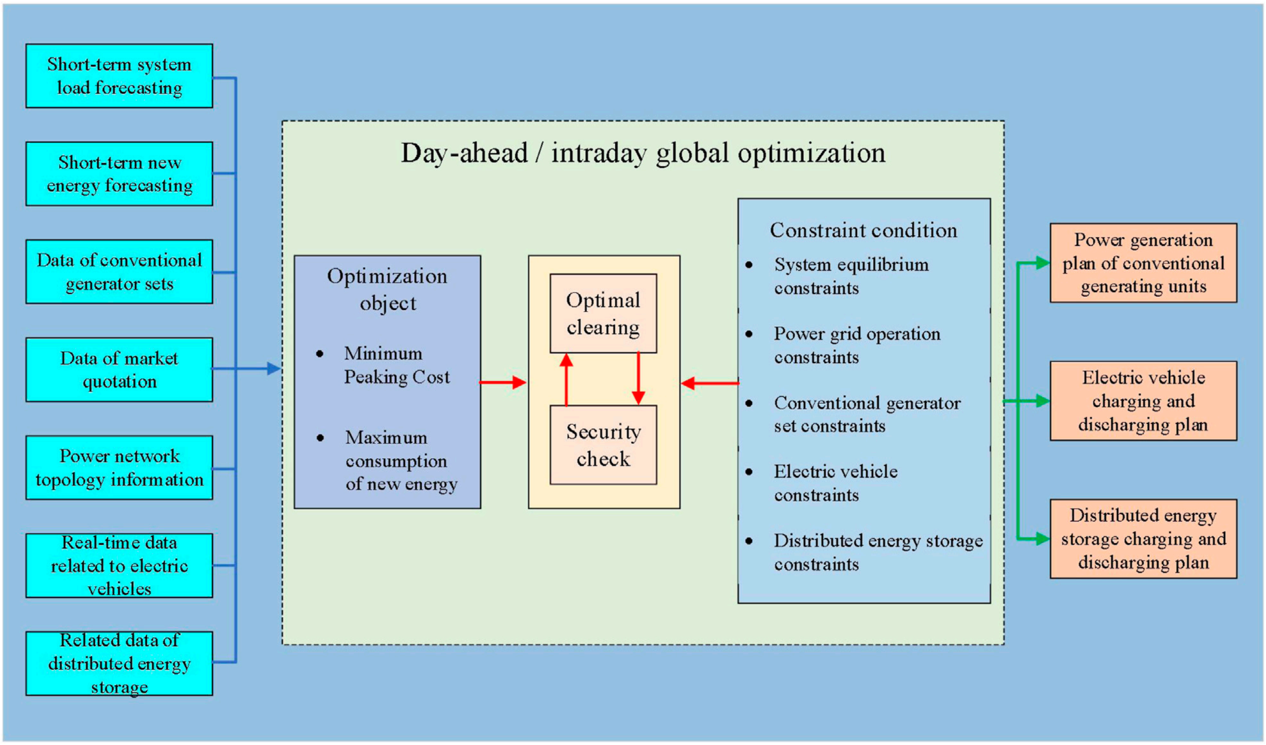

FIGURE 1 | Ideal charge–discharge planning framework for flexible load.

Flexible load resources can participate in the regulation of the power grid at the beginning of the province peak shaving auxiliary service market as the entry point as the peak shaving market price recipient is not involved in quotation. With the gradual deepening of business participation, they participate in market quotations in an appropriate form and even in the interprovincial market. At the day-ahead/day-in-day global optimization level, the minimum call cost of the whole network market can be taken as the optimization objective. According to the short-term/ultra-short-term load forecasting, based on the comprehensive consideration of the conventional constraints such as system balance constraints, unit operation constraints, and grid operation constraints, combined with the actual quotation reported by the load aggregator and the actual available capacity of the load users after aggregation, the constraints of peak regulation of thermal power units and the energy consumption or battery power of adjustable load resources are introduced to optimize the preparation of the ideal charging and discharging plan of flexible load in the future for a period of time, as shown in **Figure 1**.

DISCUSSION AND CONCLUSION

In order to fully realize the flexible load resources responding to the real-time control instructions of the power grid and participating in the flexible adjustment and realize the real load dispatching control of the multiple coordinations of the source network, load, and storage, it is necessary to continuously study and explore to realize the large-scale real-time measurability and real-time controllability of the flexible load resources. There are still many technical problems to be further explored, as follows:

(a) In terms of device performance, there is still a certain gap between the power data acquisition accuracy and real-time performance of flexible load resources and the demand of regulation business. It is necessary to continue to improve the technical level of load terminal equipment, increase the transformation of device acquisition and control performance, improve the real-time data upload frequency and tracking response ability, expand the number of load resources that can participate in real-time control, and increase the investment and construction of load terminals with strong regulation ability such as V2G and orderly charging piles.
(b) At the aggregator level, realization of the accurate rolling calculation of the security region of controllable power according to the needs of a large number of load users and the state of equipment in the operating platform so as to maximize the aggregation of the regulating space of decentralized load resources according to different optimal

strategies according to different resource characteristics is needed.

(c) In terms of interruptible load, further optimization and transformation of the current marketing demand response system and scheduling precision load shedding system in various regions, expansion of the control ability of the system platform, and its integration into the overall technical architecture in this paper so as to transform a large number of interruptible load attributes that have been gathered in this part of the system into adjustable attributes and fully release the load-side adjustment potential are needed.

AUTHOR CONTRIBUTIONS

ZT: writing the original draft and editing. BL: discussion of the topic. ST: supervising. CD: funding.

