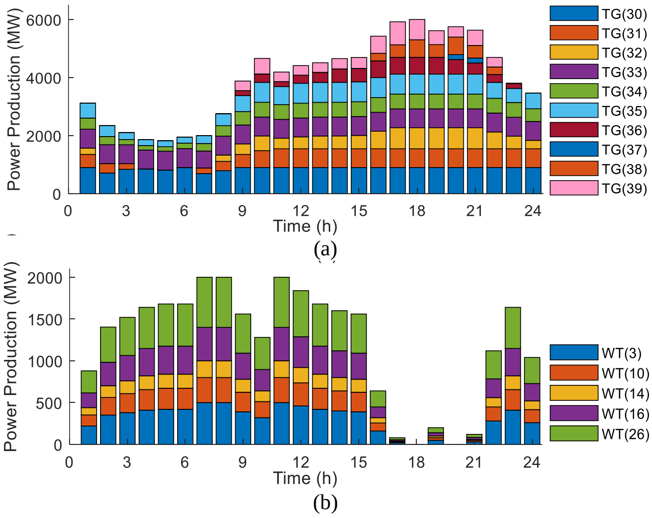


Fig. 3. Hourly power production for all generators.

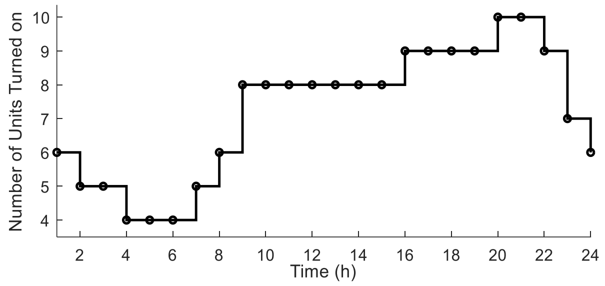


Fig. 4. The number of units turned on.

All TG are involved in the daily dispatch. TG located on nodes 30, 33, 34, and 35 are always in the turned-on state, and the other units have start-up and shut-down actions. Due to the limitation of the ramping capacity of TG, the excessive prediction deviation of wind power will lead to wind energy curtailment and load shedding. Applying the framework to assess the largest wind power interval that the power system can accommodate, the results are given in Section V-B.

B. Assessment of Wind Energy Accommodation

In this section, the output deviation range of all WT nodes is calculated through the solution strategy in Section IV, which is the envelope band of wind power accommodation. To verify the influence of wind energy leakage and load shedding on wind power envelope that electric power system can be accommodated, we designed the following four cases:

– Case 1 is the most conservative (β_w = 0 % and β_d = 0 %);

– Case 2 is load shedding only (β_w = 0 % and β_d = 5 %);

– Case 3 is wind power leakage only (β_w = 5 % and β_d = 0 %);

– Case 4 is the most radical (β_w = 5 % and β_d = 5 %).

The hourly allowable wind power deviation in different cases is given in Fig. 5.

The data in Fig. 5 shows that there are some time periods with allowable wind power deviation of 0 in all four cases. The results mean that the ability of power system to deal with wind power fluctuations is different in temporal. Wind power continuously ramping-up or ramping-down will cause wind power leakage and load shedding, which will greatly consume the dispatchability resources of power system. Besides, the mathematical statistics indexes are used to evaluate the allowable deviation of wind power in each period of four cases, and the results are given in Table II.

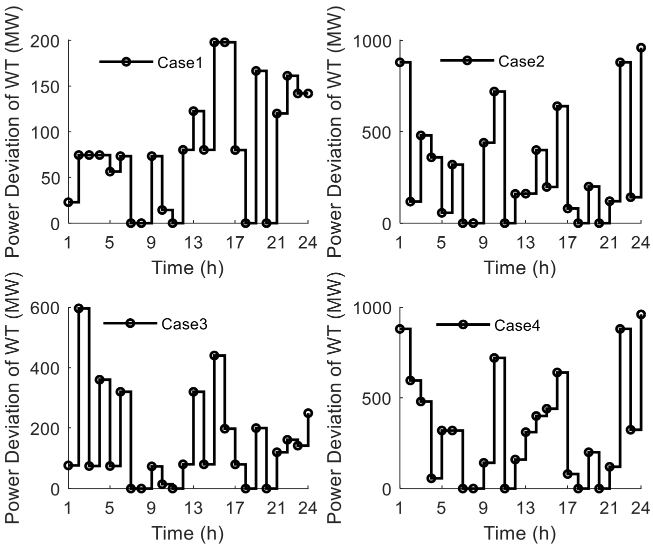


Fig. 5. Wind power deviation in different cases.

TABLE II. STATISTICAL INDEXES OF ALLOWABLE WIND POWER DEVIATION IN EACH PERIOD.

