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Reliability Investigation of Series-Parallel and Components of Power System using Interval Type-2 Fuzzy Set Theory

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ABSTRACT: Fuzzy set based methods have been proved to be effective in handling many types of uncertainties in different fields, including reliability engineering. This paper presents a new approach on fuzzy type-2 reliability, based on the use of type-2 FOU as membership function. Considering experts ideas and by asking operators linguistic variables, a rule base is designed to determine the level of reliability of each component. The outputs of the presented model are type-2 fuzzy sets representing the reliability levels of components. After determining the level of reliability of each component, the reliability of the composed system can be determined by using t-norm and s-norm functions. The system can be parallel, series, parallel- series or series-parallel.

In the present paper the probabilistic consideration of basic events is replaced by possibilities, thereby leading to fuzzy fault tree analysis. Triangular and trapezoidal type-2 fuzzy numbers are used to represent the failure possibility of basic events. The failure possibility of a basic event will be assigned more than one type-2 fuzzy numbers by different experts under various operating conditions. The proposed techniques are discussed and illustrated by taking an example of a Thermal power plant.

KEYWORDS: Fuzzy reliability of series parallel components; interval type-2 Fuzzy sets, Fuzzy Fault tree analysis (FTA).

I.INTRODUCTION

Fault tree analysis (FTA) seems to be a very effective tool to predict probability of hazard, resulting from sequences and combinations of faults and failure events. A fault tree is a logical and graphical description of various combinations of failure events. To depict a fault tree, first we determine the hazards and then look for the events causing this hazard. In conventional FTA based on a probabilistic approach the basic events are represented by the probabilities (crisp numbers). However for the system like nuclear power plants, space shuttles, clinical appliances etc., wherein available data are insufficient for statistical inference (Jackson et al., 1981), it is often very difficult to estimate precise failure rates of the basic events. For such systems it is therefore unrealistic to assume a crisp number (classical) for different basic events. Zadeh (1965) suggested a paradigm shift from a theory of total denial and affirmation to a theory of grading to give new concept of fuzzy set. Tanaka and Singer (1983, 1990) then used fuzzy set theory to replace crisp numbers by fuzzy numbers for better estimation of possibility of top event in FTA. (Suresh et al. 1996) used a method based on α-cuts to deal with FTA, treating the failure possibility as triangular and trapezoidal fuzzy numbers.

Accurate failure data is a crucial requirement for reliability assessment. In many situations, where human judgment, evaluation and decision-making are important, failure data may not be corrected accurately. It might sometime require linguistic terms to express data value (Pandey et al. 2007). But if more than one fuzzy number is assigned to a particular event then random selection of any of these fuzzy numbers to determine the failure possibility of this event is not realistic. This work proposes a method to obtain a single fuzzy number having least variance with the fuzzy numbers assigned to that particular event.

In FTA the concept of importance may be used to make some vital modifications in the designing of system. (Furuta et al. 1984) proposed the concept of fuzzy importance using max-min fuzzy operator and fuzzy integral. (Pan et al. 1988) developed a model for computing the importance measure of basic events using variance importance measure. Monte-Carlo simulation is generally used in the determination of variance importance measure even though computing process is time taking in this method. Thus for a very complex system having large number of components, the whole procedure has to be repeated again and again, thus not suitable for the fuzzy approach. (Suresh et al. 1996) proposed another method to evaluate an importance measure called fuzzy importance measure (FIM).For effective evaluation of the importance index of each basic events, we have introduced a comparatively easier method to calculate fuzzy importance index (FII), based on ranking of fuzzy numbers and Hamming distance. The proposed methods are demonstrated by taking an example of nuclear power plant.

