Transmission System Expansion Planning of KEPCO System(Youngnam Area) using Fuzzy Set Theory

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***Abstract*-- This study proposes a new method for the transmission system expansion planning using the fuzzy integer programming. It presents stepwise cost characteristics analysis which is a practical condition of an actual systems. A branch and bound method which includes the network flow method and the maximum flow - minimum cut set theorem has been used in order to proceed the stepwise cost characteristics analysis. Uncertainties of the permission of the construction cost and not strict reserve rate and load forecasting of expansion planning can be included for the long-term transmission expansion planning and also processed using fuzzy set theory in this study. The reasonable solution can be obtained using fuzzy branch and bound method which includes the network flow method and maximum flow-minimum cut set theorem. Case studies on Youngnam area of KEPCO (Korea Electric Power Corporation) system show that the algorithm proposed is efficiently applicable to the horizontal expansion planning of transmission systems in future.**

***Index Terms*-- Transmission system expansion planning, Fuzzy set theory, Fuzzy integer programming, Fuzzy branch and bound method.**

I. Introduction

The past times, the primary function of power system was that “an electric power system had to provide electrical energy to its customers as economically as possible and with an acceptable degree of continuity and quality"[1]. The conventional methods of power system expansion planning have been focused to only generation expansion planning without transmission systems. The expansion planning of the transmission system has been evaluated after planning the generation system expansion. In recent, the electricity industries, however, are asked for being winner of competition in the world under the capitalism social system and deregulation and restructure of power system[2]. It is more important to assess and construct reasonable reliability criteria at load points under localization social system controlled by local self government. And so, the recent problem of the power system expansion planning is focused to the composite power systems expansion planning considering generation system as well as components of transmission system, which are the lines, transformers, switches, etc. The power system expansion planning is an optimization problem for the cost minimization under a reliability level constraint[3-5]. If no or only a very small database for evaluation of component reliability indices is available, method based on fuzzy theory may be better approaches for the evaluation of system reliability indices than complex statistic methods until the data base completed reasonably[6-8]. Items considered for composite power system expansion planning are usually as following.

Load forecasting
System characteristics
Reliability level
Economical efficiency

It is not easy to have the expansion planning solution of power system considering the all items. In this study, a new method for the composite power systems expansion planning using the fuzzy set theory is proposed for considering the flexibility or ambiguity of investment cost and the uncertainty of the supply and delivery reserve power rate of the HLI(Hierarchical Level I) and HLII(Hierarchical Level II) [3]. Something are assumed as following. Network flow method for only active power instead of AC power flow is used. The assumed network flow method is sufficient for long term planning problem. Some draft plans/scenarios is made and come forward as candidates. And also this problem is limited to static expansion planning problem for the single-stage or horizon-year. General methodology in order to obtain the optimal solution for the expansion planning problem formulated with Integer Programming is to select a optimal plan of some draft plans/scenarios as the candidates. It presents the stepwise cost characteristics analysis which is a practical condition of an actual systems. A branch and bound method which includes the network flow theory and the

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maximum flow - minimum cut set theorem has been used in order to obtain the optimal solution and proceed the stepwise cost characteristics analysis. Uncertainty of the power system has been also included using fuzzy set theory. The effectiveness of the proposed new approach is demonstrated by case study of Youngnam area of KEPCO system.

II. Fuzzy Integer Programming

The composite power systems expansion planning is ordinary integer problem with only 0-1 as eq.(1)[6].

$$\left.\begin{aligned} &maximize\ (minimize)\ \mathbf{F(x)} \\ &sub.to\quad \mathbf{Ax} \le \mathbf{b} \\ &\quad \mathbf{x} = \{\mathbf{0},\ \mathbf{1}\} \end{aligned}\right\} \tag{1}$$

Where **x** : decision vector

F : coefficient matrix of the objective function(q×n)

A : coefficient matrix of the constraints(p×n)

b : constant vector of constraints (RHS) (p×1)

In the case of the problem of some fuzzy characteristics, it can be formulated with the FIP(Fuzzy Inter Programming) as eq.(2).

