Flexible Maintenance Scheduling of Generation System by Multi-Probabilistic Reliability Criterion in Korea Power System

Jeongje Park*, Jaeseok Choi†, Ungki Baek, Junmin Cha*** and Kwang Y. Lee******

Abstract – A new technique using a search method which is based on fuzzy multi-criteria function is proposed for GMS(generator maintenance scheduling) in order to consider multi-objective function. Not only minimization of probabilistic production cost but also maximization of system reliability level 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 in Korea in 2010.

Keywords: Generator maintenance scheduling, Fuzzy set theory, Fuzzy multi-criteria functions

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 affects 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 cost of the generators, production cost and maintenance scheduling cost. 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]-[4] ;

(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 [5]-[6]. In the present study, the method of maintenance scheduling by fuzzy search method has been developed. It is expected that more flexible solution can be obtained because fuzzy set theory that can reflect the subjective decision of decision-maker has been used in this study[7]-[11]. An alternative method for flexible GMS using various kinds of objective functions is proposed in this paper. The effectiveness of the proposed approach are demonstrated by simulation studies of a real size power system model.

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2. Fuzzy Search Method

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

$$D = (\bigcap_{i=1}^{p} G_i) \cap (\bigcap_{j=1}^{q} C_i) \tag{1}$$

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

$$\mu_D(x) = \min[\min_{i=1\sim p} \mu_G \cdot \min_{j=1\sim q} \mu_C] \tag{2}$$

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:

$$\mu_D(X^*) = \max \mu_D(X) \tag{3}$$

Where, X^* is the optimal decision solution, and max is an abbreviation of maximum.

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

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

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:

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

where, X : decision variable, F=G+C (algebraic sum of fuzzy sets)

Eq.(5) can be rewritten as:

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

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

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

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

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 The Formulation based on Fuzzy Search Method

(1) Minimization of Probabilistic Production Cost F as:

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

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

$$E_{in} = (1-q_i)T\int_{ui-1}^{ui} \Phi_{in-1}(X)dX \quad \text{[MWh]} \quad (9)$$

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

$u_i = C_1 + C_2 + \cdot\cdot\cdot + C_i$ [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 :

$$F\{E_{in}, F_i(U_{in})\} \lessapprox Z_{01} \quad (10)$$

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

(2) Minimization of LOLE

Minimizing of LOLE is defined;

$$Minimize\ Z_2 = LOLE = \Phi_{NGn}(U_{NGn}) \quad \text{[pu]} \quad (11)$$

And also, Eq.(11) can be to represented as fuzzy goal function form as:

$$Z_2 \gtrapprox Z_{02} \quad (12)$$

Where, Z_{02} : aspiration level of decision-maker for LOLE

(3) Maximization of Minimum SRR_n

Maximizing of minimum SRR(Supply Reserve Rate) in 52 weeks should be considered. It can be defined as:

$$Maximize\ Z_3 = \text{minimum}(SRR_n) \quad [\%] \quad (13)$$

Where, $SRR_n = (IC - MCAP_n - PD_n) \times 100 / PD_n$

IC: total installed capacity of generators [MW]

$MCAP_n$: maintenance capacity at n-th week [MW]

PD_n : peak load at n-th week [MW]

(4) Maximization of EIR

Maximizing of EIR(Energy Index of Reliability) can be considered as:

$$Maximize\ Z_4 = \text{EIR [pu]} \quad (14)$$

Where, EIR=1-EENS/ESD

EENS: expected energy not served [MWh]

ESD: expected energy for demand [MWh]

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

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

where, Z_{04} : aspiration level of decision-maker for EDNS.

3.2 Constraints

(1) Boundary Conditions

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

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

MD_i : time period asked for maintenance of #*i* unit

(2) Constraints for Maintenance Possible Time Period

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

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) Constraints for Maintenance Possible Time Period

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

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

(4) Constraint of Maintenance Equipments

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

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 Function

(1) Membership Function of Fuzzy Set for The Production Cost is Defined as:

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

where, $\mu_c(\cdot)$: membership function of fuzzy set for 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 Function of Fuzzy Set for the Reliability LOLE is Defined as:

$$\mu_{LOLE}\{X(t-1), u(t)\} = \begin{cases} 1 & : \Delta R(\cdot) \le 0 \\ e^{-W_{LOLE} \ \Delta R\{X(t-1), u(t)\}} & : \Delta R(\cdot) \rangle 0 \end{cases} \tag{21}$$

where, $\mu_{LOLE}(\cdot)$: membership function of fuzzy sets for reliability LOLE

