Generator Maintenance Scheduling Considering Air Pollution Based on the Fuzzy Theory

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Abstract

A new technique using a search method which is based on fuzzy multi-criteria function is proposed for generator maintenance scheduling which considering the air pollution. Not only minimization of probabilistic production cost and maximization of system reliability level but also air pollution are considered for fuzzy multi-criteria function. To obtain an optimal solution for generator maintenance scheduling under fuzzy environment, fuzzy multi-criteria relaxation method(fuzzy search method) is used. The practicality and effectiveness of the proposed approach are demonstrated by simulation studies for a real size power system model.

1. Introduction

The primary function of an electric power system is to provide electrical energy to its customers as economically as possible and with an acceptable degree of continuity and reliability.

It is, however, impossible to predict load exactly. A proper supply reliability all the time is not easy. Practically, the development of industrial utility has made the size of generation system huge and the system structure has been very complex. Therefore, problems about operation and planning of generation system are complicated[1,2].

Generator maintenance scheduling problem is an important planning problem that effects both economy and reliability for operation and planning of generating systems. Optimal maintenance scheduling is able, not only to raise supply and reserve rate, but also to postpone the period of construction of generators. And also, construction cost of generators, production cost and maintenance scheduling cost can be reduced. The important point of generator maintenance scheduling is how to choose the objective function, and until now, maintenance scheduling problem has been built using the following objective functions [3-5] ;

(1) Generation Cost Minimization Method
(2) Levelized Risk Method
(3) Levelized Reserve Method
(4) Multi-criteria Functions Method

Additionally, recently methods for considering the capacity of transmission line have been proposed in [6,7].

In the present study, we proposes the new method for generators maintenance scheduling considering air pollution constraint using fuzzy search method has been developed by the authors[8-11]. It is expected that more flexible solution can be obtained because fuzzy set theory that can reflect the subjective decision of decision-maker is used in this study[7-11]. With extending the fuzzy search method has been already developed by the authors[8-11], generator maintenance scheduling considering the effects of SO_2 and NO_x of air pollution of thermal power generators is proposed in this paper. The practicality and effectiveness of the proposed approach are demonstrated by simulation studies of a real size power system model.

2. Fuzzy search method

The fuzzy decision set D resulting from fuzzy sets of p fuzzy constraints, $C_1, C_2, \cdots, C_p$ and fuzzy sets of q fuzzy goals, $G_1, G_2, \cdots, G_q$ is as intersection defined as follows:

$$D = \left(\bigcap_{i=1}^{p} C_i\right) \cap \left(\bigcap_{j=1}^{q} G_j\right) \qquad (1)$$

The membership function μ_D resulting from the membership function of fuzzy sets of goals and constraints is defined as follows [12]:

$$m_D(x) = \min[\min_{i=1\sim p} m_{C_i}, \min_{j=1\sim q} m_{G_j}] \qquad (2)$$

where, min is an abbreviation of minimum.

If the fuzzy mathematical programming problem consists of finding maximum point of the membership function of the fuzzy decision set D, the optimal solution can be obtained as:

$$m_D(\mathbf{X}^*) = \max\ m_D(\mathbf{X}) \qquad (3)$$

Where, $\mathbf{X}^*$ is the optimal decision solution, and max is an abbreviation of maximum.

The vector form in Eq.(3) can be rewritten as :

$$m_D(X_1^*, X_2^*, .., X_N^*) = \max_{X_1,..., X_N} m_D(X_1, X_2, ..., X_N) \qquad (4)$$

In order to solve this problem by using the fuzzy search method, the principle of optimality can be applied after Eq.(4) can be reformulated as:

$$\begin{aligned} m_D(X_1^*, X_2^*,.., X_N^*) &= \max_{X_2,...,X_N} [\max_{X_1}\{\min(m_D(X_1), m_{F2}(X_2) \\ &,..., m_{FN-1}(X_{N-1}), m_{FN}(X_N))\}] \\ &= \max_{X_2,...,X_N} [\min\{m_D(X_1^*), m_{F2}(X_2),..., \\ & m_{FN-1}(X_{N-1}), m_{FN}(X_N)\}] \end{aligned} \quad (5)$$

where, X : decision variable,

F=G+C (algebraic sum of fuzzy sets)

We can rewrite Eq.(5) as:

$$m_D(X_1^*, X_2^*,.., X_N^*) = \max_{X_n,..., X_N} [\min\{m_D(X_1^*, X_2^*,.., X_{n-1}^*), m_{Fn}(X_n),.., m_{FN}(X_N)\}] \quad (6)$$

And, we can also rewrite Eq.(6) as:

$$m_D(X_1^*, X_2^*,.., X_n^*) = \max_{Xn} [\min\{m_D(X_1^*, X_2^*,.., X_{n-1}^*), m_{Fn}(X_n)\}] \quad (7.a)$$

$$m_D(S_n) = \max_{Xn} [\min\{m_D(S_{n-1}), m_{Fn}(X_n))\}] \quad (7.b)$$

where, S_n= f(S_{n-1}, X_{n-1}) n=1,2, ….N

S : state variable

f : state transition function

3. The formulation based on fuzzy search method

3.1 Objective functions

(1) Minimization of probabilistic production cost F as:

$$\begin{aligned} &\text{Minimize } F\{E_{in}, \Phi_i(U_{in})\} \\ &= \sum_{n=1}^{NT} \sum_{i=1.}^{NG} \{A_i E_{in} + B_i T \Phi_i(U_{in})\} \quad [\$] \end{aligned} \quad (8)$$

where, A_i is one dimensional coefficient of fuel cost function[$/MWh], and B_i is constant of fuel cost function[$].

