

The Unit Commitment Model and Analysis for Promoting Clean Energy Consumption with Considering of Tie Line Plan Adjustment

Xu Zhang¹, Xinhong Shi¹, Bingquan Zhu², Ke Sun² and Yanwei Xiao²

¹Nanjing Research Division, China Electric Power Research Institute, Nanjing 210003, China

²Power Dispatch and Control Centre, Zhejiang Province Electric Power Company, Hangzhou 310007, China

E-mail: zhangxu@epri.sgcc.com.cn

Abstract. In recent years, China's clean energy has developed rapidly. The development level of clean energy does not match the local power consumption, resulting in a large number of abandoned winds and abandoned light. With the gradual completion of the UHV network, the transmission capacity between regions has been rapidly enhanced, providing a broad space for optimizing the allocation of resources across a wide range of areas and improving the level of clean energy consumption. In order to cope with the problem of difficult local consumption in clean energy delivery areas and current cross-regional power delivery methods, this paper considers the factors of the adjustment of the tie line plan and increases the consumption of new energy through more reasonable tie line planning based on the traditional unit commitment algorithm. A case study shows that the model proposed in this paper can promote cross-regional consumption of clean energy and improve the economics of the interconnected power grid.

1. Introduction

Clean energy is developing rapidly in China, showing a concentrated distribution and reverse distribution of load. The clean energy power plants are mainly concentrated in the northwest, north and northeast regions, and are transported to the east-central load centre through the ultra-high voltage transmission system [1]. At present, there are a series of problems in the development of clean energy, such as abandoning wind, abandoning light and abandoning water [2]. Promoting clean energy consumption through the optimal allocation of power generation resources has become a hot research topic.

Due to the uncertainty of wind power generation, many studies have included the uncertainty of wind power forecasting into the unit commitment (UC) [3] [4] [5]. In order to improve the level of clean energy consumption, unit commitment has been optimized by many scholars. Local consumption of clean energy is a top priority strategy. Based on grid peaking capacity and transmission constraints, clean energy units are arranged for generation as much as possible [6], [7]. If the local clean energy is surplus, it is necessary to optimize the regional power grid planning and realize the joint dispatch of the two-level power grid in the district and the province [8], [9]. Finally, according to the characteristics of inter-area load difference, peak-to-valley difference, and time difference, resource allocation can be realized in a larger range to maximize the consumption of clean energy [10]. Cross-regional long-distance transportation of clean energy becomes the main means of consumption



The construction of cross-provincial power transmission channels in China has made it possible to optimize the deployment of clean energy in China. This paper optimizes the generation and transmission resources and optimizes the tie-line power plan to improve the capacity of clean energy in inter-regional clean energy. First, the minimum operating mode of all thermal power units is constrained, and the maximum consumption of local clean energy in the sending area is calculated by the optimal unit commitment. Then, optimize the tie line power plan to explore the clean energy acceptance capability of the receiving area, and use the characteristics of load difference, peak-to-valley difference and time difference between the two areas to achieve the maximum consumption of clean energy at both ends.

The Section 2 of this paper establishes a UC model for promoting the clean energy consumption considering the adjustment of the tie line plan. Compared with the traditional UC model, the model considers the multiple constraints of the tie line plan adjustment. Section 3 calculates the optimal power curve of the cross-region tie line, and analyzes the expansion of the cross-region trading channel demand providing reference for promoting cross-regional consumption of clean energy.

2. UC model with considering the adjustment of the tie line plan

In the traditional optimization scheduling, the UC problem is to determine the resource allocation problem according to the load forecasting level in a certain period, and mainly optimize the unit opening and closing mode and the output level [11]. The goal is to minimize the total cost of the system under certain constraints (including unit operation, start-up and shutdown costs) [12].

In this paper, we hope to achieve the maximum consumption of clean energy by optimizing the generation and transmission resources. So the objective function expression is:

$$\max \text{CleanEnergy} = \sum[(i_{ce}, t), pi(i_{ce}, t, brch)] * PrdMin / 60 \quad (1)$$

Where i_{ce} represents clean energy unit, $pi(i_{ce}, t, brch)$ represents the power of i_{ce} at t point in the region $brch$, $PrdMin$ is constant parameter representing time interval of unit power generation plan.