In real system, the information is inaccuracy and supposed to linguistic representation, the estimation of precise values of probability becomes very difficult in many cases. In order to handle the insufficient information, the type-2 fuzzy approach is used to evaluate the failure rate status. Singer presented a type-2 fuzzy set approach for fault tree and the reliability analysis in which the relative frequencies of the basic events are considered as fuzzy numbers. Pointed out that there are two fundamental assumptions in the conventional reliability theory, i.e. (a)Binary state assumptions: the system is precisely defined as functioning or failing. (b) Probability assumptions: the system behavior is fully characterized in the context of probability measures. However, because of the inaccuracy and uncertainties of data, the estimation of precise values of probability becomes very difficult in many systems. (Cai et al. 1993) presented the following two assumptions: (a) Fuzzy-State assumption: the meaning of the system failure can't be precisely defined in a reasonable way. At any time the system may be in one of the following two states: fuzzy success state or fuzzy failure state.(b) Possibility assumption: the system behavior can be fully characterized in the con text of possibility measures. (Cai et al. 1993) presented the following three forms of "fuzzy reliability theories". (i) Profust reliability theory, based on the probability assumption and fuzzy-state assumption. (ii)Posbist reliability theory, based on the possibility assumption and binary-state assumption. (iii) Posfust reliability theory, based on the possibility assumption and the fuzzy-state assumption.

(Cheng and Mon 1994) used interval of confidence for analyzing the fuzzy system reliability. (Chen 1994) presented a new method for analyzing the fuzzy system reliability using fuzzy number arithmetic operations and used simplified fuzzy arithmetic operations rather than complicated interval fuzzy arithmetic operations of fuzzy numbers or the complicated extended algebraic fuzzy numbers. (Chen 1994) presented a new method for fuzzy system reliability analysis based on fuzzy time series and the α-cuts arithmetic operations of fuzzy numbers. So far, in the literature, arithmetic operations between same types of vague sets are discussed. Also to analyze the fuzzy system reliability, it is assumed that the reliability of all components of a system follows the same membership functions. However, in practical problems, such type of situations rarely occurs. Therefore, it is need of a method by which we can also find the fuzzy reliability of systems having components following different type of type-2 membership functions.

To illustrate the above approach the fuzzy reliability of series, parallel, parallel-series and series-parallel systems all consisting of four components has been evaluated using the proposed algorithm.

II.RELATED WORK

The reliability of a system can be determined on the basis of tests or the acquisition of operational data. However, due to the uncertainty and inaccuracy of this data, the estimation of precise values of probabilities is very difficult in many systems (e.g. power system, electrical machine, hardware etc., Hammer (2001), El-Hawary (2000)).

The basis for this approach is constituted by the fundamental works on fuzzy set theory of Zadeh (1978), Dubois and Prade (1980), Zimmerman (1986) and other. The theory of fuzzy reliability was proposed and development by several authors, Cai, Wen and Zhang (1991, 1993); Cai (1996); Chen, Mon (1993); Hammer (2001); El-Hawary (2000), Onisawa, Kacprzyk (1995); Utkin, Gurov (1995). The recent collection of papers by Onisawa and Kacprzyk (1995), gave 654 I.M. ALIEV, Z. KARA many different approach for fuzzy reliability. According to Cai, Wen and

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Zhang (1991, 1993); Cai (1996) various form of fuzzy reliability theories, including profust reliability theory Dobois, Prade (1980); Cai, Wen and Zhang (1993); Cai (1996); Chen, Mon (1993); Hammer (2001); El-Hawary (2000); Utkin, Gurov(1995), posbist reliability theory, Cai, Wen and Zhang (1991, 1993) and posfust reliability theory, can be considered by taking new assumptions, such as the possibility assumption, or the fuzzy state assumption, in place of the probability assumption or the binary state assumption. Chen [14] analyzed the fuzzy system reliability using vague set theory. The values of the membership and non-membership of an element, in a vague set, are represented by a real number in [0, 1]. Cai, Wen and Zhang (1993) presented a fuzzy set based approach to failure rate and reliability analysis, where profust failure rate is defined in the context of statistics. El-Nawary (2000) presented models for fuzzy power system reliability analysis, where the failure rate of a system is represented by a triangular fuzzy number.