$$E_{in} = (1 - q_i) T \int_{ui-1}^{ui} \Phi_{in-1}(X) dX \quad [\text{MWh}]$$

E_{in} : probabilistic generation energy of #i unit at #n stage

T : total period for study [hours]

i : number of the economic order of generators

u_i= C_1+C_2+· · ·+C_i [MW]

C_i: capacity of #i unit

u_0=0

ϕ_{in}: effective load duration curve

q_i: forced outage rate of #i unit

Given aspiration level of decision-maker for the probabilistic production cost Eq.(8) can be represented as fuzzy goal function form as :

$$F\{E_{in}, F_i(U_{in})\} \leq Z_{01} \quad (9)$$

where, Z_{01} : aspiration level of decision-maker for the production cost

(2) Minimization of maximum $LOLP_n$

If $LOLP_n$ presents the loss of load probability of power system at #n stage, the objective as to minimize the LOLP of time stage that has maximum LOLP defined as:

$$\begin{aligned} &\text{Minimize } Z_2 = \max(LOLP_n) \\ &= \max\{\Phi_{NGn}(U_{NGn})\} \quad [\text{pu}] \end{aligned} \quad (10)$$

And also, Eq.(10) can be to represented as fuzzy goal function form as:

$$Z_2 \gtrsim Z_{02} \quad (11)$$

where, Z_{02} : aspiration level of decision-maker for LOLP

(3) Minimization of maximum $EDNS_n$

And also, as like as the LOLP, when $EDNS_n$ presents the expected demand not served of power system at #n stage, the objective as to minimize the EDNS of the stage that has maximum EDNS defined as:

$$\begin{aligned} &\text{Minimize } Z_3 = \max(EDNS_n) \\ &= \max\{T \int_{U_{NGn}}^{\infty} \Phi_{NGn}(X) dX\} \quad [\text{MWh}] \end{aligned} \quad (12)$$

And also, Eq.(12) can be to represented as fuzzy goal function form as:

$$Z_3 \gtrsim Z_{03} \quad (13)$$

where, Z_{03} : aspiration level of decision-maker for EDNS

(4) Minimization of air pollution

If AP_n means the total air pollution of SO_2 and NOx that occurr from thermal power generators operating at #n stage, the objective as to minimize the air pollution volume of time stage that has maximum air pollution volume defined as:

$$\begin{aligned} &\text{Minimize } Z_4 = \max(AP_n) \\ &= \max\{\sum_{i=1}^{NG} TMW_i(SO_{2in} + NO_{Xin}) E_{in}\} \quad [\text{ppm}] \end{aligned} \quad (14)$$

where, TMW_i: necessary fuel consumption rate for a unit generating energy of the #i unit [ppm/Ton]

SO_{2in}: discharge density of SO_2 of #i unit [ppm/Ton]

NO_{2in}: discharge density of NOx of #i unit [ppm/Ton]

And also, Eq.(12) can be to represented as fuzzy goal function form as:

$$Z_4 \gtrsim Z_{04} \quad (15)$$

where, Z_{04} : aspiration level of decision-maker for air pollution criterion

3.2 Constraints

(1) Boundary conditions

$$\begin{aligned} &\mathbf{X(1)} = \underline{\mathbf{0}} \\ &\mathbf{X(T+1)} = col[MD_1, MD_2, MD_3,...., MD_{NG}]^T \end{aligned} \quad (16)$$

Where, $\underline{\mathbf{0}}$: zero vector

MD_i: time period asked for maintenance of #i unit

(2) Constraints for maintenance possible time period

$$U_i(t) = \begin{cases} 0 & t < MS_i \;\; or \;\; t > MF_i + MD_i \\ 1 & MS_i \le t \le MF_i + MD_i \end{cases} \qquad (17)$$

where, MS_i : starting time for maintenance of first possible maintenance time period of #i unit

MF_i : starting time for maintenance of last possible maintenance time period of #i unit

(3) Maintenance crew constraint

$$\sum_{i \in P_k} U_i(t) \le 1 \qquad (18)$$

where, P_k : set of generators at #k generating plant

(4) Constraint of maintenance equipments

$$\sum_{i=1}^{NG} U_i(t) \cdot M_{kli} \le MA_k(t) \qquad (19)$$

where, k: the number of the kinds of maintenance equipment (k= 1,2, ..,K)

l: number of maintenance scheduled time of #i unit

$MA_k(t)$: amount of #k maintenance equipment available within #t stage

M_{kli}: amount of #k maintenance equipment within #l maintenance time period of #i unit