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

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

W_{LOLE}: weighting factor of the membership function for reliability LOLE

(3) Membership Functions of Fuzzy Set for the Reliability SRR is Defined as:

$$\mu_{SRR}\{X(t-1), u(t)\} = \begin{cases} 1 & : \Delta R(\cdot) \le 0 \\ e^{W_{SRR} \ \Delta R\{X(t-1), u(t)\}} & : \Delta R(\cdot) \rangle 0 \end{cases} \tag{22}$$

where, $\mu_{SRR}(\cdot)$: membership function of fuzzy sets for reliability SRR

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

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

W_{SRR}: weighting factor of the membership function for reliability SRR

(4) Membership Function of Fuzzy Set for the Reliability EIR is Defined as:

$$\mu_{EIR}\{X(t-1), u(t)\} = \begin{cases} 1 & : \Delta R(\cdot) \le 0 \\ e^{-W_{EIR} \ \Delta A\{X(t-1), u(t)\}} & : \Delta R(\cdot) \rangle 0 \end{cases} \tag{23}$$

where, $\mu_{EIR}(\cdot)$: membership function of fuzzy sets for air pollution fuzzy set

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

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

W_{EIR}: weighting factor of the membership function for reliability EIR

5. Solution Procedure by the Fuzzy Search Method

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

$$D = C \cap R1 \cap R2 \cap R3 \tag{24}$$

where, C: fuzzy set for production cost

R1: fuzzy set for reliability SRR

R2: fuzzy set for reliability LOLE

R3: fuzzy set for reliability EIR

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

$$\mu_D(X(t)) = \max_{\min(t)\le u(t)\le u\max(t)}[\min\{\mu_C(\cdot),\mu_{R1}(\cdot),\mu_{R2}(\cdot),\mu_A(\cdot),\mu_D(X(t-1))\} \quad (25)$$

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 Korea power system on 2010 and probability production cost was calculated by the cumulant method. Fig. 1 represents year load curve pattern which has weekly load peaks on 2010 in the KEPCO system. The year peak load in this year is forecasted as 62,852MW. Table 1 shows generation system in 2010.

Aspiration levels and weighting factors for probability production cost, deterministic and probabilistic reliability indices shown in Table 1 has been used for this case study.

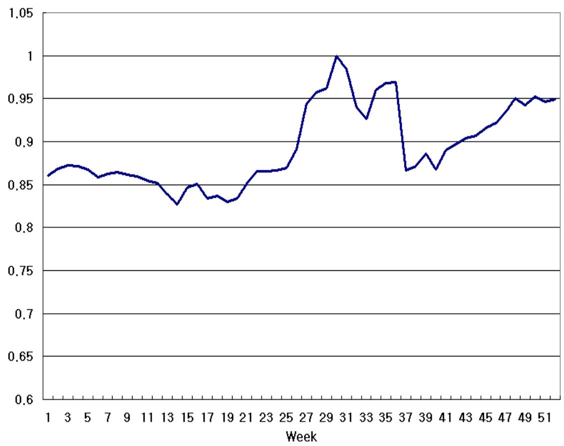

Fig. 1. Year load curve pattern with weekly load peaks.

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

	aspiration	weighting factor
Z_{01}	25,400,000[10^6Won]	10.0
Z_{02}	10.0[%/year]	5.0
Z_{03}	5.5[days/year]	5.0
Z_{04}	0.99900[pu]	5.0

6.2 Output Data

The results are in appendix. Fig. 2 shows convergence of the membership value of objective function according to iterations. The objective function which indicates the satisfaction degree of decision-maker converges over 0.9 from fourth iteration. The convergence maximum μ_{max}^* is 0.952 at fourteen iterations. Fig. 6 is a representation of maintenance of power and supply reserve rates for each week.

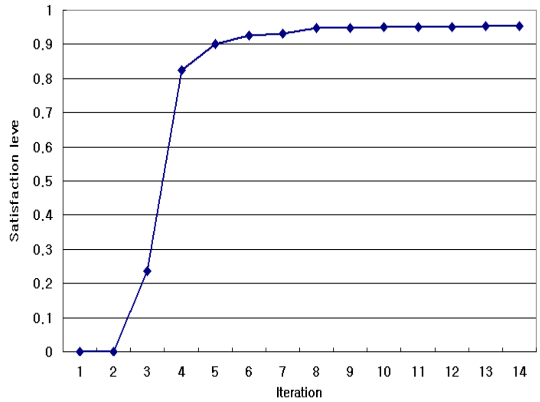

Fig. 2. Convergence of the objective function (μ_{max}).