2.1. System operation constraints

(1) Constraints of thermal unit minimum operation mode.

This constraint indicates that the online capacity and number of online units of unit group in the system cannot be less than a given value.

$$\sum [i | \text{GroupUnitList}(grp, i) = 1, Ui(i, t)] \geq \text{MinOnUnitNum}(grp) \quad (2)$$

$$\sum [i | \text{GroupUnitList}(grp, i) = 1, Pi(i, t)] \geq \text{MinOnUnitCap}(grp) \quad (3)$$

Where unit on-off flag $Pi(i, t)$ and unit power $Pi(i, t)$ are optimizable variables with other parameters. $\text{GroupUnitList}(grp, i)$ represents whether unit i belongs to unit group grp . $\text{MinOnUnitNum}(grp)$ represents the minimum number of on-line units and $\text{MinOnUnitCap}(grp)$ represents the minimum on-line capacity.

(2) Constraints of clean energy power forecast.

$$Pi(wd, t) \leq \text{SingleWindPlantPowerForecast}(wd, t) \quad (4)$$

$$pi(se, t) \leq \text{SingleSunPlantPowerForecast}(se, t) \quad (5)$$

Where $\text{SingleWindPlantPowerForecast}(wd, t)$ represents wind power generation forecast and $\text{SingleSunPlantPowerForecast}(se, t)$ represents photovoltaic power generation forecast.

(3) Constraints of Hydropower generation.

$$\text{sum}[(i,t) | \text{HydroPlantUnitList}(hdp,i), pi(i,t)] * \text{PrdMin}/60 \leq \text{HydroEnergyLimit}(hdp) \quad (6)$$

$$\text{sum}[(i,t) | \text{HydroPlantUnitList}(hdp,i), pi(i,t)] * \text{PrdMin}/60 \geq \text{HydroEnergyLimitDown}(hdp) \quad (7)$$

Where pi is optimizable variable. $\text{HydroPlantUnitList}(hdp,i)$, which is a boolean parameter, represents whether unit i belongs to hydropower unit group hdp . $\text{HydroEnergyLimit}(hdp)$ and $\text{HydroEnergyLimitDown}(hdp)$ respectively indicate the upper and lower limit values of the hydropower group generation.

(4) Constraints of system balance.

$$\sum_{i=1}^I p_i(t) = p_d(t) \quad (8)$$

Where the total power generation of the system is equal to the total power consumption.

(5) Constraints of spinning reserve.

$$\sum_{i=1}^I \bar{r}_i(t) \geq \bar{p}_r(t) \quad (9)$$

$$\sum_{i=1}^I \underline{r}_i(t) \geq \underline{p}_r(t) \quad (10)$$

Where $\bar{r}_i(t)$ and $\underline{r}_i(t)$ respectively represents the upper and lower spinning reserve which unit i can supply at time t . $\bar{p}_r(t)$ and $\underline{p}_r(t)$ respectively represents system demand of the upper and lower spinning reserve at time t .

2.2. Unit constraints

(1) Constraints of unit power.

$$\underline{p}_i u_i(t) \leq p_i(t) \leq \bar{p}_i u_i(t) \quad (11)$$

(2) Constraints of minimum running time and minimum outage time.

$$(V_{t,j}^{\text{on}} - T_j^{\text{min-on}}) \cdot f_1(U_i(t-1), U_i(t)) \geq 0 \quad (12)$$

$$(V_{t,j}^{\text{off}} - T_j^{\text{min-off}}) \cdot f_2(U_i(t), U_i(t-1)) \geq 0 \quad (13)$$

(3) The available state of unit.

$$u_i(t) = 0, t \in T_r \quad (14)$$

Where T_r is the time period of unit maintenance.

2.3. Analysis and modelling of tie line constraints

In this paper, all tie lines is high voltage direct current (DC) lines. All analysis and modelling are based on high voltage direct current (HVDC) lines.

(1) Constraints of tie line capacity

$$0 \leq tieP(tie, t) \leq tiePMax(tie) \quad (15)$$

Where $tiePMax(tie)$ is the tie line capacity and $tieP(tie, t)$ is tie line power at time t .