4. Establishment of membership functions

(1) Membership function of fuzzy set for the production cost is defined as:

$$\mu_C\{X(t-1), u(t)\} = \begin{cases} 1 & : \Delta C(\cdot) \le 0 \\ e^{-W_C \, \Delta C\{X(t-1), u(t)\}} & : \Delta C(\cdot) \rangle 0 \end{cases} \qquad (20)$$

where, $\mu_c(\cdot)$: membership function of fuzzy set for the production cost

$\Delta C\ (\cdot) = \{F(X(t))\text{-}Casp(t)\} / Casp(t)$

Casp(t) : aspiration level for production cost at #t stage

W_c : weighting factor of the membership function for production cost

(2) Membership functions of fuzzy set for the reliability (LOLP, EDNS) are defined as:

$$\mu_R\{X(t-1), u(t)\} = \begin{cases} 1 & : \Delta R(\cdot) \le 0 \\ e^{-W_R \, \Delta R\{X(t-1), u(t)\}} & : \Delta R(\cdot) \rangle 0 \end{cases} \qquad (21)$$

where, $\mu_R(\cdot)$: membership function of fuzzy sets for reliability

$\Delta R\ (\cdot) = \{RES(X(t))\text{-}REQ(t)\} / REQ(t)$

REQ(t) : aspiration level for reliability at #t stage

W_R: weighting factor of the membership function for reliability

(3) Membership function of fuzzy set for the air pollution criterion is defined as:

$$\mu_A\{X(t-1), u(t)\} = \begin{cases} 1 & : \Delta A(\cdot) \le 0 \\ e^{-W_A \, \Delta A\{X(t-1), u(t)\}} & : \Delta A(\cdot) \rangle 0 \end{cases} \qquad (22)$$

where, $\mu_A(\cdot)$: membership function of fuzzy sets for air pollution fuzzy set

$\Delta A\ (\cdot) = \{AP(X(t))\text{-}ASP(t)\} / ASP(t)$

ASP(t) : aspiration level for air pollution at #t stage

W_A: weighting factor of the membership function for air pollution

5. Solution procedure by the fuzzy search method

Fuzzy decision set D applied to the Eq.(1) can be formulated as:

$$D = C \cap R1 \cap R2 \cap A \qquad (23)$$

where, C: fuzzy set for probabilistic production cost

R1: fuzzy set for reliability LOLP

R2: fuzzy set for reliability EDNS

A : fuzzy set for air pollution

Therefore, using Eq.(7), we can obtain:

$$\mu_D(X(t)) = \max_{u\,\min(t) \le u(t) \le u\,\max(t)} [\min\{\mu_C(\cdot), \mu_{R1}(\cdot), \mu_{R2}(\cdot), \mu_A(\cdot), \mu_D(X(t-1))\} \qquad (24)$$

where, X(t)=X(t-1)+u(t)

$\mu_D(X(0))=1.0$

$\mu_D(\cdot)$:membership function of fuzzy set for decision function

6. Case study

6.1 Input data

The proposed method was applied to the recently KEPCO system and probabilistic production cost was calculated by the cumulant method. Fig.1 represents year load curve which has weekly load peaks on case study year in the KEPCO system.

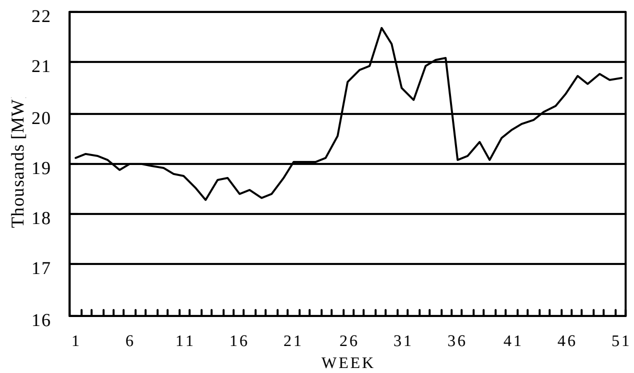


Fig. 1. Year load curve (weekly load peaks)

Aspiration levels and weighting factors for probabilistic production cost, reliability and air pollution shown in Table 1 have been used for this case study.

Table 1. Input data (aspiration level & weighting factor)

	aspiration	weighting factor
Z_{01}	25000[10^8\$]	10.0
Z_{02}	0.40[pu/week]	5.0
Z_{03}	100000[MWh/week]	2.0
Z_{04}	80000[10^8ppm/week]	5.0

Table 2 shows generator input data. Nuclear power stations are assumed to have no air pollution.