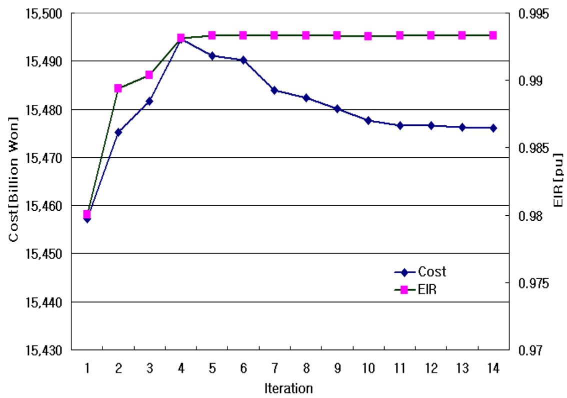

Fig. 3. Cost and EIR.

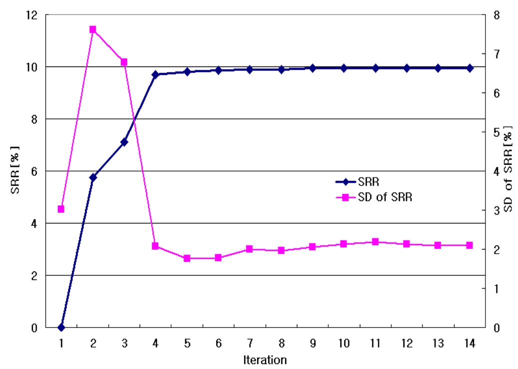

Fig. 4. SRR and standard deviation.

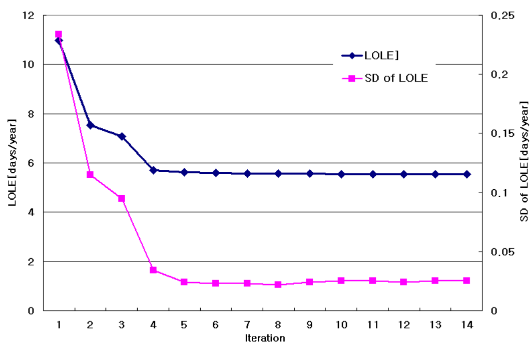

Fig. 5. LOLE and standard deviation.

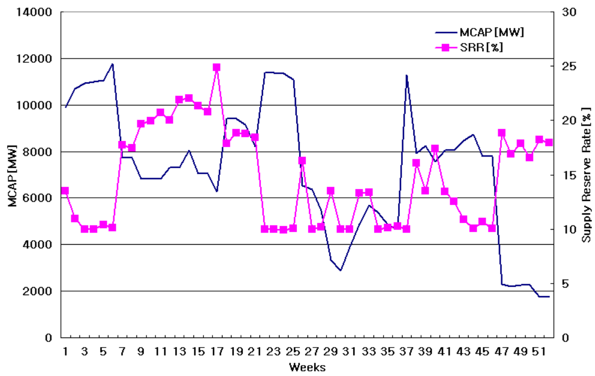

Fig. 6. Maintenance of powers and supply reserve rates.

6.3 Parametric Analysis

Case study I

Table 3 shows a parametric analysis result according to changing of aspiration level of SRR. As the aspiration level of the SRR is higher (stricter), the propose method asks for sacrifices of other objective values, cost, LOLE and EIR in order to avoid sharp decreasing of the satisfaction level as possible as. As it is, the cost and LOLE are asked for their increasing a little bit. EIR is asked for its decreasing a little bit. Therefore, the sharp decreasing of satisfaction level due to higher aspiration level of the SRR may be avoided overall. Eventually, more flexible solution is obtained using proposed method

Table 2. Aspiration Levels and Weighting Factors of Membership Functions for Cases 1, 2 and 3

	Case 1	Case 2	Case 3	Weighting Factor
Cost [106 Won]	15,400,000	15,400,000	15,400,000	10
SRR[%]	10.0	12.0	14.0	5
LOLE [days/year]	5.5	5.5	5.5	5
EIR[pu]	0.99900	0.99900	0.99900	5

Table 3. Results According to Changing of Aspiration Level of SRR(Supply Reserve Rate)

	Case 1	Case 2	Case 3	Remarks
Cost [10^6Won]	15,476,098	15,497,311	15,513,394	Increasing
SRR[%]	9.957	11.707	13.218	Increasing
LOLE [days/year]	5.554	5.632	5.804	Increasing
EIR[pu]	0.99328	0.99332	0.99319	Decreasing
Satisfaction Level	0.952	0.885	0.756	Decreasing

Case study II

Table 5 shows a parametric analysis result according to changing of aspiration level of production cost. As the aspiration level of the cost is lower(stricter), the propose method asks for sacrifices of other objective values, SRR, LOLE and EIR in order to avoid sharp decreasing of the satisfaction level as possible as. As it is, the LOLE is asked for their increasing a little bit. The SRR and EIR are asked for their decreasing a little bit. Therefore, the sharp decreasing of satisfaction level due to higher aspiration level of the cost may be avoided overall. Eventually, more flexible solution is obtained using proposed method.