Index	Case 1	Case 2	Case 3	Case 4
Maximum Value	198	960	596	960
Minimum Value	0	0	0	0
Average Value	82	305	153	335
Standard Deviation	64	307	157	307

Note that the maximum adjusted output of all TG within the response time is 246 MW. Therefore, there is wind spillage and load curtailment in Case 2, Case 3, and Case 4. As the load demand is far greater than the installed capacity of WT, the allowable wind power deviation of Case 2 is greater than Case 3. Both wind power leakage and load shedding are allowed in Case 4, which makes the maximum allowable wind power deviation. The envelope band is given in Fig. 6.

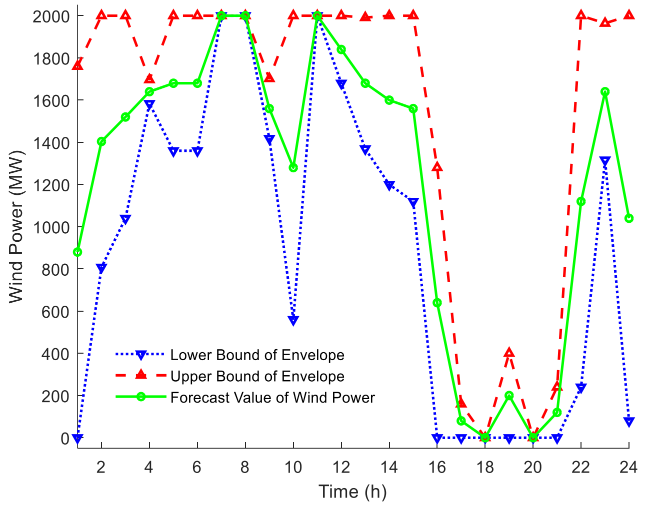
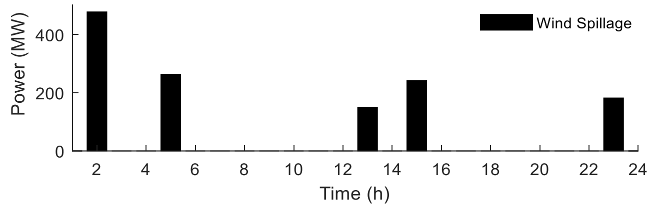
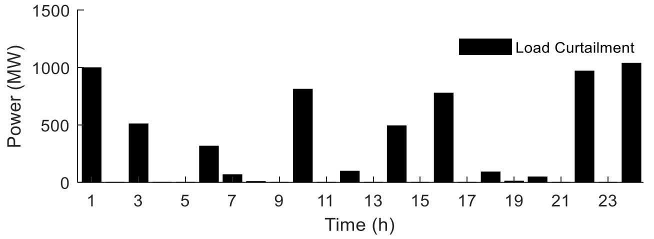


Fig. 6. The envelope band of wind power accommodation in Case 4.

The envelope band in Fig. 6 has such properties: for the realization of arbitrary wind power within the envelope, the amount of wind leakage or load shedding in the re-dispatch stage is acceptable through correcting the pre-dispatch scheme. Once the prediction deviation of wind power exceeds the range of wind accommodation envelope, wind leakage or load shedding will run out of predetermined constraints. The envelope band is similar to a metric and can provide early warning information. Furthermore, the hourly wind leakage or load shedding in Case 4 are given in Fig 7(a) and Fig. 7(b).



(a)



(b)

Fig. 7. (a) Hourly wind energy leakage in Case 4; (b) Hourly load shedding in Case 4.

The total amount of wind spillage and load curtailments are 1316 MWh and 6223 MWh, respectively. Wind spillage occurs in 2nd, 5th, 13th, 15th, and 23th periods, while the amount of load curtailment is zero. Note that the amount of load curtailment is both zero in 4th, 9th, 11th, 17th, and 21th periods. Reasonable wind power leakage and load shedding can significantly improve the ability of the system to withstand net load fluctuations.

VI. CONCLUSIONS

Based on the pre-dispatch and re-dispatch theory, the dispatchability of the power system is introduced, and the evaluation framework of wind energy accommodation is proposed. The results of numerical studies show that:

1. It is feasible to counterweight the deviation of wind power by correcting the pre-dispatch scheme. The effect of this method is related to the dispatchability resource of the electric power system.
2. Allowing certain wind spillage and load curtailment can greatly improve the ability of the grid to cope with wind power deviation. The results show that the reasonable wind spillage or load curtailment is beneficial to power system scheduling operation.
3. The envelope band of wind power accommodation represents the maximum range of wind power deviation for the power system, which can provide warning information (wind curtailment or load shedding) for decision-makers.

The envelope of wind power accommodation is affected by the electric power system pre-dispatching scheme. Therefore, the problem of co-optimization of the pre-dispatch scheme and envelope band of wind energy accommodation is worthy of attention in the future work. Besides, the deployment of energy storage to improve the envelope band of wind power accommodation is concerned.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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