Table 2. Input data for generators

NO	ANAME	TYP	PMN	PMX	CFT	A(i)	B(i)	C(i)	FOR	MS	MF	MD	MI	YEAR	MH	FCR	SO2	NOX
1	WSG 1	N/P	679	679	0.939	0.00005	1.0000	15.233	0.04408	1	52	8	1			0	0	0
2	GRI 1	N/P	580	580	1.849	0.00005	1.0000	15.233	0.04207	1	26	8	1			0	0	0
3	GRI 2	N/P	650	650	1.849	0.00005	1.0000	15.233	0.04674	1	26	8	1			0	0	0
4	GRI 3	N/P	950	950	1.849	0.00005	1.0000	15.233	0.07744	27	26	8	27			0	0	0
5	GRI 4	N/P	950	950	1.849	0.00005	1.0000	15.233	0.08893	27	26	8	27			0	0	0
6	YKG 1	N/P	950	950	1.849	0.00005	1.0000	15.233	0.08893	1	26	8	1			0	0	0
7	YKG 2	N/P	950	950	1.849	0.00005	1.0000	15.233	0.08893	27	26	8	27			0	0	0
8	UGN 1	N/P	950	950	1.849	0.00005	1.0000	15.233	0.08893	1	26	8	1			0	0	0
9	UGN 2	N/P	950	950	1.849	0.00005	1.0000	15.233	0.08893	27	26	8	27			0	0	0
10	ILD 1	G/T	200	620	7.649	0.00058	1.6133	153.842	0.03234	1	26	8	1			0.0500	450	200
11	ILD 2	G/T	200	620	7.649	0.00058	1.6133	153.842	0.03234	27	26	8	1			0.0500	450	200
12	BRG 3	T/P	200	500	7.649	0.00058	1.6133	153.842	0.03234	1	26	0	1	1993	8	0.4030	700	450
13	BRG 4	T/P	200	500	7.649	0.00058	1.6133	153.842	0.03347	27	26	0	27	1993	24	0.4030	700	450
14	BRG 1	T/P	200	475	7.649	0.00058	1.6133	153.842	0.03234	1	26	6	1			0.4030	700	450
15	BRG 2	T/P	200	475	7.649	0.00058	1.6133	153.842	0.03347	27	26	6	27			0.4030	700	450
16	SCP 3	T/P	280	560	7.649	0.00059	1.5820	183.432	0.02050	27	26	0	27	1993	24	0.4030	700	450
17	SCP 1	T/P	280	532	7.649	0.00059	1.5820	183.432	0.01718	1	26	8	1			0.4030	700	450
18	SCP 2	T/P	280	532	7.649	0.00059	1.5820	183.432	0.02050	27	26	8	27			0.4030	700	450
19	BDN 1	G/T	0	400	7.649	0.00059	1.5820	183.432	0.02050	27	26	6	27			0.4030	450	200
20	ILS 1	G/T	0	400	7.649	0.00059	1.5820	183.432	0.02050	27	26	0	27	1993	24	0.0500	450	200
21	AYN 1	G/T	0	300	7.649	0.00059	1.5820	183.432	0.02050	27	26	6	27			0.0500	450	200
22	BCN 1	G/T	0	300	7.649	0.00059	1.5820	183.432	0.02050	27	26	0	27	1993	24	0.0500	450	200
23	BDN 1	S/T	0	200	7.649	0.00059	1.5820	183.432	0.02050	27	17	0	27	1993	36	0.0500	450	200
24	ILS 1	S/T	0	200	7.649	0.00059	1.5820	183.432	0.02050	27	5	0	27	1993	48	0.0500	450	200
25	SUL 5	T/P	100	225	8.295	0.00198	1.3435	138.999	0.03691	1	26	8	1			0.0500	450	200
26	SUL 4	T/P	60	123	8.295	0.00207	1.7119	67.889	0.03691	27	26	4	27			0.0500	450	200
27	SCN 2	T/P	120	180	10.373	0.00441	0.7603	126.107	0.04210	1	26	4	1			0.4030	700	450
28	HNM 3	T/P	150	270	9.680	0.00061	1.9372	84.071	0.01420	1	26	4	1			0.4030	700	450
29	YDG 2	T/P	120	180	9.760	0.00468	0.3311	224.917	0.02334	1	52	4	1			0.4030	700	450
30	HNM 4	T/P	130	270	9.680	0.00061	1.9372	84.071	0.02690	27	26	4	27			0.4030	700	450
31	YNM 1	T/P	80	200	11.050	0.00157	1.9079	68.403	0.06520	1	52	8	1			0.4030	700	450
32	YNM 2	T/P	80	190	11.050	0.00157	1.9079	68.403	0.08010	1	52	8	1			0.4030	700	450
33	SCN 1	T/P	120	180	10.875	0.00441	0.7603	126.107	0.03221	27	26	4	27			0.4030	700	450
34	PTG 1	T/P	220	315	11.879	0.00025	1.9636	66.170	0.00508	1	13	4	1			0.0500	450	200
35	PTG 2	T/P	220	315	11.879	0.00025	1.9636	66.170	0.00215	14	13	4	14			0.0500	450	200
36	PTG 3	T/P	220	315	11.879	0.00025	1.9636	66.170	0.00332	26	13	4	26			0.0500	450	200