The work of Jerry M.Mendel and Feilong Liu (2007) on Super-Exponential Convergence of the Karnik–Mendel Algorithms for Computing the Centroid of an Interval Type-2 Fuzzy Set is a well-recognized work in the field. Design of Interval Type-2 Fuzzy Logic Based Power System Stabilizer (Imam Robandi, and Bedy Kharisma 2008) has sufficient materials as a reference work. Juan R. Castro and Oscar Castillo (2007) worked on Interval Type-2 Fuzzy Logic for Intelligent Control Applications. Also Jerry M. Mendel and Robert I.Bob John (2002) presented, how Type-2 Fuzzy Sets Made Simple. Mamdani (1974) developed the method to apply the fuzzy algorithm for simple control of dynamic plant. Qureshi (2003) published his work on power system reliability problems, control problems and protection problems. Qureshi (2004) in his Ph.D. thesis took the project work of Reliability of nuclear plants using fuzzy logic transformation. R.R.Yager(2000) reported a valuable information on fuzzy subsets of type-2 in decision. N.N.Karnik and J.M. Mendel worked on interval type-2 fuzzy logic systems and reported his findings in IEEE Transactions, fuzzy systems.

III. FUZZY NUMBERS AND ARITHMETIC OPERATIONS

FUZZY OPERATORS

Using algebraic operations on fuzzy numbers (triangular or trapezoidal) we can obtain fuzzy operators FNOT, ANDF and ORF corresponding to Boolean operators NOT, AND and OR respectively as follows.

(i) If a fuzzy event 'i' is represented by a possibility function p̃I the generalized Boolean operator NOT to be denoted by FNOT and defined as:(for triangular fuzzy numbers)

$$\mathrm{FNOT}\ P_i = 1 - P_i = 1 - (a_{i1}, a_{i2}, a_{i3}) = (1 - a_{i3}, 1 - a_{i2}, 1 - a_{i1})$$

(ii) If p̃1, p̃2,….. p̃n are the possibility functions of n basic events and p̃y be the same for resulting event. Then the fuzzy operators ANDF and ORF are defined in the following manner:

$$\tilde{p}_y = \mathrm{ANDF}(\tilde{P}_1, \tilde{P}_2, \tilde{P}_3 \dots \dots .. \tilde{P}_n) = \prod_{i=1}^{n} \tilde{p}_i,$$

(a) where ∏ denotes the fuzzy multiplication and p̃y be the possibility of resulting event.

Let p̃i 's are represented by triangular fuzzy numbers (ai1, ai2, ai3), i=1,2…n, then

$$\tilde{p}_y = \mathrm{ANDF}(\tilde{P}_1, \tilde{P}_2, \tilde{P}_3 \dots \dots .. \tilde{P}_n) = \prod_{i=1}^{n}(a_{i1}, a_{i2}, a_{i3}) = \left(\prod_{i=1}^{n} a_{i1}, \prod_{i=1}^{n} a_{i2}, \prod_{i=1}^{n} a_{i3}\right)$$

(b) Let p̃i 's are represented by triangular fuzzy numbers (ai1, ai2, ai3), i=1,2…n, then

$$\tilde{p}_y = \mathrm{ORF}(\tilde{P}_1, \tilde{P}_2, \tilde{P}_3 \dots \dots .. \tilde{P}_n) = 1 - \prod_{i=1}^{n}\left(1 - (a_{i1}, a_{i2}, a_{i3})\right) = 1 - \prod_{i=1}^{n}(1 - a_{i3}, 1 - a_{i2}, 1 - a_{i1})$$

$$= 1 - \left(\prod_{i=1}^{n}(1 - a_{i3}), \prod_{i=1}^{n}(1 - a_{i2}), \prod_{i=1}^{n}(1 - a_{i1})\right)$$

$$= \left(1 - \prod_{i=1}^{n}(1 - a_{i1}), 1 - \prod_{i=1}^{n}(1 - a_{i2}), 1 - \prod_{i=1}^{n}(1 - a_{i3})\right)$$

Using Zadeh's Extension Principle, the membership grades for union, intersection and complement of type-2 fuzzy sets A˜ and B˜ have been defined as follows:

Union: $\tilde{A} \cup \tilde{B} \Leftrightarrow \mu_{\tilde{A}\cup\tilde{B}}(x) = \mu_{\tilde{A}}(x) \cup \mu_{\tilde{B}}(x)$