Table 4. Aspiration Levels and Weighting Factors of Membership Functions for Cases 5 and 6

	Case 1	Case 5	Case 6	W_R
Cost [10^6 Won]	15,400,000	15,200,000	15,000,000	10
SRR [%]	10.0	10.0	10.0	5
LOLE [days/year]	5.5	5.5	5.5	5
EIR [pu]	0.99900	0.99900	0.99900	5

Table 5. Results According to Changing of Aspiration Level of Production Cost

	Case 1	Case 5	Case 6	Remarks
Cost [10^6 Won]	15,476,098	15,472,839	15,468,876	Decreasing
SRR[%]	9.957	9.665	9.397	Decreasing
LOLE [days/year]	5.554	5.697	5.844	Increasing
EIR [pu]	0.99328	0.99298	0.99267	Decreasing
Satisfaction Level	0.952	0.836	0.732	Decreasing

7. Conclusion

A new technique using a search method which is based on fuzzy multi-criteria function is proposed for the GMS problem in order to consider multi-objective function. Not only minimization of probabilistic production cost but also various kinds of system reliability indices levels are considered simultaneously for fuzzy multi-criteria function. To obtain an optimal flexible solution for generator maintenance scheduling under fuzzy environment, fuzzy multi-criteria relaxation method (fuzzy search method) is used.

When an aspiration level is stricter, the propose method suggests another optimal solution that avoids to decrease satisfaction level(objective function) sharply even if other objective values are asked for their sacrifices a little bit. It shows, eventually, that more flexible solution is obtained using proposed method. The practicability and effectiveness of the proposed of method are demonstrated by simulation results on real size power system model in Korea in 2010.