37	PTG 4	T/P	220	315	11.879	0.00025	1.9636	66.170	0.00234	40	13	4	40			0.0500	450	200
38	PTG 5	G/T	220	350	11.879	0.00025	1.9636	66.170	0.00234	40	13	4	40			0.0500	450	200
39	USN 4	T/P	260	400	12.221	0.00039	1.8921	74.079	0.03504	1	13	7	1			0.0234	600	200
40	USN 5	T/P	260	400	12.221	0.00039	1.8921	74.079	0.01513	14	26	7	14			0.0234	600	200
41	USN 6	T/P	260	400	12.221	0.00039	1.8921	74.079	0.00991	27	13	4	27			0.0234	600	200
42	USN 1	T/P	260	200	12.221	0.00039	1.8921	74.079	0.00991	1	13	4	1			0.0234	600	200
43	USN 2	T/P	260	200	12.221	0.00039	1.8921	74.079	0.00991	14	13	4	14			0.0234	600	200
44	USN 3	T/P	260	200	12.221	0.00039	1.8921	74.079	0.00991	27	13	4	27			0.0234	600	200
45	YDG 1	T/P	80	112	9.983	0.00175	2.1608	44.256	0.01960	1	52	8	1			0.4030	700	450
46	HNM 1	T/P	130	210	9.680	0.00061	1.9372	84.071	0.02690	27	26	4	27			0.4030	700	450
47	HNM 2	T/P	130	210	9.680	0.00061	1.9372	84.071	0.02690	27	26	4	27			0.4030	700	450
48	ILD 1	G/T	130	160	9.680	0.00061	1.9372	84.071	0.02690	27	26	4	27			0.0500	450	200
49	ILD 1	G/T	130	160	9.680	0.00061	1.9372	84.071	0.02690	27	26	4	27			0.0500	450	200
50	ILD 2	G/T	130	160	9.680	0.00061	1.9372	84.071	0.02690	27	26	4	27			0.0500	450	200
51	ILD 2	G/T	130	160	9.680	0.00061	1.9372	84.071	0.02690	27	26	4	27			0.0500	450	200
52	ICN 2	T/P	100	238	12.221	0.00068	1.8347	69.570	0.01171	1	13	8	1			0.0500	450	200
53	ICN 1	T/P	100	238	12.221	0.00250	0.9001	196.503	0.00203	13	13	8	13			0.0500	450	200
54	ICN 3	T/P	180	300	12.221	0.00023	2.1007	63.226	0.05718	27	13	4	27			0.0500	450	200
55	ICN 4	T/P	180	300	12.221	0.00023	2.1007	63.226	0.07697	40	13	4	40			0.0500	450	200
56	LNG 1	T/P	0	400	12.221	0.00023	2.1007	63.226	0.07697	1	26	4	1			0.0500	450	200
57	LNG 2	T/P	0	400	12.221	0.00023	2.1007	63.226	0.07697	27	26	4	27			0.0500	450	200
58	YSU 1	T/P	100	250	12.221	0.00134	1.8737	53.723	0.00762	1	26	8	1			0.4030	700	450
59	YSU 2	T/P	100	250	12.221	0.00134	1.8737	53.723	0.03128	27	26	8	27			0.4030	700	450
60	AYN 1	S/T	100	150	12.221	0.00134	1.8737	53.723	0.03128	27	17	0	27	1993	36	0.0500	450	200
61	BCN 1	S/T	100	150	12.221	0.00134	1.8737	53.723	0.03128	27	5	0	27	1993	48	0.0500	450	200
62	BSN 1	T/P	30	57	9.611	0.00457	2.4659	25.366	0.01197	1	52	4	1			0.0234	600	200
63	BSN 2	T/P	30	57	9.611	0.00457	2.4659	25.366	0.01197	1	52	4	1			0.0234	600	200
64	BSN 3	T/P	30	57	9.611	0.00457	2.4659	25.366	0.01197	1	52	4	1			0.0234	600	200
65	BSN 4	T/P	30	57	9.611	0.00457	2.4659	25.366	0.01197	1	52	4	1			0.0234	600	200
66	GSN 1	T/P	40	63	10.218	0.00859	1.9913	30.928	0.01420	1	52	4	1			0.0234	600	200
67	YWL 2	T/P	25	45	9.491	0.00485	2.7352	17.866	0.03749	1	52	4	1			0.4030	700	450
68	GIN 1	T/P	70	70	11.848	0.00364	1.3748	76.975	0.01644	1	26	4	1			0.4030	700	450
69	GIN 2	T/P	70	70	11.848	0.00364	1.3748	76.975	0.01171	27	13	4	27			0.4030	700	450
70	YWL 1	T/P	25	45	11.643	0.00485	2.7352	17.866	0.29191	1	52	4	1			0.4030	700	450
71	GGS 1	T/P	100	250	12.221	0.00134	1.8737	53.723	0.03128	1	52	4	1			0.4030	700	450
72	DPB 1	T/P	100	250	12.221	0.00134	1.8737	53.723	0.03128	1	52	4	1			0.4030	700	450

