발전기 기동정지 계획에 적용되는 불확실한 부하곡선에 대한 통계적 분석

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Stochastic Analysis of the Uncertain Hourly Load Demand Applying to Unit Commitment Problem

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Abstract: In this paper, the effects of the uncertain hourly load demand are stochastically analyzed especially by the consideration of the average over generation of the Unit Commitment(UC) results. In order to minimize the effects of the actual load profile change, a new UC algorithm is proposed. The proposed algorithm calculates the UC results with the lower load level than the one generated by the conventional load forecast. In case of the worse load forecast, the deviation of the conventional UC solution can be overcome with the lower load level and the more hourly reserve requirements.

The proposed method is tested with sample systems, which shows that the proposed method can be used as the basic guideline for selecting the potimal load forecast applying to UC problem.

Keywords: load demand, load forecast, unit commitment, generation scheduling, economic dispatch, power system

I. Introduction

Unit Commitment (UC) is an important optimization task to determine the unit start up and shut down schedules in the scheduling of power system operations. The objective is to minimize the overall system operation cost over the scheduling time period while meeting the system load demands and other constraints.

A number of earlier studies of generation scheduling have successfully developed various mathematical algorithms such as the priority list method, DP (Dynamic Programming), Lagrangian relaxation, and artificial intelligence techniques, etc [1-3]. In order to simplify the complexity of the problem, all of the UC algorithms adopt the following assumption. The hourly load demand is identical to the load pattern of the future. However, the actual load pattern cannot be perfectly predicted due to the social, environmental, cultural and atmospheric reasons. Therefore, the generation schedules yielded under that assumption have the following major problems. The first is infeasibility to the practical system by reason of the unpredictable changes of the actual load demand. The second is the over-generation problem caused by unseasonable weather. The third is that the expensive peaker units can be committed unnecessarily in the practical circumstances. The forth is that the original UC solution can no longer be the real optimal solution on account of the actual commitment changes. Since the accuracy of the hourly load profile is closely related with the optimality of the UC solution, an on-line UC algorithm must be developed in order to solve these problems. However, this causes the extreme complexity of a calculation algorithm considering numerous constraints. Therefore, conventional studies focus their approaches on the solution refinement method of the pre-calculated UC results.

In this paper, the effects of the uncertain hourly load demand are stochastically analyzed especially by the consideration of the average over generation of the UC results. In order to minimize the effects of the actual load profile change, a new UC algorithm is proposed. The proposed algorithm calculates the UC results with the lower load level than the one generated by the conventional load forecast. In case of the worse load forecast, the deviation of the conventional UC solution can be overcome with the lower load level and the more hourly reserve requirements.

II. Mathematical Model

Unit commitment is an optimization problem to minimize the total fuel cost over the study time period while satisfying the system load demands and constraints. This cost includes unit fuel cost for generating power and the start up cost. Constraints consist of system load demand, spinning reserve, unit generation limits, minimum up / down times, ramp rate limits and schedule constraints, etc. The considered constraints and the notations used in this paper are shown below:

F : total operation cost of the entire system

P_i^t : power generation of unit i at hour t

$F_i(P_i^t)$: fuel cost of unit i when generating power is equal to P_i^t

N : total number of units

M : total study time span in hours

St_i^t : commitment state of unit i at hour t (1 or 0)

H_i^t : time duration for which unit i has been on/off at hour t

$H_i^t > 0$ if $St_i^t = 1$

$H_i^t < 0$ if $St_i^t = 0$

$Su_i(H_i^{t-1})$: hours off start up cost of unit i after H_i^{t-1} hours off

L_t : system load demand at hour t

$P_{i,\min}$:rated upper generation limit of unit i

$P_{i,\max}$: rated lower generation limit of unit i

R_t : generating reserve requirement at hour t

Mu_i : minimum-up time of unit i

Md_i : minimum down time of unit i

C_i^t : constrained generating capacity of unit i at hour t

Rp_i : ramp rate limit of unit i (MW/h)