Acknowledgements

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Appendix

Table 1. Generation system in Korea in 2010

NG	Name	ID	Cap. [MW]	FOR	A [Gcal/ MW^2h]	B [Gcal/ MWh]	C [Gcal/hr]	Fuel cost [10^3won/Gcal]	Duration of Maint. [weeks]
1	WLSN	2	700	0.106	0	1.991	389.736	0.944	8
2	WLSN	1	679	0.106	0	2.002	389.736	0.946	8
3	WLSN	3	700	0.106	0	2.019	389.736	1.018	8
4	WLSN	4	700	0.106	0	2.019	389.736	1.019	8
5	ULJN	1	950	0.096	0	1.958	348.674	1.233	8
6	ULJN	2	950	0.096	0	1.955	348.674	1.27	8
7	ULJN	3	1000	0.096	0	1.996	348.674	1.254	8
8	ULJN	4	1000	0.096	0	1.972	348.674	1.273	8
9	YNGN	1	950	0.096	0	2.029	275.783	1.28	8
10	YNGN	2	950	0.096	0	2.053	275.783	1.29	8
11	YNGN	3	1000	0.096	0	2.056	96.878	1.288	8
12	YNGN	4	1000	0.096	0	2.073	96.878	1.278	8
13	NGRI	5	1000	0.096	0	1.164	667.365	1.419	8
14	GORI	1	587	0.106	0	2.21	176.36	1.254	8
15	GORI	2	650	0.106	0	2.025	263.184	1.399	8
16	GORI	3	950	0.096	0	2.35	119.201	1.27	8
17	GORI	4	950	0.096	0	2.346	119.2	1.295	8
18	ULJN	5	1000	0.096	0.001	1.213	668.248	1.251	8
19	YNGN	6	1000	0.096	0.001	1.213	668.248	1.299	8
20	YNGN	5	1000	0.096	0.001	1.213	668.248	1.307	8
21	ULJN	6	1000	0.096	0.001	1.213	668.248	1.324	8
22	HADN	5	500	0.053	0	1.709	150.742	8.462	6
23	BORY	6	500	0.053	0	1.775	135.506	8.395	6
24	DNJN	5	500	0.053	0	1.671	152.67	8.983	6
25	DNJN	6	500	0.053	0	1.711	143.251	8.983	6
26	HADN	3	500	0.053	0	1.817	129.229	8.462	6
27	BORY	2	500	0.053	0	1.844	138.866	8.395	6
28	BORY	3	500	0.053	0	1.851	122.508	8.395	0
29	DNJN	1	500	0.053	0	1.769	132.81	8.983	6
30	DNJN	3	500	0.053	0	1.781	130.192	8.983	6
31	DNJN	7	500	0.053	0	1.784	92.894	8.983	6
32	DNJN	8	500	0.053	0	1.784	92.894	8.983	6
33	DNJN	4	500	0.053	0	1.785	128.954	8.983	6
34	DNJN	2	500	0.053	0	1.795	128.351	8.983	6
35	TEAN	8	500	0.053	0	1.698	103.771	9.602	6
36	TEAN	2	500	0.053	0	1.739	139.644	9.602	6
37	TEAN	3	500	0.053	0	1.739	139.644	9.602	6
38	TEAN	4	500	0.053	0	1.739	139.644	9.602	6
39	YNHN	2	800	0.042	0	1.85	168.042	9.157	8
40	SMCN	6	500	0.053	0	1.87	111.914	9.063	6
41	SMCN	5	500	0.053	0	1.877	112.037	9.063	6
42	HADN	6	500	0.053	0	2.027	89.259	8.462	6
43	TEAN	1	500	0.053	0	1.789	130.662	9.602	6
44	YNHN	1	800	0.042	0	1.933	150.791	9.157	8
45	SMCN	4	560	0.053	0	1.956	118.25	9.063	6
46	TEAN	7	500	0.053	0	1.848	107.291	9.602	6
47	TEAN	5	500	0.053	0	1.86	120.76	9.602	6
48	TEAN	6	500	0.053	0	1.86	120.76	9.602	6
49	SMCN	1	560	0.053	0	1.999	119.952	9.063	6
50	SMCN	3	560	0.053	0	2.034	100.646	9.063	6
51	BORY	1	500	0.053	0.001	1.444	222.667	8.395	6
52	BORY	4	500	0.053	0.001	1.62	161.724	8.395	6
53	HADN	4	500	0.053	0.001	1.606	167.842	8.462	6
54	BORY	5	500	0.053	0.001	1.665	162.298	8.395	6
55	HADN	2	500	0.053	0.001	1.641	160.883	8.462	6
56	HADN	1	500	0.053	0.001	1.667	156.249	8.462	6
57	SMCN	2	560	0.053	0.001	1.642	188.31	9.063	6
58	HONM	1	250	0.044	0	2.271	56.12	10.328	3
59	HONM	2	250	0.044	0	2.271	56.12	10.328	3
60	YNDN	12	200	0.044	0	2.253	72.113	18.775	3
61	DNHE	1	200	0.044	0	2.238	42.252	20.965	3
62	DNHE	2	200	0.044	0.001	2.088	54.383	20.965	3
63	POSC	2	1000	0.053	0	1.534	74.532	23.999	6
64	YGWL	1	450	0.053	0.001	1.628	26.615	44.214	6
65	YGWL	2	450	0.053	0.001	1.628	26.615	44.214	6
66	WIC1	24	225	0.026	0	1.332	77.547	41.837	3
67	ILSN	22	300	0.05	0	1.335	143.203	41.837	4
68	WIC2	27	225	0.026	0	1.345	79.233	41.837	3
69	WIC2	26	225	0.026	0	1.412	72.021	41.837	3
70	YNDN	11	125	0.035	0.001	2.268	40.823	24.403	3
71	WIC2	28	225	0.026	0.001	1.024	117.466	41.837	3
72	ICNB	21	504	0.044	0	1.56	53.548	41.837	6
73	BORB	23	450	0.044	0	1.577	54.962	41.837	4
74	BUND	22	340	0.05	0	1.595	126.558	41.837	4
75	BORB	24	450	0.044	0	1.599	64.521	41.837	4
76	BORB	21	450	0.044	0	1.608	59.26	41.837	4
77	ULSB	22	450	0.044	0	1.609	71.325	41.837	4