6.2 Output results

It can be assumed that generators start to operate in 1993 need not be maintained. Fig. 2 shows convergence of the membership value of objective function according to iterations. The objective function which indicate the satisfaction degree of decision-maker converges to 0.9 after seven iterations.

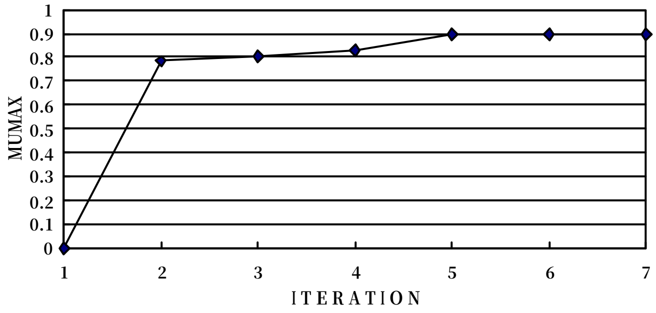


Fig. 2. Convergence of the objective function (μ)

Also, Fig. 3 shows convergence of the value of membership functions of production cost, reliability and air pollution with iterations.

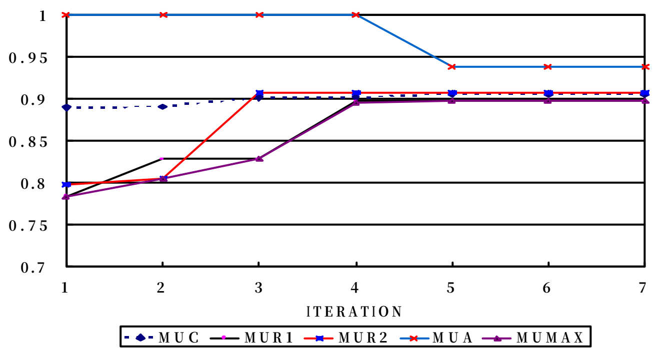


Fig. 3. Convergence of the objective function and membership functions with iteration

In Fig. 3, the MUC, MUR1, MUR2 and MUA present membership functions of production cost, LOLP, EDNS and air pollution. Also, the change shapes of standard deviations of the LOLP and EDNS with iteration are shown as in Fig. 4.

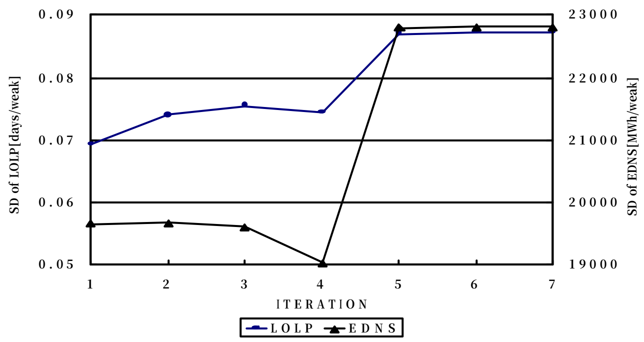
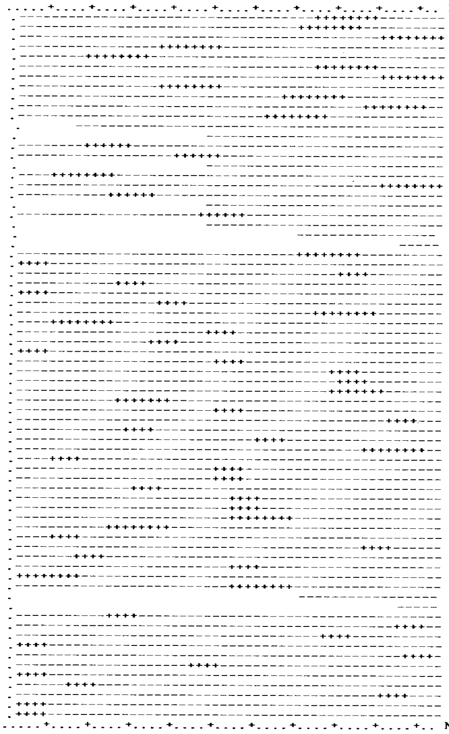


Fig. 4. LOLP, EDNS standard deviation with iteration

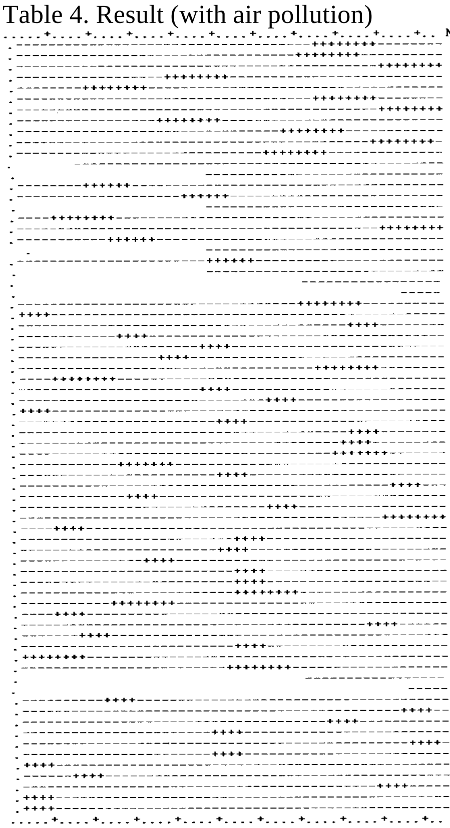
Table 3 shows the results obtained in case of air pollution not considered and Table 4 shows the result obtained in case of air pollution considered. These Tables show that maintenance scheduling of thermal type units in case of air pollution considered occur some different from the other case. These units are underlined in Table 4. In these Tables, dotted lines mean the weeks of mean possible maintenance scheduling and crosses mean the weeks of maintenance scheduling obtained by the proposed fuzzy search method.

