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OPINION
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Multi-Time-Scale Analysis of Power Balance Considering Coordination Between Distributed and Centralized PV Power Generation

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INTRODUCTION

Renewable energy has become an important source of power because of the benefits of a low-carbon economy. Hydrogen is a clean fuel and has also aroused great concern around the world. Renewable energy can be used to produce hydrogen energy. Zhang et al. presented a novel approach to coordinated control of renewable energy and hydrogen production, and the operation economics of hydrogen fueling stations and the energy system had been improved (Zhang et al., 2022). Much work, so far, has focused on renewable energy systems and energy internet (Zhang, 2018). Notably, photovoltaic (PV) technologies have always been a hotspot in renewable energy systems. There is an urgent need, but it is still a significant challenge to control PV systems in an uncertain environment. A two-stage PV structure was investigated by Fu et al. (2019), who presented an effective technique for PV power integration using μ theory. Li et al. presented a maximum power point tracking method, which can ensure stable PV power generation under partially shaded conditions (Li et al., 2021). With the increase of PV capacity in renewable energy systems, the grid-connected configuration is changing the operation mode of energy networks (Eftekharnejad et al., 2015). To reduce the cost of a PV generation system with battery storage, Hao al. presented a bi-level control method, which also ensured stable PV power generation (Hao et al., 2021). It is worthwhile mentioning that solar PV projects will play an important role in the economy of future electric generation portfolios (Vithayasrichareon et al., 2015). One of the great challenges is that uncertainty in PV modules makes distributed generation planning extra hard in distribution networks. It is generally accepted that statistical machine learning is an effective technology for modeling uncertainties in PV power (Fu et al., 2020). In terms of a distribution network with PV generation, we often need to configure reactive power devices to improve the performance of the energy networks (Fu, 2022). Fu et al. presented an adaptive reactive power control strategy to balance the trade-off between power quality and power loss, and the method enhanced the friendliness of the utility connection for a PV solar system (Fu et al., 2015). In terms of a centralized PV power generation, power factor control and voltage control are the key technologies of PV-grid connection. Awadhi and Moursi invented a novel controller for a centralized PV plant to avoid voltage imbalance, and the transient response was also enhanced (Awadhi and Moursi, 2017). Emmanuel et al. presented a power factor control method based on wavelet variability, and they reported the analysis results of the influence of power factor on the output of centralized photovoltaic power station (Emmanuel et al., 2017).

Scholars have performed a lot of research work on deploying and controlling distributed PV, but they pay little attention to the relationship between distributed and centralized PV power generation.

