Strategies of Daily Economical Dispatch Considering Large-scale Wind Power Integration and Electricity Contract

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Abstract-**In power market environment, before the electrical transaction, the power companies not only consider the bids of power plants, but also pay attention to the original purchase contract with the original power plants. With new energy requirements increase, it is not be neglected for the large-scale wind power integration influences on the power system economical dispatching. Aiming at this goal, based on analysis the values and integration characteristics of wind power, the daily dispatching model was constructed considering the large-scale wind power integration and electricity contract transaction. At the same time, a simplified model is taken for the seeking process. The method of integrated Linear Programming and Dynamic Programming was used to solve the model, and the process became simple and credible. The analysis of case proves this approach is reasonable, correctable and practicable.**

Keywords-Electricity market, Large-scale Wind Power, Generation scheduling, Linear Programming, Dynamic Programming

I. INTRODUCTION

In the electricity market environment, it is very important how to ensure the power system generation capacity and maintain the power supply safety. The power system would face the collapse danger of lacking generation capacity. It is proved firmly by the California's crisis of power supply at the beginning of 2001.One key way of keeping the power system operation safety and steady is signing power contracts with the power plants and maximizing the benefit of each partner in the market. So, it is very necessary to keep contract transaction in the electricity market[1].

The disposable fossils energy depletion crisis daily, it is inevitable choice of finding the new big-scale energy source. Developing the wind power is a feasibility way. In the traditional economical dispatching, the proportion of wind power is very small in the whole capacity of power grid. It is usually only a few percent. It is dealed with the negative load. But, with the development of wind power scale, the programming of wind power capacity is nearly same as the total load requirements in some area, such as Xingjiang and Gansu in China[2]. The influence of wind power is growing on the power system. In the future, the influence and requirements of large-scale wind are not neglected during the economical dispatch.

At present, the study on economical dispatch has substantial results, such as the network lost minimizing, coal consumption minimizing, purchase cost minimizing , electricity contract transaction cost minimizing, the influence of wind power. But, in electricity market, the two important factors of wind power generation and contract are seldom considered at the same time. Thus, study on it has extremely important actual significance. The key point influencing wind power dispatching is the randomness of wind power output. The paper [3-7] has deep study on it and obtains important progress. In this paper, based on them, the question of strategies for the daily economical dispatch considering large-scale wind power integration and electricity contract is explored and analyzed.

II. EVALUATION OF THE WIND POWER COST

The wind energy cost mainly includes three aspects[2]: one is increase of the system reserve capacity cost for the power output differences from the predicted output between the actual output with wind power randomness; another is lost wind loss because of the dispatching congestion with the wind power penetration limit; the other is average operation cost of wind power investment and maintenance.

In literature[3], the way based on the credibility of wind power output predicted is used to evaluate the increasing of system spinning reserve capacity cost. The credibility evaluation is strong randomness. It is difficult to apply actually. In fact, the randomness of wind power output has certain probability, the probability may be used to statistic calculation[8]. So, the compensation cost of system spinning reserve capacity for wind power may be defined as:

$$F_{WCRt} = \sum_{j=1}^{J} C_{Rt}(1-\eta_{jt})P_{Wjt}' \qquad (1)$$

Where: F_{WCRt} is the spinning reserve capacity compensation cost of wind power in period t, million￥; C_{Rt} is the spinning reserve capacity compensation price in period t, million￥/MW; η_{jt} is the probability of predicted output P_{Wjt}' (The max is $\overline{P_{Wjt}'}$) from wind farm j in period t; J is the number of wind farm in whole the grid. One wind farm is seen as one unit.

For the question of the wind power penetration limit, because of no losing wind energy in dispatching process, the

wind power must be used as possible. Thus, the influence of wind power penetration limit is ignored.

In one period t, the average operation investment and maintenance cost of wind power is linear with the wind power output. Then, it is defined as: $F_{WOPt} = \sum_{j=1}^{J} C_{Wjt} P_{jt}$. Where: C_{Wjt} unit generation cost of wind farm j in period t, P_{jt} is actual power output.

III. BUILDING THE MATHEMATICS MODELING

A. Market base

Power company is the single buyer. Only thermal unit and large-scale wind power unit in the power grid.The thermal unit has unit predicted marginal cleaning price in one period, the thermal unit contract volume is performed with the designed contract price.The unit competitive is perfect, no coordination between the units.Everyday has 48 bid periods.