78	ULSB	23	450	0.044	0	1.609	71.325	41.837	4
79	BUSN	23	450	0.044	0	1.613	29.921	41.837	4
80	BUSN	24	450	0.044	0	1.621	26.53	41.837	4
81	BUSN	21	450	0.044	0	1.628	26.615	41.837	4
82	BUSN	22	450	0.044	0	1.628	26.615	41.837	4
83	BORB	22	450	0.044	0	1.631	54.619	41.837	4
84	PYNT	1	350	0.062	0	1.828	101.733	37.527	4
85	SIC1	22	450	0.044	0	1.643	43.561	41.837	4
86	SIC2	23	450	0.044	0	1.643	43.561	41.837	4
87	SIC2	24	450	0.044	0	1.643	43.561	41.837	4
88	WIC1	22	225	0.026	0.001	1.249	86.087	41.837	3
89	SIC1	21	450	0.044	0	1.662	38.765	41.837	4
90	WIC1	23	225	0.026	0.001	1.256	89.919	41.837	3
91	PYNT	2	350	0.062	0	1.863	97.022	37.527	4
92	PYNT	4	350	0.062	0	1.873	95.447	37.527	4
93	WIC2	25	225	0.026	0.001	1.285	76.76	41.837	3
94	WIC1	21	225	0.026	0.001	1.299	78.656	41.837	3
95	PYNB	21	480	0.044	0	1.764	76.606	41.837	4
96	SECN	2	200	0.044	0.001	2.393	52.304	28.016	3
97	SECN	1	200	0.044	0.002	2.12	77.257	28.016	3
98	ILSN	21	600	0.044	0	1.798	79.812	41.837	6
99	ULSB	21	300	0.05	0	1.853	42.16	41.837	4
100	PYNT	3	350	0.062	0.001	1.662	118.091	37.527	4
101	YNAM	2	200	0.075	0	2.227	62.344	37.521	3
102	BUND	21	560	0.044	0	2.012	63.828	41.837	6
103	SJJU	4	100	0.049	0.001	1.833	22.927	43.3	3
104	YESU	2	329	0.062	0.002	1.202	173.653	39.101	4
105	WIC1	11	150	0.04	0	2.076	96.549	41.837	3
106	WIC1	12	150	0.04	0	2.076	96.549	41.837	3
107	WIC1	13	150	0.04	0	2.076	96.549	41.837	3
108	WIC1	14	150	0.04	0	2.076	96.549	41.837	3
109	WIC2	15	150	0.04	0	2.076	96.549	41.837	3
110	WIC2	16	150	0.04	0	2.076	96.549	41.837	3
111	WIC2	17	150	0.04	0	2.076	96.549	41.837	3
112	WIC2	18	150	0.04	0	2.076	96.549	41.837	3
113	ULSN	4	400	0.031	0.001	1.663	128.78	38.139	4
114	ULSN	5	400	0.031	0.001	1.663	128.78	38.139	4
115	ULSN	6	400	0.031	0.001	1.663	128.78	38.139	4
116	JEJU	1	40	0.031	0.025	0.364	28.484	43.599	3
117	YNAM	1	200	0.075	0.001	2.072	61.059	37.521	3
118	ICNC	3	325	0.05	0	2.156	72.851	41.837	4
119	ICNC	4	325	0.05	0	2.173	73.848	41.837	4
120	SJJU	3	100	0.049	0.004	1.512	45.207	43.3	3
121	ICNC	1	250	0.026	0.001	1.823	68.429	41.837	3
122	ICNC	2	250	0.026	0.001	1.823	68.429	41.837	3
123	NJJU	3	75	0.031	0.001	2.016	23.401	43.599	3
124	SJJU	1	20	0.031	0.006	1.999	1.36	43.3	3
125	SJJU	2	20	0.031	0.006	1.999	1.36	43.3	3
126	YESU	1	200	0.075	0.001	2.09	43.303	39.101	3
127	NJJU	2	75	0.031	0.003	1.832	30.231	43.599	3
128	BUSN	11	300	0.05	0	2.284	82.893	41.837	4
129	BUSN	12	300	0.05	0	2.284	82.893	41.837	4
130	BUSN	13	300	0.05	0	2.284	82.893	41.837	4
131	BUSN	14	300	0.05	0	2.284	82.893	41.837	4
132	ULSN	1	200	0.075	0	2.228	31.473	43.207	3
133	ULSN	3	200	0.075	0	2.228	31.473	43.207	3
134	SEOL	4	138	0.04	0.003	1.786	46.556	41.837	3
135	SEOL	5	250	0.026	0.002	1.633	89.488	41.837	3
136	ICNB	11	321	0.05	0	2.389	59.494	41.837	4
137	ULSB	12	300	0.05	0	2.492	45.972	41.837	4
138	ULSB	13	300	0.05	0	2.492	45.972	41.837	4
139	SIC1	12	300	0.05	0.001	2.103	91.148	41.837	4
140	SIC2	13	300	0.05	0.001	2.103	91.148	41.837	4
141	SIC2	14	300	0.05	0.001	2.103	91.148	41.837	4
142	ULSN	2	200	0.075	0.001	2.175	36.324	43.207	3
143	ILSN	12	200	0.026	0	2.576	52.137	41.837	3
144	SIC1	11	300	0.05	0	2.688	36.055	41.837	4
145	BORB	13	300	0.05	0.001	2.359	65.677	41.837	4
146	BORB	11	300	0.05	0.001	2.377	62.025	41.837	4
147	BORB	14	300	0.05	0.002	1.994	87.277	41.837	4
148	ULSB	11	200	0.026	0	2.808	29.642	41.837	3
149	BORB	12	300	0.05	0.001	2.483	57.931	41.837	4
150	ILSN	11	400	0.044	0	2.971	16.219	41.837	4
151	BUND	12	225	0.026	0	2.997	24.846	41.837	3
152	BUND	11	375	0.05	0	3.034	49.47	41.837	4
153	NJJU	1	10	0.031	0.062	2.1	5.971	43.599	3
154	PYNB	11	320	0.05	0	3.287	9.374	41.837	4
155	HNLM	21	105	0.049	0	1.948	16.8	77.909	3
156	HNLM	13	55	0.031	0	1.944	53.78	79.905	3
157	HNLM	11	70	0.031	0.004	2.401	20.32	77.909	3