(2) Constraints of tie line power change rate

$$tieP(tie, t) - tieP(tie, t-1) \leq RampUp(tie, t)\Delta t \quad (16)$$

$$tieP(tie, t-1) - tieP(tie, t) \leq RampDown(tie, t)\Delta t \quad (17)$$

Where $RampUp(tie, t)\Delta t$ and $RampDown(tie, t)\Delta t$ respectively represent upper and lower limits of power change rate. The tie line power change at adjacent time period cannot break the limits.

(3) Constraints of tie line continuous power adjustment direction

In order to protect the DC converter and ensure the smoothness of the DC plan, the increase and decrease of the adjacent time period cannot be adjusted in the opposite direction. Defining the boolean variables $x(tie, t)$, $x^+(tie, t)$, $x^-(tie, t)$ separately, where indicate whether the DC power is changed in each period, whether it changes in the forward direction (increased power), and whether it changes in the reverse direction (reduced power). The Related constraints are as follows:

$$x^+(tie, t) + x^-(tie, t) = x(tie, t) \leq 1 \quad (18)$$

The power of adjacent period cannot be adjusted. The constraints are as follows:

$$x^+(tie, t) + x^-(tie, t+1) \leq 1 \quad (19)$$

$$x^+(tie, t+1) + x^-(tie, t) \leq 1 \quad (20)$$

The value $x^+(tie, t)$ and $x^-(tie, t)$ can be obtained by constraining the change in DC power $tieP(tie, t)$ and by introducing auxiliary boolean variables $z_1(tie, t)$ and $z_2(tie, t)$.

$$tieP(tie, t) - tieP(tie, t-1) \leq M_1 z_1(tie, t) \quad (21)$$

$$x^+(tie, t) \geq z_1(tie, t) \quad (22)$$

$$tieP(tie, t-1) - tieP(tie, t) \leq M_2 z_2(tie, t) \quad (23)$$

(4) Constraints of the time interval of tie line power adjustment

After the DC power is adjusted once, at least a minimum time interval is run smoothly. In order to maintain the stability of the DC plan, after the DC power is adjusted once (single or multiple consecutive periods of rise or fall), at least a minimum interval is smoothly run. The following formula can be obtained with the values of boolean variables $IsTieUp(tie, t)$ and $IsTieDown(tie, t)$:

$$IsTieDown(tie, t) - \sum_{\tau=t+1}^{t+N_T} IsTieUp(tie, \tau) \leq 1 \quad (24)$$

Where N_T is the minimum number of intervals in which the DC line cannot be adjusted.

Constraints are obtained by introducing an additional boolean variable $y(tie, t)$:

$$IsTieUp(tie, t) \geq x(tie, t+1) - y(tie, t) \quad (25)$$

$$IsTieDown(tie, t) \geq x(tie, t) - y(tie, t) \quad (26)$$

$$y(tie, t) \leq x(tie, t) \quad (27)$$

$$y(tie, t) \leq x(tie, t+1) \quad (28)$$

$$y(tie, t) \geq x(tie, t) + x(tie, t+1) - 1 \quad (29)$$

(5) Constraints of interface power flow

$$P_{ij}(t) \leq \overline{P_{ij}} \quad (30)$$

Where P_{ij} and $\overline{P_{ij}}$ represents interface power flow and its limit value.

3. Case study

3.1. Case setting

The actual two regions are selected as the research object. Region 1 is the delivery end with rich clean energy. Region 2 is the receiving end which is load center. The two regions are connected by 3 DC lines. The capacity of each tie line is shown in Table 1. Under the condition that the basic constraints of DC lines are satisfied, the tie line power curve can be freely optimized without increasing the cost of receiving region.

Table 1. The capacity of tie line

Tie Line	Capacity(MW)
Tie line 1	4000
Tie line 2	3500
Tie line 3	1200

3.2. Input data processing

In the model, each power plant is equivalent to one unit. If the capacity is too large, it will be divided into several equivalent units. The Region 1 has 74 million kW of new energy installed capacity, including 308 wind power plants and 506 photovoltaic power stations. 32 million new energy installed at Region 2, including 120 wind power plants and 329 photovoltaic power stations.