B. Mathematical model

Based on the dispatching requirements, the objective function includes thermal unit purchasing cost and wind unit generation cost, may be defined as the follow:

$$F_{cost} = \min \sum_{t=1}^{48} [\sum_{i=1}^{I} [U_{it}(C_i P_{it} + C_t' P_{it}') + S_i(U_{it} - U_{i(t-1)})] + \sum_{j=1}^{J} [C_{Wjt} P_{jt} + C_{Rt}(1-\eta_{jt})P_{Wjt}']]] \quad (2)$$

Where:

F_{cost} is minimum payment of the power company,(¥); t is the bidding period t; I is total number of thermal unit; i: the thermal unit i; U_{it} is commitment state (1 or 0) of thermal unit i in period t; C_i is contract price of unit i, (¥/MW); P_{it} is contract volume of unit i in period t,(MW); C_t' (CPP) is predicted marginal cleaning price in period t,(¥/MW); P_{it}' is competitive bidding volume of unit i in period t(MW); S_i is start up and stop cost of unit i.

The constraints for the problem are:

1) System power balance in period t:

$$\sum_{i=1}^{I} U_{it}(P_{it} + P_{it}') + \sum_{j}^{J} P_{jt} = Q_t \quad (3)$$

2) Daily total competitive bidding volume:

$$Q_c' = \sum_{t=1}^{48} \sum_{i=1}^{n} U_{it} P_{it}' \quad (4)$$

3) Daily total contract volume:

$$Q_c = \sum_{t=1}^{48} \sum_{i=1}^{n} U_{it} P_{it} \quad (5)$$

4) Daily system total load balance:

$$Q = \sum_{t=1}^{48} Q_t = Q_c + Q_c' \qquad \alpha Q \le Q_c \quad (6)$$

5) Unit generation limits:

$$\underline{P_m} \le P_{mt} + P_{mt}' \le \overline{P_m} \quad i, j \in m, P_{jt}' = 0 \quad (7)$$

The wind power unit has no contract volume

6) Generating volume limit of the unit k which must be operated: $P_{kt} + P_{kt}' \ge P_{kt0}$ \quad (8)

Using the equitation $\eta = (Pm_i / Pmd_i)/(30 - Dr)$ is able to calculate the index，which the unit i must be operated in a day. Using the same method may calculate the index, which the unit i must be operated in a month yet. Then the monthly contract volume of a unit may be dispatched according to the yearly contract volume and real load demand.

7) Power flow limits of transmission line in period t:

$$P_{lt\min} \le A(P_{kt} + P_{kt}') \le P_{lt\max} \quad (9)$$

8) Minimum run-time and stop-time limits (h): $t_{irun} \ge \min t_{irun}$
$$t_{istop} \ge \min t_{istop} \quad (10)$$

Daily up and down frequency limits in a day:
$$N_i \le N_{imax} \quad (11)$$

9) System total spinning reserve capacity in period t:

$$\sum_{i=1}^{n} U_{it} \overline{P_i} = Q_t + Q_{rt} \quad (12)$$

Where: Q_t is system load in period t , (MW); Q_{ct}' is daily total contract volume, (MW); Q_c' is total contract volume in period t , (MW); Q is daily system total load, (MW); α is adjustment factor of daily total contract volume, usually is 80%; $\underline{P_m}$ is down limit of generation unit m,(MW); $\overline{P_m}$ is up limit of generation unit m,(MW); P_{kt0} is minimum generating volume of unit k which must be operated in period t (MW); η is index,which unit i must be operated in a day; Pm_i: the residual monthly generating volume of unit i, (MW); Pmd_i: the daily maximum generating volume of unit i, (MW); Dr: number of the residual generating days in a month; P_{ltmin} , P_{ltmax} is power flow limits of transmission line l in period t,(MW); A is the DC power flow transfer matrix, and may be calculated with the grid branch parameters; Q_{rt} System total spinning reserve capacity.