$$\left.\begin{aligned} &\mathbf{F(x)} \lesssim \mathbf{Z_0}\ \text{(fuzzy objective functions: q)} \\ &\mathbf{Ax} \lesssim \mathbf{b}\ \text{(fuzzy constraints: p)} \\ &\mathbf{x} = \mathbf{0,1}\ \text{(0,1 constraints: n)} \end{aligned}\right\} \tag{2}$$

If the fuzzy mathematical programming problem consist of finding a maximum point of the membership functions according to the fuzzy optimal decision policy which is the maximization of the satisfaction level of a decision maker, the optimal solution **x*** for the above problem can be obtained as eq.(3).

$$\max_{\mathbf{X}\ge 0}[\min\{\min_{i=1,\dots,q} m_i(\mathbf{F(x)}), \min_{i=1,\dots,p} m_i(\mathbf{Ax})\}]$$

$$= \max_{\mathbf{x}\ge 0}[\min_{i=1,\dots,p+q} m_i(\mathbf{B(x)})] \tag{3}$$

Where, **x*** is the optimal decision solution.

max and min are abbreviations of maximum and minimum respectively.

$m_i(\cdot)$: the membership function of #i-th fuzzy inequality constraints

$$\mathbf{B} = \begin{bmatrix} \mathbf{F(x)} \\ \mathbf{Ax} \end{bmatrix}$$

Using a parameter, λ, which means a satisfaction level of the decision maker, eq.(3) can be equalized to eq.(4) which is a formulation of the numerical analysis problem as following.

$$\left.\begin{aligned} &maximize\quad l \\ &sub.to\quad l \le m_i(\mathbf{B(x)}) \\ &\mathbf{x} = \{\mathbf{0,1}\} \\ &\lambda ^3\ \mathbf{0} \end{aligned}\right\} \tag{4}$$

The optimal solution of the problem can be obtained by an optimization algorithm. The arbitrary shape of the membership functions is available for fuzzy integer programming because the fuzzy integer programming is originally nonlinear programming.

III. The Transmission Systems Expansion Planning Problem

A. Network Modeling of Power System

The generators, substations and load points have the limited capacities and it is difficult to check a shortage power supply of the power system because the generators, substations and load points are presented as nodes in real system model diagram. Network modeling of the power system is convenient for checking a shortage of power supply because the generators, substations and load points are presented as branches with the capacity limitation[4]. Aspects of a shortage of power supply according to bottle neck are as followings as Table 1.

TABLE 1
VARIOUS ASPECTS OF POWER SUPPLY BOTTLE NECK

Fm=L≤G	no shortage supply
Fm=G<L	shortage of the supply power of generation system
Fm<L≤G	shortage of the delivery capacity of transmission system
Fm<G<L	shortage of the supply power and delivery capacity of generation system and transmission system

Where, *Fm*: maximum flow of the network

G: total generation power

L: total load

B. Formulation of Expansion Planning

The following eq.(5) constraints for no shortage power supply of a power system have to be satisfied using the maximum flow - minimum cut set theorem.

$$P_c(X, \overline{X}) \ge L \qquad (s \in X,\ t \in \overline{X}) \tag{5}$$

Where, $P_c(X, \overline{X})$ is the maximum flow of minimum cut set of sets , X and $\overline{X}$ of branches between

(Source)s and (Sink) t (=Fm)
N is a set of all branches,
X is a subset including source of N ,
$\overline{X}$ is a subset including sink of $N - X$,
complementary set of X.

The composite power systems expansion planning based on the minimum cut-set theorem can be formulated as fuzzy integer programming as follow.

