Supplementary Material for "Multi-Time-Scale Energy Storage Planning Based on Wavelet Packet Decomposition"

I. Time Scales of Different Energy Storage Technologies in Introduction

As summarized in Table S1, various energy storage technologies (ESTs) can provide multi-time-scale flexibility in a variety of services [5-11].

TABLE S1
TIME SCALES OF DIFFERENT ENERGY STORAGE TECHNOLOGIES

Time scale	Typical ESTs	Services
Intra-hourly	SC, power-type Li-ion battery	Frequency regulation, fluctuation smoothing for RES
Daily	Capacity-type Li-ion battery, PHS, CAES	Intra-daily peak shaving, spinning reserve
Seasonal	PtG	Seasonal peak shaving

II. Choice of Emergency Reserve in Section III-C

Reference [S1] indicates that contingency reserve is usually determined by the largest generator capacity in the control area. Based on the Operating Reserve Scheduling and Management Regulations (Trial) of East China Power Grid, these regulations specify that the total spinning reserve demand should be the sum of the largest online generator capacity and the maximum DC transmission power, and it should not be less than 2% of the forecasted maximum load. It is important to note that the East China Power Grid effectively reduces reserve requirements through inter-area reserve sharing [S2]. Taking the year 2030 as an example, the largest generator capacity in this province is 1,150 MW, which is less than 2% of the maximum load (69,000 MW*0.02=1,380 MW). Thus, we use 2% of the maximum load as the emergency reserve.

III. Reasons for Clustering Three Typical Day Types Each Month in Section III-D

To validate the reasonability of the cluster number in each month, we take the example of net load data for a specific month in 2030. We employ the elbow method [36] to demonstrate the rationality of the cluster number K, as illustrated in Fig. S1. It is evident that the curve exhibits an elbow point at K = 3, indicating that the judgment category should be three categories, consistent with the categories in [14].

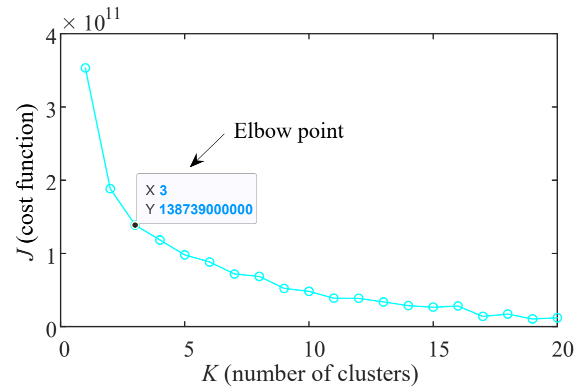


Fig. S1. Descent curve of the cost function J

IV. Choice of Confidence Level Parameter for Reserve Requirements in Case Study

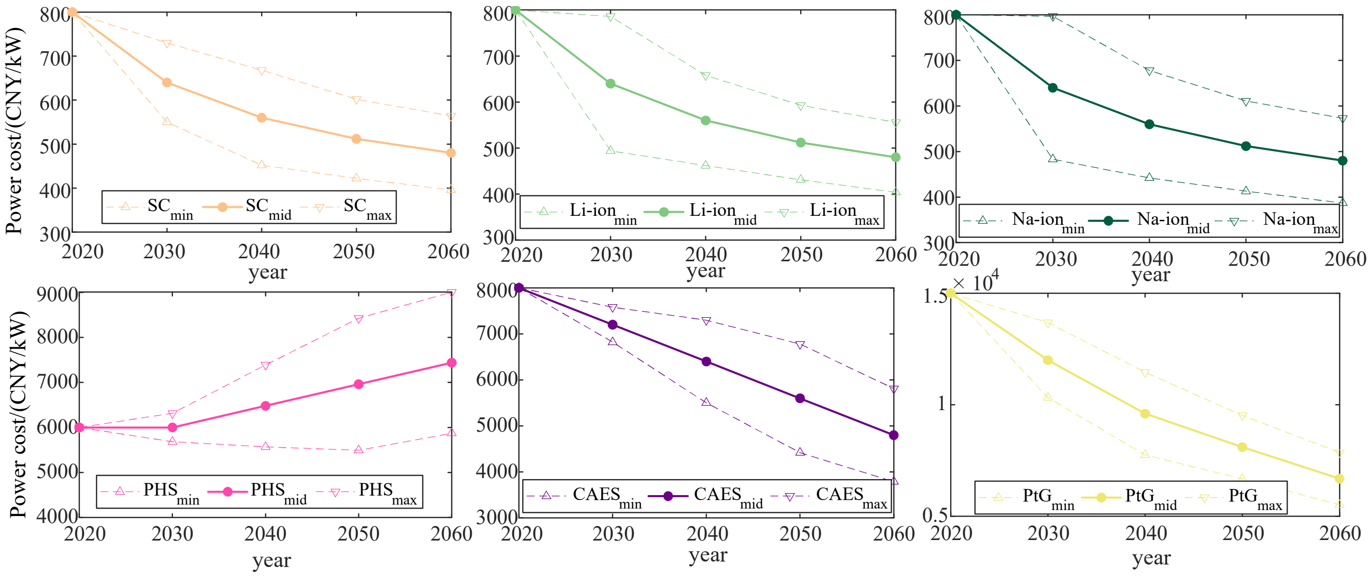
A higher confidence level would result in unnecessary waste of reserve resources, while a lower confidence level would compromise the operational security of power systems. In this study, only generation-side reserve resources are considered in system operation simulations, while power grids also include demand-side response as reserve resources. In the event of a rare occurrence exceeding the confidence level threshold due to prediction errors, the power grid can still ensure safe operation by appropriately curtailing wind and PV generation and activating demand-side response for unplanned reserve requirements [18]. Moreover, references [S3], [S4] also adopt a 90% confidence level for reserve requirements in addressing forecasting errors of renewable energy. Therefore, a 90% confidence level is chosen in this study.