IV. SIMPLIFYING AND SOLVING THE MODEL

Evidently, the mathematic model described in equation (2) is a nonlinear dynamic programming optimization model with the mixed-integral variables and constraints. It is difficult to solve this model directly. For the seeking process simply and practically, it is necessary to approximately simplify the model and constraints in certain scope. Using the similar seeking method as in the literature [1], changing the network safety constrains as the output linear constrains of all units, the dynamic programming is transformed into static programming of each period. Then, using the linear programming simplifies the seeking process. This avoids the dimension-disaster from the dynamic programming. After setting the variable of commitment state U_{it} as 1, the time constraint is shorten in every period. In this way, the equation (1) is simplified as follow:

$$F_{costt} = \min[\sum_{i=1}^{I} [C_i P_{it} + C_t' P_{it}'] + \sum_{j=1}^{J} [C_{Wjt} P_{jt} + C_{Rt}(1-\eta_{jt})P_{Wjt}']] \quad (13)$$

Correspondingly:
The constrain(2) is simplified as:

$$\sum_{i=1}^{I} (P_{it} + P_{it}') + \sum_{j=1}^{J} P_{jt} = Q_t \quad (14)$$

The constrains (4-5) are simplified as:

$$Q_{ct}=\sum_{i=1}^{n}P_{it}\; \alpha Q_{t}\le Q_{ct}\; ; \qquad Q=\sum_{t=1}^{48}Q_{t}=\sum_{t=1}^{48}Q_{ct}+Q_{ct}^{'}\; ; \qquad Q_{t}=\sum_{i=1}^{n}P_{it} \qquad (15)$$

The constrain(12) is simplified as:

$$\sum_{m=1}^{M}\overline{P_{m}}=Q_{t}+Q_{rt} \qquad (16)$$

So, the whole seeking process is separated into two phases. One is finding unit commitment and the other is calculating the correspondingly power volumes.

Firstly, evaluating the wind power output with its probability, using the linear programming seeks the competitive bidding volumes, contract volumes and spinning reserve volumes of the units from the objective function(13) and the constraints (14-16), (7-9). Then the preliminary unit commitment is found in each period.

Secondly, the unit's start-stop is fixed through the results of the first step and constraints (10,11) with minimizing cost principle. After washing out the units of smaller total generation volumes or no generation volumes in each period, reusing the linear programming seeks the newly unit commitment.

Thirdly, based on the second step and the minimized cost principal, the half-stop units not generating in all periods are adjusted. Some units do not satisfy the generation volume limits, but they affect the whole system greatly and may lead the whole system power insufficiently if these units are washed out. It is the best way to adjust the volume of these units to the rated minimum generation volume and let them generate. Finally, the unit commitment is fixed.

Fourthly, based on the fixed unit commitment, corresponding constraints and linear programming, further seeking for the competitive bidding volumes, contract volumes and spinning reserve volumes, the total competitive bidding volumes $Q'c$, total contract Qc volumes and correlative costs are calculated.

V.   SIMULATION AND CASE ANALYSIS

The simulation is based on the IEEE30 bus system data. Hypothesis it includes 7 thermal units(TH), 4 wind power unit(WU) , the main running parameters of the units is in Table.1-2. In the case, $C_{Rt}=C_{t}^{'}/3$, α is 80%. In each period, Q_{Rt} is 300MW and the TH6 must be operated.

The simulating results of WU output, total volumes and competitive bidding volumes in each period of the next transaction day are shown as the corresponding curves in Figure.1-3. The predicted total cost is ￥1764.02 million, including ￥1358.22million total TH contract cost, ￥145.04 million TH competitive bidding cost, ￥199.22 million WU cost,￥61.53 million WU spinning reserve cost.

Seeing curves in the Figure.1, all WU output is almostly its max output in every period. The wind energy is used perfectly. That satisfied the new energy utility rules. Seeing

curves in the Figure.2 and 3, the low cost unit output is more than the higher. Especially, TH 7 only generats in serveral load spike periods. This meets the social requirments of energy saving and GHGs reduction.

If the market degree improves, the contract volumes decrease and the competitive bidding volumes increase, it is essential to decrease the factor α. If the α decreases to 0.4 and all parameters are not changed, using the method in this paper, the predicted total cost would be ￥1310.07 million. The total cost is ￥453.95 million more than the situation of α=0.8. It shows the higher the market degree the more saving the total cost of the power company and optimizing the social resource.

VI.   SUMMARIES

In this paper, at first, the wind power operation cost evaluation model was given. At the same time, the optimzation dispatching model considering wind power and the thermal power was put forward. Then, the method of integrated Linear Programming and Dynamic Programming was used to seeking the model. This method solves the difficult of seeking the nonlinear dynamic programming model containing the mixed-integral variables and constraints for large-scale power grid include wind power. The simlulation and case analysis prove the correctness and practicability of the method in this paper powerfully. It accords with the practical market theory social requirements.