FX_i^t : fixed power generation of unit i at hour t

MR_i^t : must-run state of unit i at hour t (1 or 0)

OT_i^t : outage state of unit i at hour t (1 or 0)

NC_i : no load cost of unit i

FC_i : full load average cost of unit i

UT_i : start up time of unit i

DT_i : shut down time of unit i

L_i^{new} : lower limit of system load demand at hour t

L_t^a : actual load demand at hour t

R_t^{new} : generating reserve requirement at hour t considering the permitted load forecast error

TC_i : turbine start up cost of unit i

CH_i : boiler cooling time of unit i (hour)

BC_i : boiler start up cost of unit i

SMC_i : start up management cost of unit i

The objective function of unit commitment problem is to minimize the total generation cost:

$$F = \sum_{t=1}^{M}\sum_{i=1}^{N}[\, St_i^t F_i(P_i^t) + St_i^t(1 - St_i^{t-1})\, Su_i(H_i^{t-1})] \quad (1)$$

where,

$$Su_i(H_i^t) = TC_i + (1 - e^{-t/CH_i}) \times BC_i + SMC_i$$

The constraints for the problem are given by

(C.1) System load demand

$$\sum_{i=1}^{M} P_i^t = L_t^{new} \qquad t = 1, \ldots, M \quad (2)$$

(C.2) Hourly reserve requirements

$$\sum_{i=1}^{M} St_i^t Rp_i \ge R_i^{new} \qquad t = 1, \ldots, M \quad (3)$$

(C.3) Unit generation limits

$$C_{i,\min} \le P_i^t \le C_{i,\max} \quad i = 1, .., N \;\; t = 1, .., M \quad (4)$$

(C.4) Unit minimum up/down times

$$[H_i^{t-1} - Mu_i] \times [St_i^{t-1} - St_i^t] \ge 0 \quad (5)$$

$$[-H_i^{t-1} - Md_i] \times [St_i^t - St_i^{t-1}] \ge 0 \quad (6)$$

(C.5) Ramp rate limits for unit constrained generating capability

$$|C_i^t - \bar{C}_i^{t-1}| \le Rp_i \quad (7)$$

(C.6) Ramp rate limits for unit generation changes

$$|P_i^t - P_i^{t-1}| \le Rp_i \quad (8)$$

(C.7) Start up constraint

$$P_i^t = P_{i,\min}, \quad \forall i \; st. \; St_i^{t-1} = 0, \; St_i^t = 1 \quad (9)$$

The relations of the lower limit of system load demand (L_i^{new}) to the system load demand (L_i) and the generating reserve requirement considering the permitted load forecast error (R_i^{new}) to the generating reserve requirement (R_i) are as follows:

$$L_i^{new} = L_i \times (1 - \frac{E_{LF}}{2} \times 0.01) \quad (MW) \quad (10)$$

$$R_i^{new} = L_i \times 0.01 \times \left(R_i + \frac{E_{LF}}{2} \right) \quad (MW)$$

$$R_i^t = \frac{L_i \times 0.01 \times \left(R_i + \frac{E_{LF}}{2} \right)}{L_i^{new} \times 0.01} \quad (\%) \qquad (11)$$

$$= \frac{R_i + \frac{E_{LF}}{2}}{1 - \frac{E_{LF}}{2} \times 0.01} \quad (\%)$$

where, E_{LF} is the maximum permitted load forecast error rate.

The graphical relations of (10) and (11) are depicted in the following Fig. 1.