V. Deviation of Technology Cost in Case Study

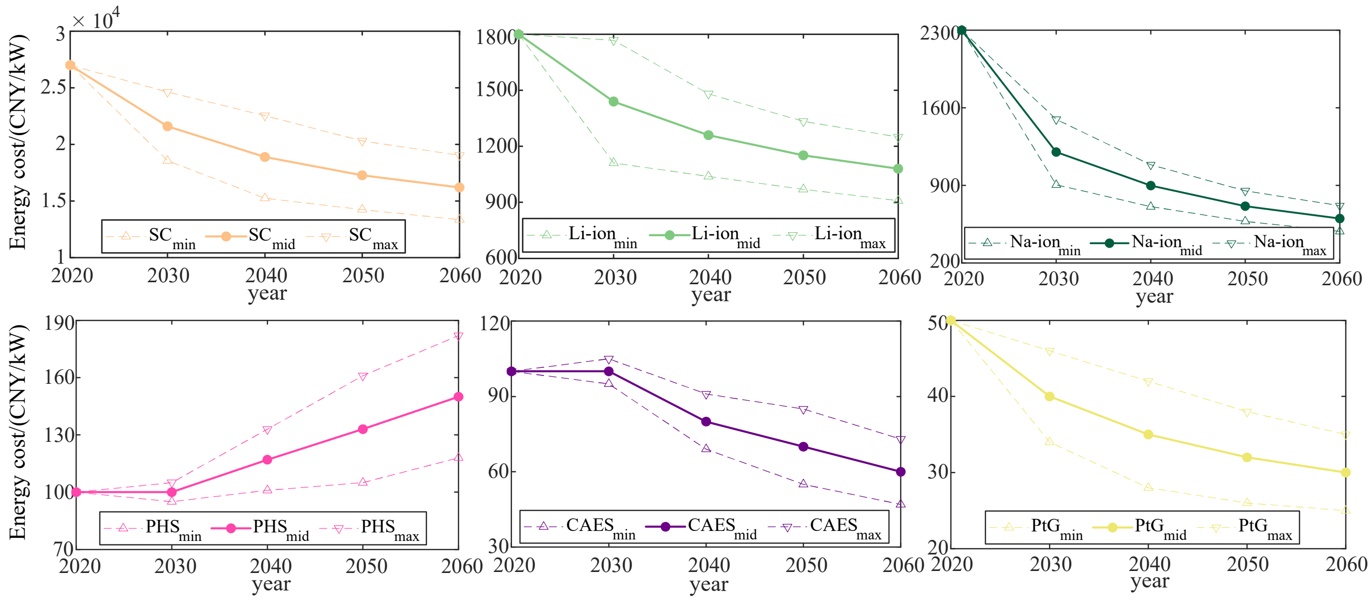
The single plot of Fig.6 in the manuscript is illustrated in Fig. S2. To facilitate a clear comparison of various EST costs, a logarithmic y-axis is employed in the composite figure. In the sub-figures, a regular y-axis is utilized to enable a precise comparison of technology price deviations.

VI. Comparison with EMD in Case Study

We select net load time series from two representative days in 2030 to compare the decomposition performance of WPD and empirical mode decomposition (EMD) [S5], as shown in Fig. 3. The results show that EMD yields inconsistent decomposition results across scenarios (e.g., 6 IMFs + residual in Scenario 1 vs. 7 IMFs + residual in Scenario 2), making it difficult to directly incorporate into multi-time-scale ES planning. In contrast, WPD provides more stable and balanced frequency resolution for non-stationary signals, making it better suited for the proposed planning model.



(a)



(b)

Fig. S2. Investment cost of ESTs with forecast uncertainty (single plot). (a) Power cost. (b) Energy cost.

REFERENCE

[S1] H. Hu *et al.*, “Construction method of an operating reserve system for east china power grid oriented to new power systems,” *J. Shanghai Jiao Tong Univ.*, vol. 55, no. 12, pp. 1640–1649, Dec. 2021, (in Chinese).