The minimum output of the heat supply unit in winter is 50% of its rated capacity. The minimum output of nuclear power unit is 80% of its rated capacity. The minimum output of hydropower unit is 20% of its rated capacity. The minimum output of photovoltaic unit and wind turbine is 0. The maximum output of all units is equal to the unit capacity.

The minimum operating time and minimum outage time of the thermal power unit is 36 hours. These time of nuclear power unit are 2,500 hours. For other types of units, the minimum operating time and minimum outage time are set as 0.

The system load is utilized for the actual load in 2017, and the system spinning reserve is set to 2% of the load.

Regional clean energy forecast electricity uses clean energy generation curve and the proportion of abandoned wind in 2017. The clean energy power of a single plant is predicted to be calculated from the region clean energy power forecast and the installed capacity of a single plant account for the proportion of all such clean energy installed in the region.

3.3. Results analysis

After optimization calculation, the proportion of abandoned wind in Region 1 is 1.62%. Compared with the actual transaction, the proportion of abandoned wind is reduced by 49.56% adding the use of 598 million kWh of wind power, and the maximum consumption of wind power is 5.27 billion kWh.

The proportion of abandoned light in Region 1 is 2.76%. Compared with the actual transaction, the proportion of abandoned photovoltaic is reduced by 39.8%, the power of abandoned wind is reduced by 120 million kWh, and the maximum consumption of photovoltaic is 2.38 billion kWh. Table 2 shows the power values before and after optimization of each tie line.

Table 2. The power values of each tie line before and after optimization

Periods	power before optimization (MW)			power after optimization (MW)		
	Tie line 1	Tie line 2	Tie line 3	Tie line 1	Tie line 2	Tie line 3
1	2400	980	777	3713.857	1800	550.10
2	2400	980	777	3713.857	1800	1105.10
3	2400	980	777	3713.857	1800	1110
4	2400	980	777	3713.857	1800	1110
5	2400	980	777	3713.857	1800	1110
6	2400	980	777	3713.857	1800	1110
7	2400	980	777	3713.857	1800	1110
8	2400	1190	777	3713.857	1800	1110
9	2400	1400	1110	3463.909	1800	1110
10	3000	1400	1110	3463.909	1800	1110
11	3000	1400	1110	3463.909	3000	1110
12	3000	1400	1110	3463.909	3000	1110
13	3000	1400	1110	3463.909	3000	1110
14	3000	1400	1110	3463.909	3000	1110
15	3000	1400	1110	3463.909	3000	1110
16	3000	1400	1110	3463.909	3000	1110
17	3000	1400	1110	3463.909	3000	1110
18	3000	1400	1110	2759.172	1556.25	1110
19	3000	1400	1110	2759.172	56.25	1110
20	3000	1400	1110	2759.172	56.25	1110
21	2400	1400	1110	2759.172	56.25	1110
22	2400	1190	1110	2759.172	56.25	1110
23	2400	980	1110	2759.172	1556.25	1105.10
24	2400	980	777	3713.857	1800	550.10
Electricity (MWh)	64200	29400	23643	81154.93	44137.5	25510.4
Total(MWh)	117243			150802.83		

Corresponding to Table 2, Figure 1 shows tie line power curve before and after optimization. Symbol b represents before optimization and Symbol a represents after optimization.

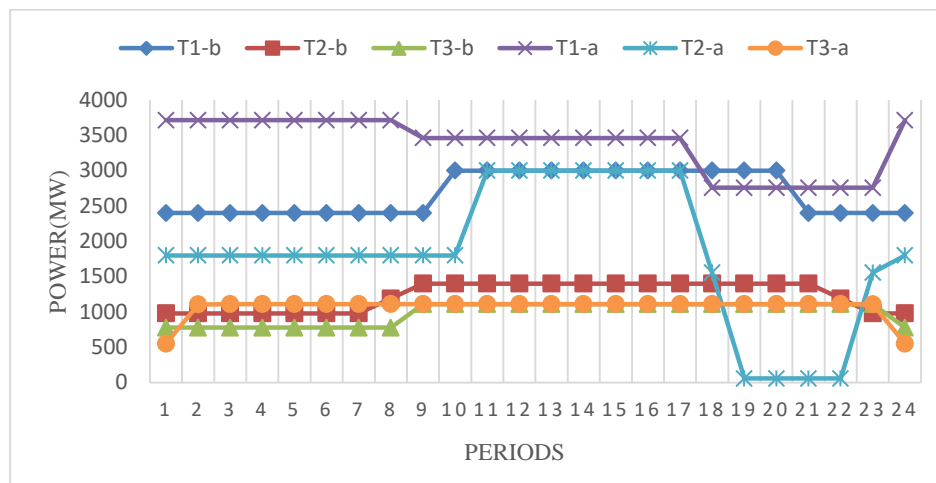


Figure 1. Power curves of tie lines.