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TABLE I.   MAIN RUNNING PARAMETERS OF TH

Unit	C_i	$\overline{P_i}$	$\underline{P_i}$	C_i''	mintistop	Nimax
1	264	300	80	26	4	1
2	268	240	50	27	3	1
3	272	240	50	28	3	2
4	300	240	40	31	3	2
5	312	160	30	32	3	2
6	360	160	30	35	2	2
7	400	80	40	40	2	2

TABLE II.   MAIN RUNNING PARAMETERS OF WU

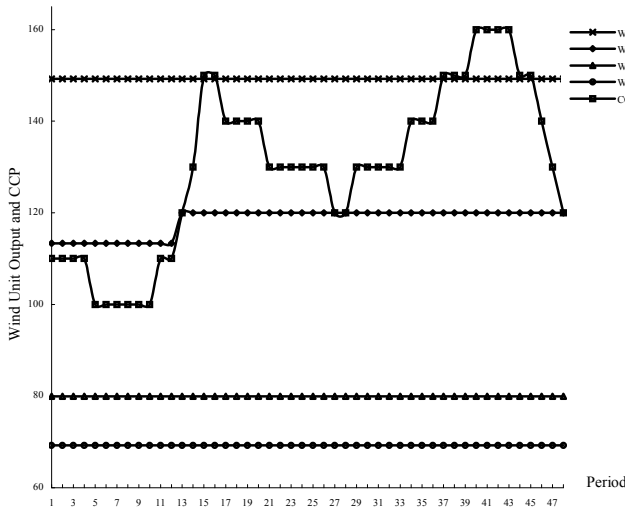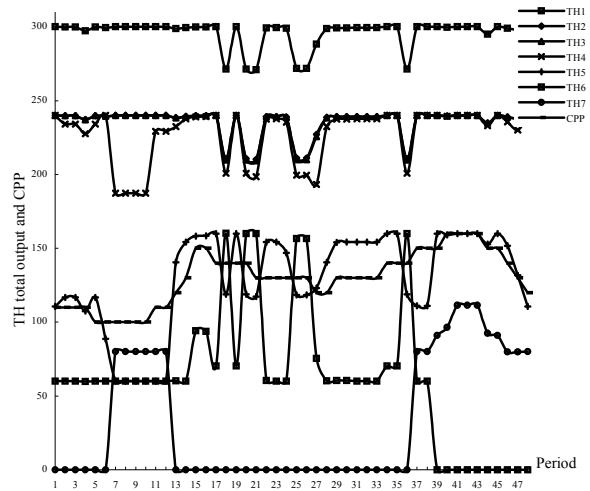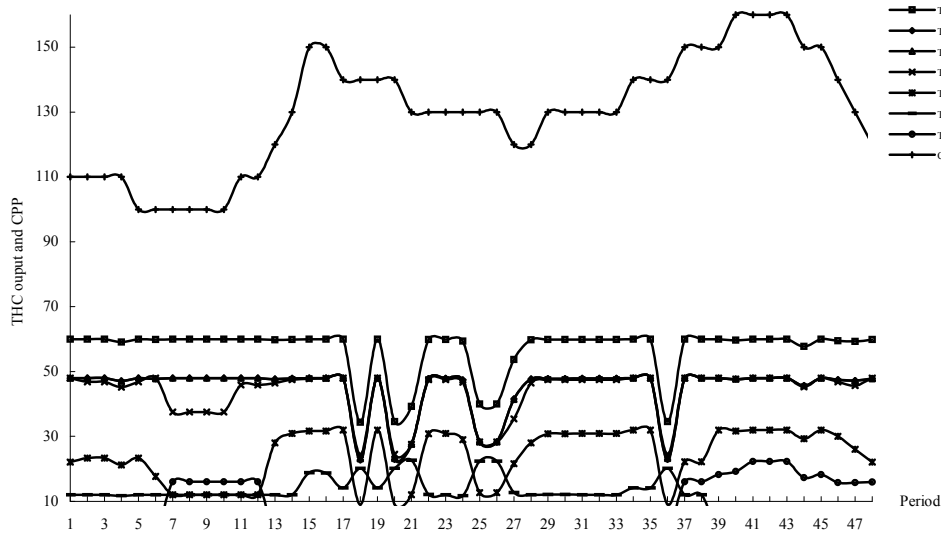| Unit	C_{Wjt}	$\overline{P_j}$	$\overline{P_{Wjt}}'$	$\underline{P_j}$
1	83	200	150	10
2	99	150	120	20
3	112	100	80	30
4	122	80	70	30

Figure 1. Wind Unit Output

Figure 2. Thermal Unit total output

Figure 3. Thermal Unit Competitive output and CPP