1) Objective Functions(minimization of construction cost)

$$minimize \quad C^T = \sum_{(x,y)\in B} [\sum_{i=1}^{m(x,y)} C^i{}_{(x,y)} U^i{}_{(x,y)}] \quad (6)$$

The fuzzy goal function with the given aspiration level of the decision-maker for the construction cost, eq.(6) can be represented as following eq.(7).

$$C^T \lessapprox z_c^* \quad (7)$$

2) Constraints

$$\sum_{(x,y)\in(x_k,\bar{x}_k)} [P^{(0)}_{(x,y)} + \sum_{i=1}^{m(x,y)} P^{(i)}{}_{(x,y)} U^i{}_{(x,y)}] \geq L \quad (8)$$

And also, the fuzzy constraint function with the fuzziness of the power delivery of the transmission system can be formulated as following eq.(9).

$$\sum (P_{(x,y)} - L) \times 100 / L \gtrapprox z_R^* \quad (9)$$

Where, variables and parameters are used as following.

$$C^{(i)}_{(x,y)} = \sum_{j=1}^{i} \Delta C^{(j)}_{(x,y)} \quad (10)$$

$$P^{(i)}_{(x,y)} = \sum_{j=1}^{i} \Delta P^{(j)}_{(x,y)} \quad (11)$$

$$\sum_{i=1}^{m(x,y)} U^i_{(x,y)} = 1 \quad (12)$$

$$U^i_{(x,y)} = \left[\begin{array}{l} 1, P_{(x,y)} = P^{(0)}_{(x,y)} + P^{(i)}_{(x,y)} \\ 0, P_{(x,y)} \neq P^{(0)}_{(x,y)} + P^{(i)}_{(x,y)} \end{array} \right. \quad (13)$$

$$P_{(x,y)} = P^{(0)}_{(x,y)} + \sum_{i=1}^{m(x,y)} P^{(i)}_{(x,y)} U^{(i)}_{(x,y)} \quad (14)$$

L : total demand of loads
$\Delta C^{(j)}_{(x,y)}$: construction cost of #*j* parallel element of branches between node x and node y
$\Delta P^{(j)}_{(x,y)}$: capacity of #*j* parallel element of branches between node x and node y
k : number of cut-set(=1, 2, 3 ... n)
B : set of all branches
$m(x,y)$: the number of new and additional branches between node x and node y

C. Equivalent Integer Programming and Branch and Bound Method

The eq.(6)-eq.(8), the fuzzy expansion planning problem of the composite power system is equalized to crisp type equivalent integer programming, eq.(15) using eq.(4).

$$\begin{array}{ll} maximize & l \\ sub.\,to & C^T + d_1 l \leq z_c^* + d_1 \\ & \sum (P_{(x,y)} - L) \times 100 + d_2 l \geq z_R^* + d_2 \end{array} \quad (15)$$

Where, d_i : permissible width of membership function of the i-th fuzzy inequality equation

Cutting plane method, Implicit enumeration method and branch and bound method can be used in order to obtain the optimal solution of integer programming problem. The branch and bound method has a merit that the problem has more constraints, the better it is. Therefore, the general branch and bound method has been used in order to search the optimal solution of this problem formulated with fuzzy integer programming in this study.

IV. MEMBERSHIP FUNCTIONS

A. Membership function of fuzzy set for the construction costs is defined as [11,12]:

$$m_c\{P_{(x,y)}\} = \left\{ \begin{array}{ll} 1 & : \Delta C(\cdot) \leq 0 \\ e^{-Wc \quad \Delta C\{P_{(x,y)}\}} & : \Delta C(\cdot) \rangle 0 \end{array} \right\} \quad (16)$$

Where, $\mu_c(\cdot)$: membership function of fuzzy set for the construction cost
$\Delta C(\cdot) = \{C(P_{(x,y)}) - Casp\} / Casp$
Casp : aspiration level for construction cost
W_c : weighting factor of the membership function for construction cost
$C(P_{(x,y)})$: construction cost at $P_{(x,y)}$

B. Membership function of fuzzy set for the supply reserve rate of HLII is defined as:

$$m_r\,\{P_{(x,y)}\} = \begin{cases} 1 & : \Delta R(\cdot) \geq 0 \\ e^{W_r \,\Delta R\{P_{(x,y)}\}} & : \Delta R(\cdot) < 0 \end{cases} \qquad (17)$$

where, $\mu_r(\cdot)$: membership function of fuzzy sets for supply reserve rate

$\Delta R(\cdot) = \{RES(P_{(x,y)}) - Rasp\} / Rasp$

Rasp: aspiration level for supply reserve rate of composite power system (HLII)