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REFERENCES

Cao, W. (2021). Application of Internet of Things Technology in Power System in 5g Era. *Digit. Commun. World* (04), 148–149.

Galus, M. D., Koch, S., and Andersson, G. (2011). Provision of Load Frequency Control by PHEVs, Controllable Loads, and a Cogeneration Unit. *IEEE Trans. Ind. Electron.* 58 (10), 4568–4582. doi:10.1109/tie.2011.2107715

Gao, C. W., Li, Q. Y., Li, H. X., Zhai, H. B., and Zhang, L. (2013). Methodology and Operation Mechanism of Demand Response Resources Integration Based on Load Aggregator. *Automation Electr. Power Syst.* 37 (17), 78–86.

Geng, X., Yan, Q. M., Xu, W. T., and Xiao, D. X. (2021). Research on Control Strategy of Multi-Source Power System Based on Cloud Computing. *Electr. Eng.* (08), 45–47.

Goldman, C., Hopper, N., and Bharvirkar, R. (2007). *Estimating Demand Response Market Potential Among Large Commercial and Industrial Customers: A Scoping Study*. Berkeley, California: LBNL Environmental Energy Technologies Division.

Jia, Y. L., Mi, Z. Q., Wang, J. J., Yu, Y., and Fan, H. (2019). Multi-time Scale Collaborative Optimal Scheduling Strategy with Flexible Load Aggregator Participating in Power System. *J. North China Electr. Power Univ.* 46 (06), 17–26.

Jiang, T. Y., Li, Y. P., Ju, P., Yang, Y., and Zhao, J. (2020). Overview of Modeling Method for Flexible Load and its Control. *Smart Power* 48 (10), 1–8.

Kurucz, C. N., Brandt, D., and Sim, S. (1996). A Linear Programming Model for Reducing System Peak through Customer Load Control Programs. *IEEE Trans. Power Syst.* 11 (04), 1817–1824. doi:10.1109/59.544648

Li, D., Mou, Q., and Shen, D. T. (2016). Research on Flexible Load Control Technology in Intelligent Park. *Electron. Technol. Softw. Eng.* 12, 230.

Ning, J., Jiang, C. M., Zhang, Z., Zhang, Y., Guo, L., Shi, P. R., et al. (2020). Thinking and Technical Practice of Adjustable Load Resources Participating in Dispatching and Control of Power Grid. *Automation Electr. Power Syst.* 44 (17), 1–8.

Ruiz, N., Cobelo, I., and Oyarzabal, J. (2009). A Direct Load Control Model for Virtual Power Plant Management. *Power Syst. IEEE Trans.*24 (02), 959–966. doi:10.1109/tpwrs.2009.2016607

Sarkar, V., and Khaparde, S. A. (2013). Improving Demand Response and Bid-Consistency of Price Outcome in the Security-Constrained Dispatch Scheduling. *IEEE Trans. Power Syst.* 28 (03), 2433–2445. doi:10.1109/tpwrs.2013.2239668

Strbac, G., and Kirschen, D. (1999). Assessing the Competitiveness of Demand-Side Bidding. *IEEE Trans. Power Syst.* 14 (01), 120–125. doi:10.1109/59.744498

Tan, Z. F., Chen, G. J., Zhao, J. B., Hou, J. C., and Jiang, H. Y. (2009). Optimization Model for Designing Peak-Valley Time-Of-Use Power Price of Generation Side and Sale Side at the Direction of Energy Conservation Dispatch. *Proc. CSEE* 29 (01), 55–62.

Wang, K., Yao, J. G., Yao, L. Z., Yang, S. C., and Yong, T. Y. (2014). Survey of Research on Flexible Loads Scheduling Technologies. *Automation Electr. Power Syst.* 38 (20), 127–135.

Wang, X. Y., Xu, J., Liao, S. Y., and Ke, D. P. (2021). Flexible Load Regulation Margin Evaluation Method Considering Virtual Energy Storage Characteristics. *Huadian Technol.* 43 (09), 37–45.

Xu, E. Q., and Dong, E. R. (2019). Exploration and Practice of Collaborative Development of Cloud Computing and Edge Computing. *Commun. World* (09), 46–47.

Xu, H. Q., Sun, S. M., Ge, Z. Q., Qu, G., Sun, Y. F., Wang, X. Z., et al. (2019). Research and Application of Architecture and Key Technologies for Power Grid Real-Time Dispatching and Control Data Platform. *Automation Electr. Power Syst.* 43 (22), 157–164.

Yang, N., Wang, B., Liu, D. C., Zhao, J., and Wang, H. (2013). An Integrated Supply-Demand Stochastic Optimization Method Considering Large-Scale Wind Power and Flexible Load. *Proc. CSEE* 33 (16), 63–69+17.

You, F., Zhang, H. L., Shi, J., Zhang, C. P., Deng, B. Y., and Yang, Y. L. (2021). Design of Flexible Load Aggregation Regulation System Based on Cloud Edge Collaboration Technology. *Distribution Util.* 38 (12), 64–73.

Zhan, H. X., Chen, Y. H., Zhang, R. D., Lu, F., Yuan, J. H., Chen, Y., et al. (2014). Research on Joint Management Model Considering Flexible Load Peaking. *Electr. Energy Manag. Technol.* (21), 59–64.

Zhang, J., and Li, B. (2020). New Generation Smart Grid Technical Standard System Supports High Quality Development of Power Grid. *Distribution Util.* 37 (03), 2+1.

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