Table 2 shows the results obtained the fuzzy set based method for GMS proposed in this paper. In the GMS Table, dotted lines and cross marks mean the weeks of available maintenance scheduling and the weeks of maintenance scheduling respectively. It was assumed that generators whose operations start since 2010 need not be included in the maintenance scheduling.

Table 2. Result

.....+....+....+....+....+....+....+....+....+....+..	NG	NM	CAP [MW]	Init. Poin. [weeks]
.------------++++++++--------------------------------	1	WLSN	700	13
.++++++++--	2	WLSN	679	1
.--++++++++	3	WLSN	700	45
.------------------------------------++++++++--------	4	WLSN	700	37
.-----------++++++++---------------------------------	5	ULJN	950	12
.++++++++--	6	ULJN	950	1
.------------------------------------++++++++--------	7	ULJN	1000	37
.--++++++++	8	ULJN	1000	45
.------------++++++++--------------------------------	9	YNGN	950	13
.++++++++--	10	YNGN	950	1
.-----------++++++++---------------------------------	11	YNGN	1000	12
.++++++++--	12	YNGN	1000	1
.--------++++++++------------------------------------	13	NGRI	1000	9
.----------------++++++++----------------------------	14	GORI	587	17
.--------++++++++------------------------------------	15	GORI	650	9
.------------------------------------++++++++--------	16	GORI	950	37
.++++++++--	17	GORI	950	1
.-------------------++++++++-------------------------	18	ULJN	1000	20
.--------------++++++++------------------------------	19	YNGN	1000	15
.------------------------------------++++++++--------	20	YNGN	1000	37
.---++++++++---	21	ULJN	1000	4
.-------------------++++++---------------------------	22	HADN	500	20
.--------++++++--------------------------------------	23	BORY	500	9
.-----------------++++++-----------------------------	24	DNJN	500	18
.--------++++++--------------------------------------	25	DNJN	500	9
.------------++++++----------------------------------	26	HADN	500	13
.++++++--	27	BORY	500	1
. -------------------	28	BORY	500	0
.++++++--	29	DNJN	500	1
.---------------------++++++-------------------------	30	DNJN	500	22
.------------------------------------++++++----------	31	DNJN	500	37
.-------------------------------------++++++---------	32	DNJN	500	38
.--++++++	33	DNJN	500	47
.------------------++++++----------------------------	34	DNJN	500	19
.--------------------++++++--------------------------	35	TEAN	500	21
.-------------++++++---------------------------------	36	TEAN	500	14
.------------------------------------++++++----------	37	TEAN	500	37
.++++++--	38	TEAN	500	1
.------------------++++++++--------------------------	39	YNHN	800	19
.--------------------++++++--------------------------	40	SMCN	500	21
.-------------++++++---------------------------------	41	SMCN	500	14
.-------------------++++++---------------------------	42	HADN	500	20
.---------------------------------------++++++-------	43	TEAN	500	40
.-----------------------------------++++++++---------	44	YNHN	800	36
.-----------------------------------++++++-----------	45	SMCN	560	36
.--++++++	46	TEAN	500	47
.-------++++++---------------------------------------	47	TEAN	500	8
.------------------------++++++----------------------	48	TEAN	500	25
.--------------++++++--------------------------------	49	SMCN	560	15
.-------------------++++++---------------------------	50	SMCN	560	20
.-------------------------------++++++---------------	51	BORY	500	32
.-------------------++++++---------------------------	52	BORY	500	20
.--------------------------------++++++--------------	53	HADN	500	33
.--++++++------	54	BORY	500	41
.--------++++++--------------------------------------	55	HADN	500	9
.---------------++++++-------------------------------	56	HADN	500	16
.++++++--	57	SMCN	560	1
.----------------+++---------------------------------	58	HONM	250	17
.-----------------------------------+++--------------	59	HONM	250	36
.+++---	60	YNDN	200	1
.+++---	61	DNHE	200	1
.----------------------+++---------------------------	62	DNHE	200	23
.--------++++++--------------------------------------	63	POSC	1000	9
.--------------------++++++--------------------------	64	YGWL	450	21
.++++++--	65	YGWL	450	1
.--------+++---	66	WIC1	225	9
.------------------------------------++++------------	67	ILSN	300	37
.----------------------+++---------------------------	68	WIC2	225	23
.+++---	69	WIC2	225	1
.-----------------------+++--------------------------	70	YNDN	125	24
.------------------------------+++-------------------	71	WIC2	225	31
.--++++++--	72	ICNB	504	45
.----------------++++--------------------------------	73	BORB	450	17