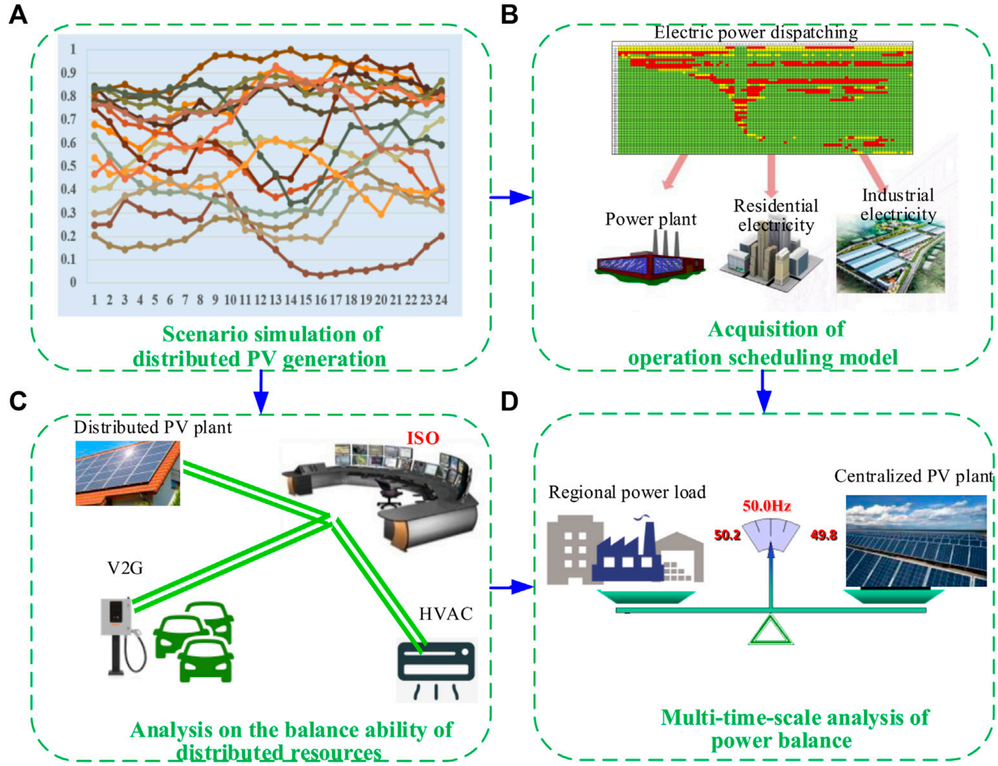

FIGURE 1 | Framework for multi-time-scale power balance considering centralized PV generation. **(A)** Scenario simulation of distributed PV generation. **(B)** Acquisition of operation scheduling model. **(C)** Analysis on the balance ability of distributed resources. **(D)** Multi-time-scale analysis of power balance.

However, due to a decrease in capacity installations, the reliability of operation of power systems may be affected by the superposition of distributed and centralized PV power generation. The components of distributed and centralized PV power generation are the same, and solar panel is made of polycrystalline silicon or thin-film. Distributed PV panels are always installed on the roofs of farm houses and greenhouses, and then the project is mainly concentrated in North and South China. Centralized PV power generation is mainly installed in the Gobi deserts, which spreads on Ningxia, Gansu, Xinjiang, Qinghai, Northwest China.

NUMERICAL POWER BALANCE

Solution Framework

As shown in **Figure 1**, we proposed a solution framework for analyzing the power balance of a regional power system with distributed and centralized PV power generation. Four modules are given to realize different functions. With respect to the first module, a scenario simulation model of distributed PV generation should be developed for making day-ahead forecasts. The predicted PV power generation results are provided to the dispatching center. We deal with the uncertainty of distributed PV power generation in two ways. Demand-side energy management is given priority to balance the output of distributed PV generation, so as to improve the consumption of local distributed PV generation and prevent the reverse power flow from the PV generation to the distribution networks. With respect to the second module, the aim of acquisition of operation scheduling model is to estimate the electricity supply-demand gap, and the power plant should meet the demands of residential electricity, industrial electricity, and so on.

The day-ahead balance scheme mainly provides support for economic operation. Relying on the day-ahead prediction data, the day-ahead generation schedules are given. The day-ahead balance scheme is passed to the intraday balance analysis, and the day-ahead balance scheme is further adjusted according to the ultra-short-term PV generation forecast to improve both economy and security. The real-time balancing scheme takes security as the sole purpose and provides an absolutely safe balancing scheme for real-time scheduling.

Key Technologies

We address three key technologies for multi-time-scale power balance considering coordination between distributed and centralized PV power generation. *1*) It is generally accepted that energy storage technology offers significant benefits for the multi-time-scale power balance in a power system with a high proportion of PV power generation. However, the project-oriented economic performance is a difficult one to improve the potential for the expansion of PV plus storage systems. We can assume that regardless of the project-oriented economic performance, no one can deny that energy storage is the most effective way to deal with the uncertainty in PV power. *2*) There is thereby an urgent need but it is still a significant challenge to accurately predict the power generation amount from PV for integration with power systems. The forecast results of PV power for the next day can never be completely right, no matter how good the algorithm is. However, an accurate PV power generation prediction will significantly reduce the percentage of reserve capacity or the amount of PV power generation abandoned. *3*) Optimization under uncertainty is critical for the analysis of power balance considering coordination between distributed and centralized PV power generation. In terms of deterministic generation and demand, power balance surplus is deterministic. In terms of the power grid with high penetration PV power generation, power balance surplus is uncertain due to the volatility and randomness of the PV power generation, and this was such a big challenge for power balance measures. When the power balance measures are too conservative, the economic performance of the economic dispatch scheme for the power balance will be greatly reduced. On the contrary, power balance measures with better economic performance often bring security risks to the safe operation of energy networks with high proportion of PV power generation. Therefore, the power balance scheme must balance a trade-off between the security level and economic performance, and stochastic programming provides a framework to obtain the optimal balance scheme.