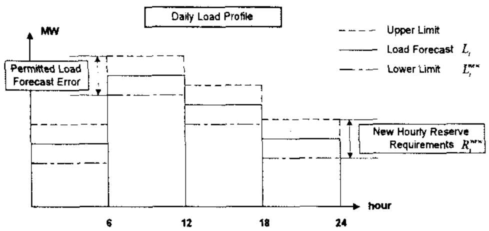

Fig. 1 The normal load forecast vs. the actual uncertain load demand

Considering the permitted error rate E_{LF}, the lower limit of the system load demand and the new reserve requirement should be eq. (10) and (11) respectively as shown in the above Fig. 1. Therefore, the UC results produced by the proposed UC formulation can be adapted to the unpredictable load forecast.Considering the permitted error rate E_{LF}, the lower limit of the system load demand and the new reserve requirement

III. Case Study

The proposed algorithm has been tested with sample systems. The generator data are the same as used in reference [1]. The load demand and system reserve requirement in the test cases are given in Table 1 ~ 2.

Table 1. Load demand in test cases

Hr	Load (MW)	Hr	Load (MW)	Hr	Load (MW)
1	2070	9	2420	17	2520
2	1880	10	2540	18	2340
3	1820	11	2600	19	2380
4	1770	12	2630	20	2260
5	1890	13	2780	21	2320
6	2020	14	2840	22	2110
7	2160	15	2810	23	2030
8	2310	16	2740	24	2090

Table 2. System reserve requirement

Hr	Reserve %	Hr	Reserve %	Hr	Reserve %
1	5	9	6	17	6
2	5	10	6	18	6
3	4	11	7	19	6
4	4	12	7	20	6
5	5	13	7	21	6
6	5	14	7	22	5
7	6	15	7	23	5
8	6	16	7	24	5

This paper deals with 6 test cases, and Table 3 shows the simulation condition for each case.

Table 3. Test cases

Case	$E_{LF}(\%)$
1	0%-Original L_t is used
2	1 %
3	2 %
4	3 %
5	4 %
6	5 %

The results of each case are shown in Table 4 ~ 5. The test results are yielded by adapting 60,000 random load profiles to each test case. Under such condition, Average Over Generation (AOG) and Average Under Generation (AUG) are calculated and listed in the following tables.

Table 4 Average Over Generation (MW) per each stage

Case \ E_{LF}	1%	2%	3%	4%	5%
1	2.88	5.77	8.67	11.53	14.38
2	0.0	0.16	2.88	5.75	8.61
3	0.0	0.0	0.0	0.15	2.92
4	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0

Table 5 Average Under Generation (MW) per each stage

Case \ E_{LF}	1%	2%	3%	4%	5%
1	2.87	5.76	8.63	11.55	14.39
2	11.53	11.59	14.43	17.36	20.16
3	22.99	22.99	22.99	23.12	25.91
4	34.53	34.53	34.54	34.59	34.59
5	46.07	46.07	46.08	46.13	46.13
6	57.73	57.73	57.74	57.80	57.80

As shown in Table 4, the over generation problem exists only in the upper right triangular region. This means that the deviation of the conventional UC solution can be overcome with the lower load level (L_i^{new}) and more hourly reserve requirements (R_i^{new}). Therefore, if the maximum permitted error of the load forecast is known, L_i^{new} and R_i^{new} should be adapted for the UC optimization problem to reduce over generation problem.

Comparing Table 5 with Table 4, AUG is distributed normally than that of AOGs. Though, AUG of Case 1 is rather sensitive than that of others. It means that the proposed method does not influence on AUG heavily. However much the amount of AUG may be, the shortage of the total generation can be compensated by the system reserve requirement. Therefore, it is expected that the proposed method can be used as the basic guideline for selecting the optimal load forecast applying to UC problem.

IV. Conclusions

In this paper, the effects of the uncertain hourly load demand are stochastically analyzed especially by the consideration of the AOG and AUG results. In order to minimize the effects of the actual load profile change, a new UC algorithm is proposed. The proposed algorithm calculates the UC results with the lower load level than the one generated by the conventional load forecast. In case of the worse load forecast, the deviation of the conventional UC solution can be overcome with the lower load level and the more hourly reserve requirements.

Therefore, it is expected that the proposed method can be used as the basic guideline for selecting the optimal load forecast applying to UC problem.

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