Table 3. Result (with no air pollution)



NUMG	NAME	IDD	CAP	NOPT
1	WSG	1	679.0	37
2	GRI	1	580.0	35
3	GRI	2	650.0	45
4	GRI	3	950.0	18
5	GRI	4	950.0	9
6	YKG	1	950.0	37
7	YKG	2	950.0	45
8	UGN	1	950.0	18
9	UGN	2	950.0	33
10	ILD	1	620.0	43
11	ILD	2	620.0	31
12	BRG	3	500.0	1
13	BRG	4	500.0	27
14	BRG	1	475.0	9
15	BRG	2	475.0	20
16	SCP	3	560.0	27
17	SCP	1	532.0	5
18	SCP	2	532.0	45
19	BDN	1	400.0	12
20	ILS	1	400.0	27
21	AYN	1	300.0	23
22	BCN	1	300.0	27
23	BDN	1	200.0	27
24	ILS	1	200.0	27
25	SUL	5	225.0	35
26	SUL	4	123.0	1
27	SCN	2	180.0	40
28	HNM	3	270.0	13
29	YDG	2	180.0	1
30	HNM	4	270.0	18
31	YNM	1	200.0	37
32	YNM	2	190.0	5
33	SCN	1	180.0	24
34	PTG	1	315.0	17
35	PTG	2	315.0	1
36	PTG	3	315.0	25
37	PTG	4	315.0	39
38	PTG	5	350.0	40
39	USN	4	400.0	39
40	USN	5	400.0	13
41	USN	6	400.0	25
42	USN	1	200.0	46
43	USN	2	200.0	14
44	USN	3	200.0	30
45	YDG	1	112.0	43
46	HNM	1	210.0	5
47	HNM	2	210.0	25
48	ILD	1	160.0	25
49	ILD	1	160.0	15
50	ILD	2	160.0	27
51	ILD	2	160.0	27
52	ICN	2	238.0	27
53	ICN	1	238.0	12
54	ICN	3	300.0	5
55	ICN	4	300.0	43
56	LNG	1	400.0	8
57	LNG	2	400.0	27
58	YSU	1	250.0	1
59	YSU	2	250.0	27
60	AYN	1	150.0	27
61	BCN	1	150.0	27
62	BSN	1	57.0	12
63	BSN	2	57.0	47
64	BSN	3	57.0	38
65	BSN	4	57.0	1
66	GSN	1	63.0	48
67	YWL	2	45.0	22
68	GIN	1	70.0	1
69	GIN	2	70.0	7
70	YWL	1	45.0	45
71	GGS	1	250.0	1
72	DPB	1	250.0	1
NUMG	NAME	IDD	CAP	NOPT

Table 4. Result (with air pollution)



NUMG	NAME	IDD	CAP	NOPT
1	WSG	1	679.0	37
2	GRI	1	580.0	35
3	GRI	2	650.0	45
4	GRI	3	950.0	19
5	GRI	4	950.0	9
6	YKG	1	950.0	37
7	YKG	2	950.0	45
8	UGN	1	950.0	18
9	UGN	2	950.0	33
10	ILD	1	620.0	44
11	ILD	2	620.0	31
12	BRG	3	500.0	1
13	BRG	4	500.0	27
14	BRG	1	475.0	9
15	BRG	2	475.0	21
16	SCP	3	560.0	27
17	SCP	1	532.0	5
18	SCP	2	532.0	45
19	BDN	1	400.0	12
20	ILS	1	400.0	27
21	AYN	1	300.0	24
22	BCN	1	300.0	27
23	BDN	1	200.0	27
24	ILS	1	200.0	27
25	SUL	5	225.0	35
26	SUL	4	123.0	1
27	SCN	2	180.0	41
28	HNM	3	270.0	13
29	YDG	2	180.0	23
30	HNM	4	270.0	18
31	YNM	1	200.0	37
32	YNM	2	190.0	5
33	SCN	1	180.0	23
34	PTG	1	315.0	31
35	PTG	2	315.0	1
36	PTG	3	315.0	25
37	PTG	4	315.0	41
38	PTG	5	350.0	40
39	USN	4	400.0	39
40	USN	5	400.0	13
41	USN	6	400.0	25
42	USN	1	200.0	46
43	USN	2	200.0	14
44	USN	3	200.0	31
45	YDG	1	112.0	45
46	HNM	1	210.0	5
47	HNM	2	210.0	27
48	ILD	1	160.0	25
49	ILD	1	160.0	16
50	ILD	2	160.0	27
51	ILD	2	160.0	27
52	ICN	2	238.0	27
53	ICN	1	238.0	12
54	ICN	3	300.0	5
55	ICN	4	300.0	43
56	LNG	1	400.0	8
57	LNG	2	400.0	27
58	YSU	1	250.0	1
59	YSU	2	250.0	26
60	AYN	1	150.0	27
61	BCN	1	150.0	27
62	BSN	1	57.0	11
63	BSN	2	57.0	47
64	BSN	3	57.0	38
65	BSN	4	57.0	24
66	GSN	1	63.0	48
67	YWL	2	45.0	24
68	GIN	1	70.0	1
69	GIN	2	70.0	7
70	YWL	1	45.0	44
71	GGS	1	250.0	1
72	DPB	1	250.0	1
NUMG	NAME	IDD	CAP	NOPT

Fig. 5 is a representation of maintenance of power and supply reserve rates for each week. And also, comparisons of LOLP and EDNS for each week are shown in Fig. 6.