According to Table 2 and Figure 1, the capacity of the regional transmission channel is more fully utilized, but the upper limit has not been reached. There is still a lot of room for clean energy consumption.

4. conclusion

In order to promote cross-regional consumption of clean energy, this paper analyzes and models the operational characteristics of tie line considering the DC line polarization adjustment direction constraint, the adjustment rate constraint and the adjustment interval constraint in the traditional unit commitment algorithm. Coordinating the output plans of traditional thermal power and new energy to promote the use of regional transmission channels and maximize the use of clean energy. The study shows that adjusting the tie line plan can maximize the consumption of clean energy according to the characteristics of inter-regional load difference, peak-to-valley difference and time difference.

5. References

- [1] Liu Zhengya, Zhang Qiping and Dong Cun, Efficient and security transmission of wind, photovoltaic and thermal power of large-scale energy resource bases through UHVDC projects, 2014 *Proceedings of the CSEE*. **34(16)** 2513-2522
- [2] Wang Jianhui, Botterud A and Miranda V, Impact of wind power forecasting on unit commitment and dispatch, 2009 *Proceedings of the 8th International Workshop on Large-scale Integration of Wind Power into Power Systems*
- [3] Wang Caixia, and Lu Zongxiang, Unit commitment based on wind power forecast, 2011 *Automation of Electric Power Systems*. **35(7)** 13-17
- [4] Tuiz P A, Philbrick C R and Sauer P W, Wind power day-ahead uncertainty management through stochastic unit commitment policies, 2009 *Proceedings of Power Systems Conference and Exhibition*. 1-9
- [5] Wang Caixia, Qiao Ying and Lu Zongxiang, Day-ahead dispatch mode for wind-thermal power system in low-carbon economy, 2011 *Automation of Electric Power Systems*. **35(22)** 111-117
- [6] Li Pengbo, Luo Rongjun and Mou Chunxiao, Digestion of wind power based on unit commitment, 2015 *Advanced Technology of Electrical Engineering and Energy*. **34(8)** 25-30
- [7] Liu Dewei, Huang Yuehui, Wang Weisheng and Guo Jianbo, Analysis on provincial system available capability of accommodating wind power considering peak load dispatch and transmission constraints, 2011 *Automation of Electric Power Systems*. **35(22)** 77-81
- [8] Yuan Tiejiang, Peng Chaofeng and Mei Shengwei, A partitioning method to enhance accommodation capability of power network with balanced region of wind power, 2015 *Advanced Technology of Electrical Engineering and Energy*. **39(8)** 2129-2134

- [9] Wang Xiuli, Li Jun and Huang Bin, A two-stage optimal dispatching model for provincial and regional power grids connected with wind farms to promote accommodation of wind power, 2015 *Power System Technology*. **39(7)** 1833-1838
- [10] Xu Qian Yao, Kang Chongqing and Jiang Changming, Preliminary analysis on wind power accommodation system from multiple temporal and spatial scale perspective, 2013 *Power System Protection and Control*. **41(1)** 28-32
- [11] Baldick R, The generalized unit commitment problem, 1995 *IEEE Trans. Power Syst.* **10(1)** 465-475
- [12] Carrion M and Arroyo J M, A computationally efficient mixed-integer linear formulation for the thermal unit commitment problem, 2006 *IEEE Trans. Power Syst.* **21(3)** 1371-1378

Acknowledgments

This work was supported by the Science and Technology Foundation of Zhejiang Province Electric Power Company “Research on Key Technologies of Zhejiang Electricity Spot Market Technical Support System” and the Science and Technology Foundation of State Grid Corporation of China “Research and Development of Provincial Electricity Spot Market Operation Deduction Platform”.