DISCUSSION

Difference Analysis

The existing literature talks more about distributed and centralized PV power generation and less about centralized PV power generation. Therefore, we are here to discuss the difference between distributed and centralized PV power generation. First, distributed and centralized PV plants are under different grid voltage conditions. Usually, 380 V is regarded as the grid-connected voltage of distributed PV plants, and the specific grid-connected voltage of a centralized PV power generation shall be 35 or 110 kV. In terms of a PV central power station above 30 MW, a main transformer is necessary to connect 110 kV transmission lines. Second, a centralized PV power generation has a long distance power transmission, while the distributed PV power generation is consumed by local demands. Third, distributed and centralized PV plants have different requirements in electricity power generation. The number of equipment for centralized PV generation is greater than that of distributed PV generation. The primary equipment for a centralized PV generation should include a station transformer, switch cabinets, various mutual inductors, arc suppression coil, and main transformer. The secondary equipment for a centralized PV generation should include microcomputer protection, watt hour meters, and dispatch screen. In terms of a distributed PV power station, a wall-mounted solar inverter is necessary and its size is small. Finally, the environmental factors of the installation site also make characteristics of distributed and centralized PV power vary greatly.

Difficulty Analysis

The centralized PV power generation model and regional dispatching model are easy to obtain, and these models are accurate. The difficulty of power balance analysis is that distributed PV power generation is difficult to predict accurately. The real problem is not only the difficulty of modeling distributed PV power, but also the lack of historical data and even the lack of power data. The variability of micro meteorology makes a single distributed PV power generation uncertain. The overall impact of all distributed PV plants in a region poses a great challenge to the power balance, and the result is that the local utility should use more controllable resources to deal with uncertainty. In view of the aforementioned difficulties, the authors put forward a feasible scheme. First, the region is divided into small spaces, and the models of distributed PV power generation in different spaces are established respectively. Second, the installation of distributed PV measuring devices does not need to achieve full coverage of each household, but we can select typical households for the deployment of measuring devices in each space. Advanced machine learning algorithms can be used to simulate distributed PV data of those without a measuring device, and the inputs of machine learning algorithms are weather data and PV power generation data of neighbors having installed with measuring devices. The proposed method can greatly reduce the purchase cost of PV measuring devices. Third, the comprehensive impacts of time, space, and weather are considered to help make short-term and ultra-short-term predictions of a distributed PV power generation in a space. Finally, a power flow model based on the spatiotemporal correlation theory can be built to analyze the overall impact of distributed PV power generation in different regions on the power balance of the whole region.

CONCLUSION

With the high proportion of distributed PV generation access, the traditional centralized energy management and scheduling operation will inevitably face many new problems, such as high communication cost, low optimization efficiency, frequent changes in operating conditions, and so on. Coordinated control of a large number of uncontrollable distributed PV generations will significantly increase the difficulty and safety risk of power grid dispatch. Through the multi-time-scale analysis of power balance considering coordination between distributed and centralized PV power generation, it is conducive to fully tap the safety and stability to support the ability of PV power generation to the power grid. Establishing a multi-time-scale dynamic aggregation model of distributed PV power generation in the whole region is the key to realize the power balance analysis under different operation scenarios. Power balance analysis provides a decision-making basis for day-ahead scheduling and real-time dispatching.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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