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Intersection: $\tilde{A} \cap \tilde{B} \Leftrightarrow \mu_{\tilde{A}\cap\tilde{B}}(x) = \mu_{\tilde{A}}(x) \cap \mu_{\tilde{B}}(x)$
Complement: $\overline{\tilde{A}} \Leftrightarrow \mu_{\overline{\tilde{A}}}(x) = 1 - \mu_{\overline{\tilde{A}}}(x)$

INTERVAL TYPE-2 FUZZY SETS:

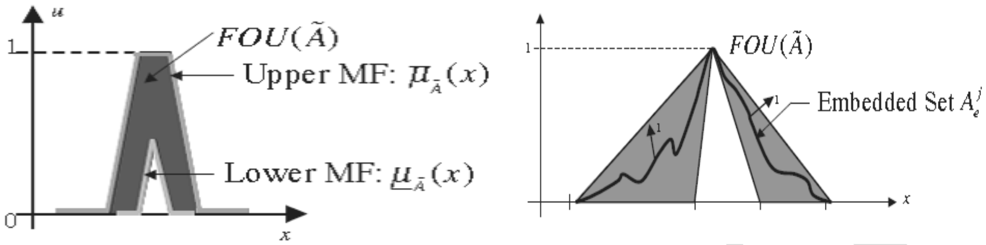

Fig.1 Interval Type-2 Fuzzy Sets

The upper MF is abbreviated to UMF, and lower MF is abbreviated to LMF. An over-bar on the T2 MF denotes the former, and an under-bar on the T2 MF denotes the latter. The LMF and UMF play very important roles in all calculations involving IT2 FSs. An embedded set (also called an embedded T1 FS) is a function that lies within or on the FOU. Two other examples of embedded sets are the LMF and UMF. A short arrow labeled "1" is shown along the embedded T1 FS. When it is included with the embedded T1 FS, the result is an embedded T2 FS. Because the third dimension of a general T2 FS is irrelevant for an IT2 FS, it is unnecessary to carry along the equal unit secondary grades. The FOU says it all for an IT2 FS. For a continuous FOU (i.e. a completely filled-in FOU) there are an uncountable number of embedded sets. Don’t' worry, though, because such sets will only be used for theoretical derivations, and never for computation. If both the primary and secondary variable axes are discretized, then there will be a countable number of embedded sets, but there could still be an astronomical number of them. Again, don't worry because such sets will only be used for theoretical derivations, and never for computation Observe that an embedded set looks like a wavy slice that cuts through the FOU.

$$\overline{A} = {}^{1}\!\big/_{\mathrm{FOU}(\overline{A})} = {}^{1}\!\big/_{\cup_{j=1}^{n_A} A_e^j} = \begin{cases} {}^{1}\!\big/_{\{\underline{\mu}_A(x),\ldots.\overline{\mu}_A(x)\}} & \forall x \in X_d \\ {}^{1}\!\big/_{[\underline{\mu}_A(x),\overline{\mu}_A(x)]} & \forall x \in (X) \end{cases}$$

The 1/FOU(x) notation is a shorthand notation. It means the secondary grades equal 1 at all points in the FOU.

- $\tilde{A} \cup \tilde{B} - {}^{1}\!\big/_{[\underline{\mu}_A(x) \vee \underline{\mu}_B(x), \overline{\mu}_A(x) \vee \overline{\mu}_B(x)]} \quad \forall x \in X$
- $\tilde{A} \cap \tilde{B} - {}^{1}\!\big/_{[\underline{\mu}_A(x) \wedge \underline{\mu}_B(x), \overline{\mu}_A(x) \wedge \overline{\mu}_B(x)]} \quad \forall x \in X$
- $\overline{\overline{A}} = {}^{1}\!\big/_{[1-\overline{\mu}_A(x), 1-\underline{\mu}_A(x)]} \quad \forall x \in X$

TRIANGULAR INTERVAL TYPE 2 FUZZY SET

A triangular interval type-2 fuzzy $\tilde{A}^i$ set over the universe of discourse X shown in Fig. 2 may be denoted $\tilde{A}^i = < [(a_1, a_2, a_3); \mu_{\tilde{A}}(x)], [(a_1', a_2', a_3'); v_{\tilde{A}}(x)] >$. The membership function is denoted as $\mu_{\tilde{A}}(x)$.