W_r: weighting factor of the membership function for supply reserve rate of HLII

$RES(P_{(x,y)})$: reserve rate at $P_{(x,y)}$

V. Case Studies

The proposed method was applied to the Youngnam area of KEPCO system as Fig.1. Table 2 shows input data of real size system for case studies. In Table 2, GN, TL and LD present the type of generator, transmission and load buses respectively. Also, SB and EB are starting bus and ending bus respectively. Table 3 shows the results of a crisp case with minimization of construction cost. The configuration of the transmission system expansion planning obtained in the crisp case study is shown in Fig. 1. In this Figure, the dotted transmission lines mean the new construction lines of the transmission system expansion planning obtained in the crisp case study. Input data of fuzzy cases are shown in Table 4. Z_c and Z_r are the aspiration level of cost and reserve rate respectively. W_c and W_r mean weighting factors of membership functions eq.(16) and eq.(17). Also, Fig. 2 and Fig. 3 show the shape of membership functions for construction cost and the supply and delivery reserve rate respectively.

TABLE 2
INPUT DATA OF CAPACITY AND COST

NL	SB	EB	ID	P(0)	P(1)	P(2)	P(3)	P(4)	C(0)	C(1)	C(2)	C(3)	C(4)
1	1	4	GN	3240	0	0	0	0	0	0	0	0	0
2	1	8	GN	210	0	0	0	0	0	0	0	0	0
3	1	15	GN	1000	0	0	0	0	0	0	0	0	0
4	1	23	GN	500	0	0	0	0	0	0	0	0	0
5	1	49	GN	660	0	0	0	0	0	0	0	0	0
6	1	62	GN	1237	0	0	0	0	0	0	0	0	0
7	1	63	GN	1900	0	0	0	0	0	0	0	0	0
8	1	68	GN	2800	0	0	0	0	0	0	0	0	0
9	7	78	GN	400	0	0	0	0	0	0	0	0	0
10	17	82	GN	100	0	0	0	0	0	0	0	0	0
11	13	116	GN	1397	0	0	0	0	0	0	0	0	0
12	9	123	GN	90	800	0	0	0	0	0	0	0	0
13	2	125	GN	50	800	0	0	0	0	0	0	0	0
14	2	3	TL	104	104	0	0	0	0	40	29	0	0
15	2	4	TL	816	408	408	0	0	0	82	82	0	0
16	3	4	TL	816	408	408	0	0	0	82	82	0	0
17	4	5	TL	73	73	0	0	0	0	34	0	0	0
18	4	11	TL	73	73	0	0	0	0	34	0	0	0
19	4	44	TL	4000	1000	1000	1000	1000	0	200	200	200	200
20	4	47	TL	308	308	0	0	0	0	82	0	0	0
21	5	6	TL	73	73	0	0	0	0	34	0	0	0
:		:		:		:		:		:		:	
:		:		:		:		:		:		:	
295	119	130	LD	22	0	0	0	0	0	0	0	0	0
296	121	130	LD	53	0	0	0	0	0	0	0	0	0
297	122	130	LD	18	0	0	0	0	0	0	0	0	0
298	124	130	LD	93	0	0	0	0	0	0	0	0	0
299	126	130	LD	62	0	0	0	0	0	0	0	0	0
300	127	130	LD	30	0	0	0	0	0	0	0	0	0
301	128	130	LD	28	0	0	0	0	0	0	0	0	0
302	129	130	LD	63	0	0	0	0	0	0	0	0	0

TABLE 3
RESULTS OF CRISP CASE

Total construction cost	226(M$)
Supply reserve rate	18.429(%)
Delivery reserve rate	18.079(%)
Total branches	3181
Solutions	Samchunpo Thermal-Chungmu:1line Samchunpo Thermal-Chungmu:1line Pusan Thermal-Youngdo: 1line New Ulsan-New Gyeongsan:1line