[S2] D. Wu, N. Zhang, C. Kang, Y. Ge, Z. Xie, and J. Huang, “Techno-economic analysis of contingency reserve allocation scheme for combined UHV DC and AC receiving-end power system,” *CSEE J. Power Energy Syst.*, vol. 2, no. 2, pp. 62–70, Jun. 2016.

[S3] J. Wang, H. Zhong, Q. Xia, C. Kang, and E. Du, “Optimal joint-dispatch of energy and reserve for CCHP-based microgrids,” *IET Gener. Transm. Distrib.*, vol. 11, no. 3, pp. 785–794, Feb. 2017.

[S4] Y. Zhuo *et al.*, “Research on reserve demand evaluation algorithm for power systems with high proportion of renewable energy,” in *2021 IEEE Sustain. Power Energy Conf. (iSPEC)*, Dec. 2021, pp. 538–543.

[S5] O. Abedinia, M. Lotfi, M. Bagheri, B. Sobhani, M. Shafie-khah, and J. P. S. Catalão, “Improved EMD-based complex prediction model for wind power forecasting,” *IEEE Trans. Sustain. Energy*, vol. 11, no. 4, pp. 2790–2802, Oct. 2020.

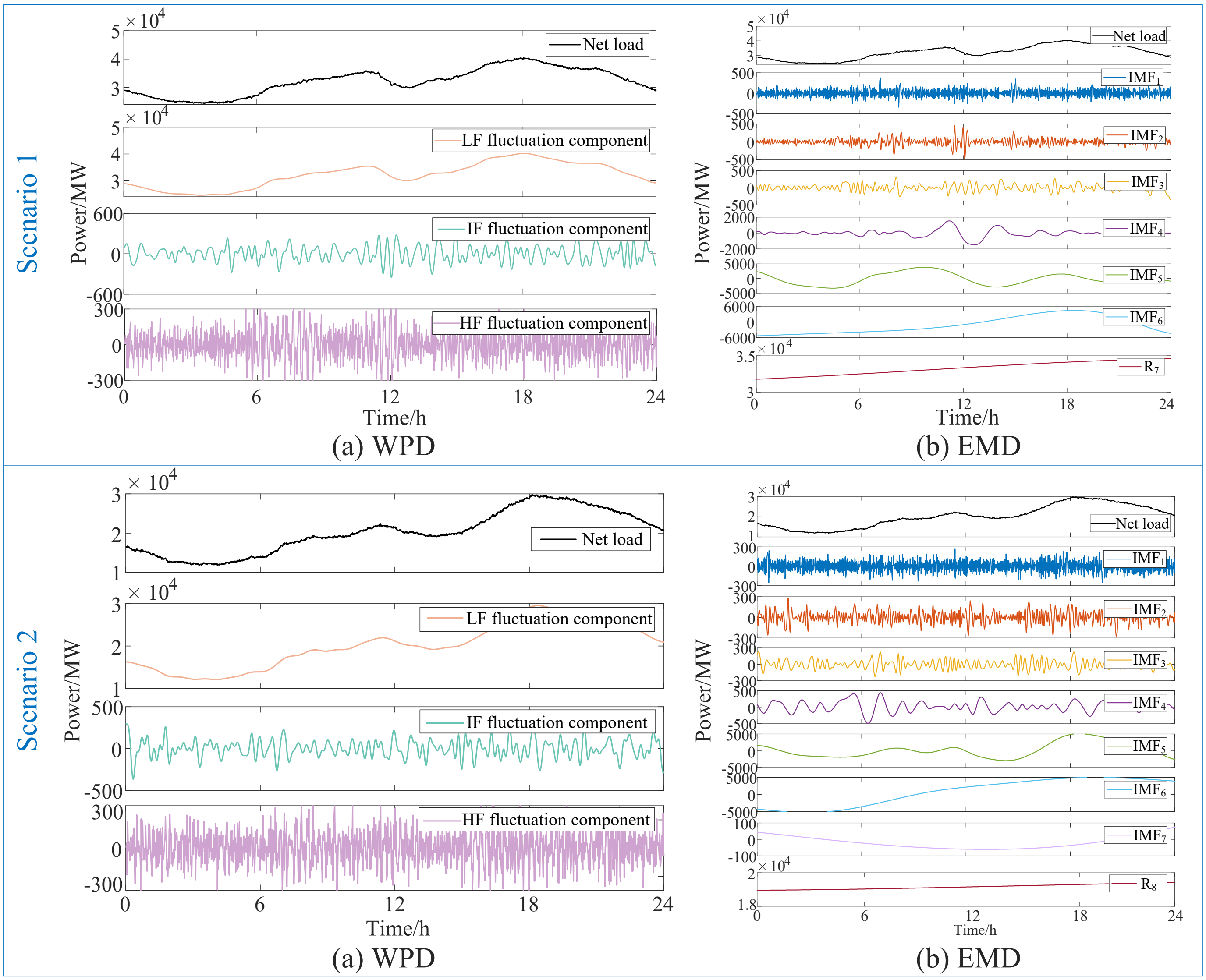


Fig. 3. Comparative results of WPD and EMD