.----------------------++++--------------------------	74	BUND	340	23
.-------------------------------++++-----------------	75	BORB	450	32
.------------------------------------++++------------	76	BORB	450	37
.-------------------------++++-----------------------	77	ULSB	450	26
.----------++++--------------------------------------	78	ULSB	450	11
.------++++--	79	BUSN	450	7
.--++++------	80	BUSN	450	43
.-------------------------------++++-----------------	81	BUSN	450	32
.--++++	82	BUSN	450	49
.-------------------------++++-----------------------	83	BORB	450	26
.--++++----	84	PYNT	350	45
.++++--	85	SIC1	450	1
.-------------------------++++-----------------------	86	SIC2	450	26
.---++++-----	87	SIC2	450	44
.---------+++--	88	WIC1	225	10
.----------------------++++--------------------------	89	SIC1	450	23
.------------------+++-------------------------------	90	WIC1	225	19
.----------++++--------------------------------------	91	PYNT	350	11
.----------------++++--------------------------------	92	PYNT	350	17
.---+++------	93	WIC2	225	44
.-----------------------+++--------------------------	94	WIC1	225	24
.----------++++--------------------------------------	95	PYNB	480	11
.-------------------------------+++------------------	96	SECN	200	32
.----+++---	97	SECN	200	5
.------++++++--	98	ILSN	600	7
.------------------------------------++++------------	99	ULSB	300	37
.----------------++++--------------------------------	100	PYNT	350	17
.--------+++---	101	YNAM	200	9
.-----++++++---	102	BUND	560	6
.+++---	103	SJJU	100	1
.-------------++++-----------------------------------	104	YESU	329	14
.------------------------------+++-------------------	105	WIC1	150	31
.-----------------------+++--------------------------	106	WIC1	150	24
.------+++---	107	WIC1	150	7
.--+++-----	108	WIC1	150	45
.----------------+++---------------------------------	109	WIC2	150	17
.---+++	110	WIC2	150	50
.-------------------------------+++------------------	111	WIC2	150	32
.-------------------+++------------------------------	112	WIC2	150	20
.-------------------------------++++-----------------	113	ULSN	400	32
.------------------------------------++++------------	114	ULSN	400	37
.----------------++++--------------------------------	115	ULSN	400	17
.------------+++-------------------------------------	116	JEJU	40	13
.------------------------------+++-------------------	117	YNAM	200	31
.---------------------------------------++++---------	118	ICNC	325	40
.---------++++---------------------------------------	119	ICNC	325	10
.----+++---	120	SJJU	100	5
.--+++-----	121	ICNC	250	45
.--------------+++-----------------------------------	122	ICNC	250	15
.+++---	123	NJJU	75	1
.---+++------	124	SJJU	20	44
.------------------------------+++-------------------	125	SJJU	20	31
.--------------+++-----------------------------------	126	YESU	200	15
.------------+++-------------------------------------	127	NJJU	75	13
.--------------++++----------------------------------	128	BUSN	300	15
.---++++-----	129	BUSN	300	44
.------------------------++++------------------------	130	BUSN	300	25
.-----------------++++-------------------------------	131	BUSN	300	18
.--------------------+++-----------------------------	132	ULSN	200	21
.------+++---	133	ULSN	200	7
.------------------------------+++-------------------	134	SEOL	138	31
.---+++------	135	SEOL	250	44
.-------------------------------++++-----------------	136	ICNB	321	32
.--------------------++++----------------------------	137	ULSB	300	21
.++++--	138	ULSB	300	1
.------++++--	139	SIC1	300	7
.------------------------------++++------------------	140	SIC2	300	31
.-----------++++-------------------------------------	141	SIC2	300	12
.--------------------------+++-----------------------	142	ULSN	200	27
.--------------------------+++-----------------------	143	ILSN	200	27
.--------++++--	144	SIC1	300	9
.----++++--	145	BORB	300	5
.-------------++++-----------------------------------	146	BORB	300	14
.------------------------++++------------------------	147	BORB	300	25
.------------------------------+++-------------------	148	ULSB	200	31
.-----------------------------++++-------------------	149	BORB	300	30
.--------++++--	150	ILSN	400	9
.+++---	151	BUND	225	1
.----++++--	152	BUND	375	5
.---+++------	153	NJJU	10	44
.------++++--	154	PYNB	320	7
.--------------------+++-----------------------------	155	HNLM	105	21
.------------------------------+++-------------------	156	HNLM	55	31
.+++---	157	HNLM	70	1

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