Economic Viability and Optimal Strategy of Transmission Line Expansion under High Variable Renewable Energy Penetration in China

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Overview

Interregional transmission lines represented by Ultra-High Voltage (UHV) are used to effectively utilize variable renewable energy (VRE) in resource-rich areas and accelerate the low-carbon transformation of the power system. However, considering its high construction cost, whether the transmission line expansion is cost-effective under high VRE penetration remains unknown. Besides, large amounts of power transmission may affect the locally distributed energy development causing the waste of renewable energy resources. Finding an optimal transmission expansion strategy has become a key issue that needs to be solved urgently. To address the above issue, we develop an hourly scale model to simulate power system operations and expansions under different VRE penetrations by 2050. However, inter-regional power transmission requires a huge investment, and whether this investment is reasonable and cost effective has become a key issue that needs to be examined urgently. Besides, it may affect the distributed energy development that cause the waste of renewable energy resources. Excessive and unreasonable transmission expansion may generate idle infrastructure and result in economically ineffective. The choice between distributed energy sources with local consumption and long-distance power transmission has become the key issue influencing power system transformation. There exists urgent need for rational planning of transmission lines that achieve the optimal proportion between distributed energy sources and remote power transmission. A wide-ranging discussion has arisen due to the substitution effect for each other.

Methods

Our model contains generation and transmission lines expansion as well as power system stimulation during 2020-2050. It contains 6 stages, and each cover five years, as does the real scheme in China. For years in each stage, we select 4 typical days to obtain the seasonal characteristics. And 6 hours for each typical day to grasp the feature of load and generation output within one day. To describe major generation technology development, our model considers nine generation type considering technically feasibility. It includes coal, gas, nuclear, hydro, biomass, onshore wind, offshore wind, Utility PV, and distributed PV. At present, battery energy storage (BESS) and the pumped hydro storage (PHS) are the technically feasible for large scale application. Our study takes these two storage technologies into account. Considering the model complexity and computational power limitations, taking the province as a bus are commonly applied in the study of national power system simulation. Each provincial power system is regarded as a bus in the national power system.

Results

Transmission line expansion significantly increased centralized PV installed capacity, while reducing the installed capacity of distributed PV. It will significantly affect the installed capacity of energy storage. The demand for energy storage facilities increases with lower VRE proportion. As it increases, inter-regional transmission facilities will be effective in reducing the demand for installed energy storage. Transmission line expansion will increase the cost of power system transformation with the lower proportion of VRE sources. As it increases, reasonable transmission line investments can save the costs, and excessive transmission line investments will increase costs due to the misutilization of the equipment. The transmission lines expansion accelerates the centralized wind and solar power construction with lower proportion of intermittent renewable energy. With a higher proportion of renewable energy, the expansion of transmission lines significantly reduces the installed generating capacity of the power system as well as the amount of VRE curtailment. Transmission line expansion significantly increased centralized PV installed capacity, while reducing the installed capacity of distributed PV. It will significantly affect the installed capacity of energy storage. The demand for energy storage facilities increases with lower VRE proportion. As it increases, inter-regional transmission facilities will be effective in reducing the demand for installed energy storage.

The inter-regional transmission lines have significantly promoted the construction of centralized wind and solar power in the provinces of the “three North” regions, especially in Inner Mongolia and Xinjiang. In the scenario with no transmission lines expansion, the installed capacity of each province tends to be averaged out. The DC lines are dominated by the transmission of long-distance power especially in Inner Mongolia, Xinjiang. While the AC lines are dominated by the transmission of short-distance power in the other regions. The distributional characteristics of centralized and distributed PV differ significantly. The distributed PV has developed rapidly in load-concentrated areas under the scenario with no transmission lines expansion. It relies mainly on centralized PV construction in the Northwest region under optimal new transmission lines. This effect will be pronounced with the larger expansion of

transmission lines expansion. The distributional characteristics of energy storage vary significantly. The scenario without transmission line expansion requires a large amount of storage facilities in each province to smooth the VRE output. In the scenario with new transmission lines, energy storage facilities are concentrated in the provinces of Xinjiang, Inner Mongolia, Gansu, Qinghai, Ningxia, Hebei and Shandong, while pumped storage is concentrated in the provinces of Sichuan and Yunnan.

The transmission line expansion has further widened the boundaries of power sources and load. The region with power exported is concentrated in Northwest and Southwest, and power imported in is concentrated in the Central China, North China, and East China. The eastern region of Fujian will become the exporting provinces due to the large-scale development of offshore wind. The cross-provincial power transmission has been significantly increased under transmission line construction scenarios. The transmission volume from Xinjiang, Inner Mongolia, Gansu has increased significantly. Inner Mongolia sent to Hebei, Shandong, Jiangsu, Xinjiang sent to Anhui will become an important power transmission channel. The penetration of transmission line significantly reduces the share of energy storage and distributed PV in the national electricity operation.

Conclusions

The results show that: (1) Transmission line expansion will decrease the cost of power system under high VRE penetration. The expansion of transmission lines significantly reduces the installed generating capacity of the power system as well as the amount of VRE curtailment. (2) The inter-regional transmission lines have significantly promoted the construction of centralized wind and solar power in the provinces of the “three North” regions, especially in Inner Mongolia and Xinjiang. The distributed PV has developed rapidly in load-concentrated areas with no transmission line expansion. (3) The proposed optimal transmission line expansion can better balance the relationship between interregional power transmission and locally distributed consumption. It achieves cost-effectiveness while avoiding resource wastage.

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