TABLE 4
INPUT DATA OF FUZZY CASE

	Z_c	W_c	Z_r	W_r
Case F1	200	15	15	10
Case F2	250	15	20	20
Case F3	230	15	19	15

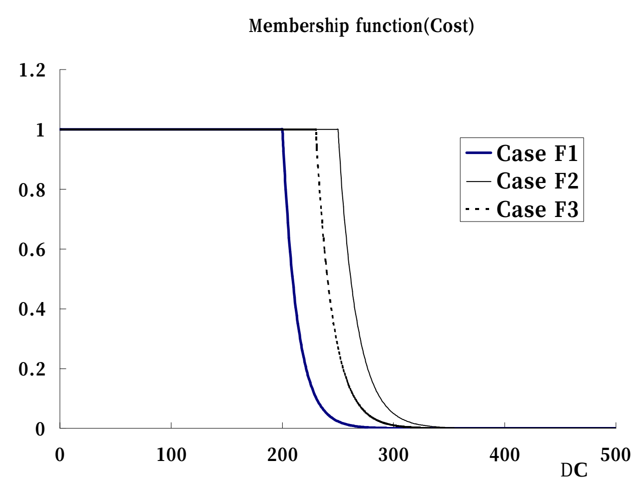

Fig. 3. Membership function of construction cost

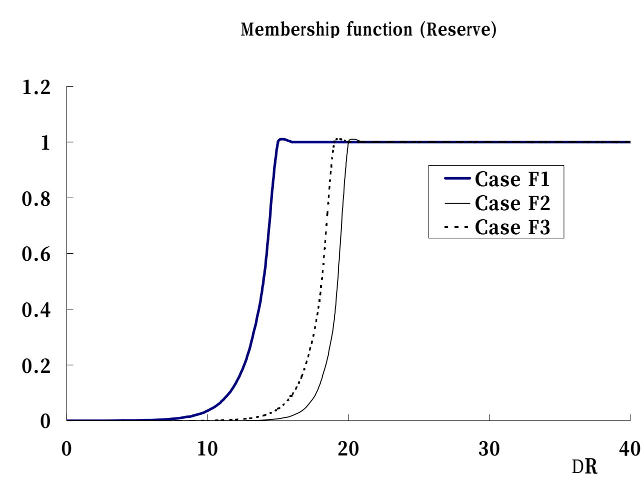

Fig. 4. Membership function of supply and delivery reserve rate.