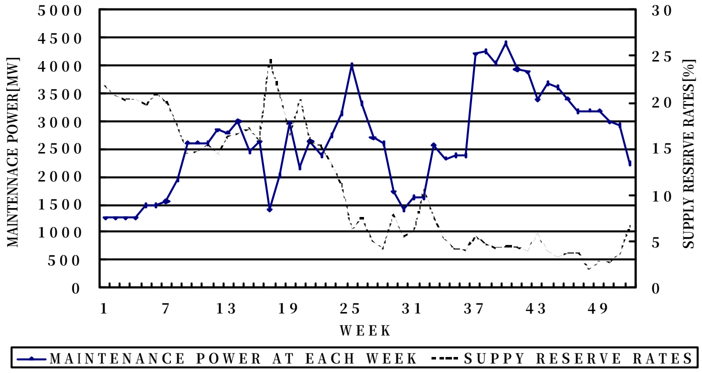


Fig. 5. Maintenance powers and supply reserve rates.

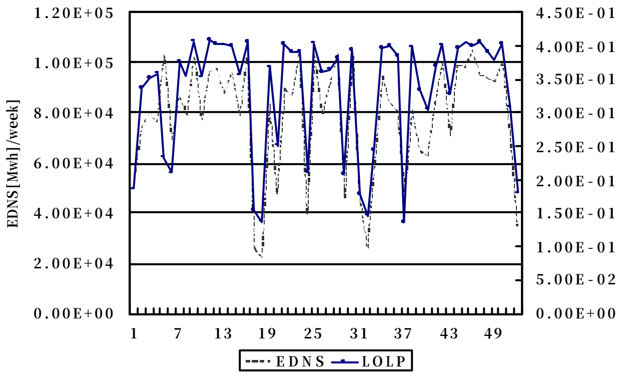


Fig. 6. LOLP and EDNS at each week

And, Fig. 7 shows the variation of μ_{max} which is objective function defining the satisfaction degree by changing the aspiration levels. In this Fig. 7, we know that μ_{max} value at 80000×10^{8}[ppm/Ton] of aspiration level , Z_{04} of air pollution is nearly same to value at 60000×10^{8}[ppm/Ton]. Based on this result, we can reasonably determine an aspiration level of the membership function of air pollution fuzzy set.

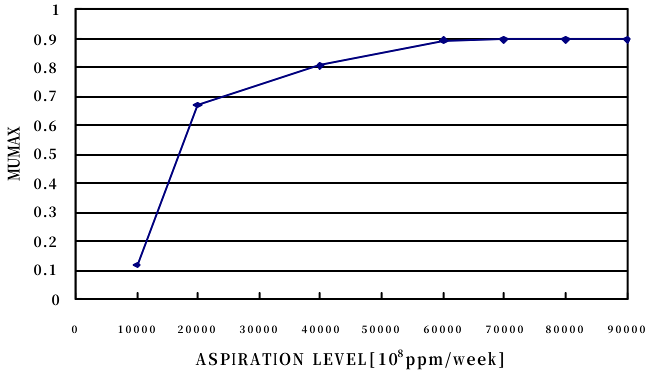


Fig. 7. Variation of μ_{max} by changing of the aspiration levels

Finally, comparisons of results obtained for two cases of with air pollution, and with no air pollution are shown in Table 5.

Table 5. Comparison of results

Cases / Results	with no air pollution	with air pollution
objective function aspiration level	0.90203	0.89667
total production cost[10^9\$]	2525.78	2525.27
maximum LOLP [pu]	0.40724	0.40866
total EDNS [MWh]	4136708	4078015
mean of supply reserve rates [%]	10.81521	10.84839
standard deviation of supply reserve rate[%]	6.37200	6.80950

7. Conclusion

Using the extending fuzzy search method has already been developed by authors[10], a new fuzzy search method is proposed for generator maintenance scheduling considering the effects of SO_2 and NO_X air pollutions of thermal power generators. The practicability and effectiveness of the proposed method are demonstrated by simulation results on real size power system model.

Main conclusions are as follows.

1. The maintenance scheduling of thermal power generators in case of air pollution considered is obtained somewhat differently from the case of air pollution not considered.
2. The maintenance scheduling of nuclear power generator is not nearly effected in the case of the air pollution considered.
3. It is expected that membership functions can be reasonably obtained using μ_{max} based on results from sensitivity analysis as shown as in case study.

We are going to take a plan to study on maintenance scheduling considering transmission system and air pollution constraint at load points in the future.

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