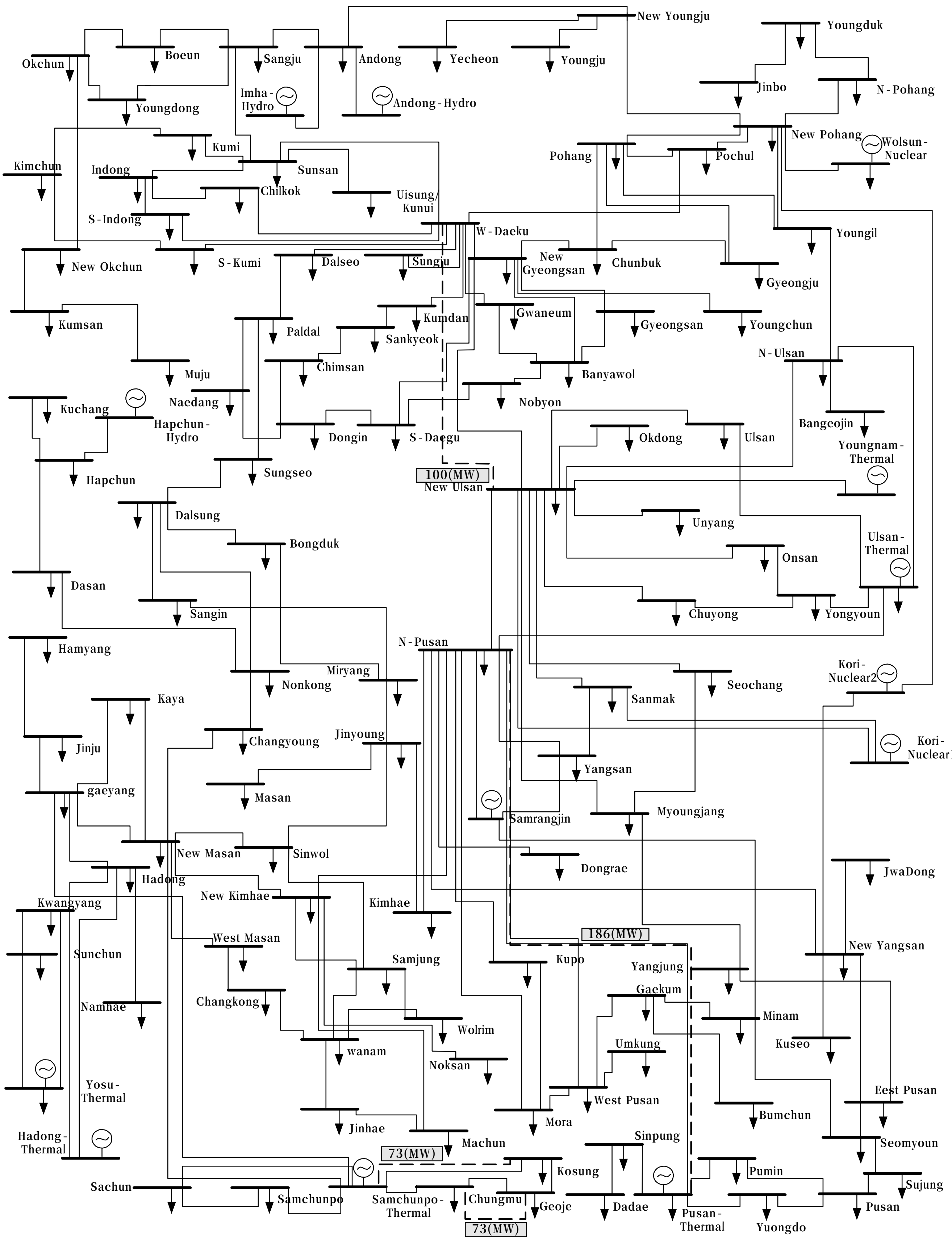

Fig. 1. The single line diagram of the KEPCO system(Youngnam area) and new lines for construction obtained in the crisp case study (dotted mark lines).

Results of three fuzzy cases are shown in Table 5. While Case F1 has the budget constraint of construction cost in strict, Case F2 is strict for reliability constraint than Case F1. And, Case F3 is the case study of which the budget of construction cost and constraint of reliability level are more flexible than Case F1 and Case F2. Table 5 shows that the highest satisfaction level can be obtained from Case F3 of the three cases studies. It means that membership functions of the Case F3 provide the more flexible expansion plan. According to the analysis of the case studies, the expert for planning can obtain reasonable aspiration level and weighting factor of the membership function for the system.

TABLE 5
RESULT OF FUZZY CASES

	Branches	Satisfaction Levels
Case F1`	3181	0.14227
Case F2	14861	0.14653
Case F3	5076	0.48347

VI. CONCLUSIONS

This study proposes a new method for the expansion planning of transmission systems with uncertainties of the construction cost(economics) and supply and delivery reserve rate(reliability) using fuzzy integer programming. The composite power system expansion planning problem with the uncertainties of power system has been formulated. The FIP(Fuzzy Integer Programming) has been used in order to obtain the optimal solution of the composite power system expansion planning problem with uncertainty. A fuzzy branch and bound method which includes the network flow method and the maximum flow - minimum cut set theorem has been used in order to obtain the optimal solution and proceed the stepwise cost characteristics analysis. A optimal plan of some draft plans/scenarios candidated can be selected by the method. The practicability and effectiveness of the proposed method have been demonstrated by simulation results of Youngnam area of KEPCO system. It is necessary to develop and study an algorithm for the transmission expansion planning considering nodal probabilistic reliability constraints in future.

VII. ACKNOWLEDGEMENT

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IX. BIOGRAPHIES

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