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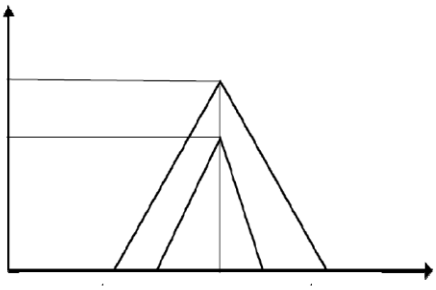

Fig. 2 Triangular interval type-2 fuzzy Number

IV. FUZZY IMPORTANCE

In FTA we have observed that each basic event play different role in the occurrence of top event, which infers that the basic events are of different importance. Thus a critical analysis of the importance of different basic events may help in making a proper sequence of their importance. On improving the reliability of the event having greater importance, one can improve the reliability of the system. The fuzzy importance of any event is always calculated in the form of fuzzy importance index (FII). This FII may be evaluated by ranking fuzzy numbers (PT –PTi) for i=1,2,3…n. Here PT and PTi denote the possibility of absolute occurrence of top event and the possibility of occurrence of top event in absence of basic event i respectively. In our analysis we have used less complicated and very significant method for ranking of fuzzy numbers. To rank the fuzzy numbers (PT –PTi)'s for i=1, 2,...n, first of all we have to find MAX (PT –PTi) i=1,2…n, where the MAX operator on fuzzy numbers is defined as below.

$$\mathrm{MAX}(A_1, A_1, A_1, \dots. A_n)(z) = \sup_{z=\max(x_1, x_{2,---}x_n)} \min\, [A_1(x_1), A_2(x_2), \dots. A_n(x_n)]$$

Where A1, A2, A3 … An are different fuzzy numbers.

Taking the MAX of given fuzzy numbers, we try to get the distance of all these fuzzy numbers from their MAX with the help of Hamming distance formula [0,1]

$d_H(A, B) = \int |A(x) - B(x)|\, dx$ Between two fuzzy numbers A and B.

The distance of these fuzzy numbers (PT –PTi) for i =1, 2 …n from their MAX decides the rank of fuzzy numbers (PT –PTi). Smaller the distance of fuzzy number (PT –PTi) from MAX (PT –PTi) ,i=1,2…n, in comparison to distance of PT PT2 − from MAX (PT –PTi) implies that fuzzy number (PT –PTi) is greater than (PT –PTi). It concludes that the fuzzy importance index (FII) may be defined in form of distance of PT from PTi i.e.

$$\mathrm{FII}(i) = \frac{1}{1 + \text{Distance of fuzzy number } \left(P_T - P_{T_i}\right) \text{ from their MAX}}$$

V. RELIABILITY ANALYSIS OF SERIES AND PARALLEL COMPONENTS

In this section, taking the reliability of each component to be a triangular interval type-2 fuzzy set we have evolved a fuzzy reliability evaluation technique for series and parallel systems. Let us consider a system consisting of n components, the interval type-2 fuzzy $\tilde{R}_j^i$sets j=1,2,3…….n, are taken to represent the reliability of each component. If the components are connected as a series system as shown in Fig.3, the reliability $\tilde{R}_s^i$ of the series system is defined as follows:

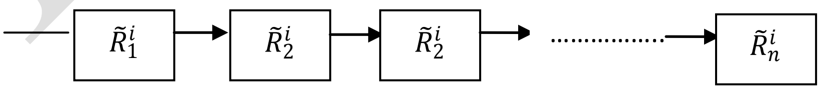

Fig. 3 Systems in Series

$$\tilde{R}_s^i = \otimes_{j=1}^n \tilde{R}_j^i = < \left[\left(\prod_{j=1}^{n} a_{1j}, \prod_{j=1}^{n} a_{2j}, \prod_{j=1} a_{3j}\right): \min_{j=1\dots n} \mu_{\tilde{A}_j}(x)\right], \left[\left(\prod_{j=1} a_{1j}, \prod_{j=1} a_{2j}, \prod_{j=1}^{n} a_{3j}\right): \max_{j=1\dots n} v_{\tilde{A}_j}(x)\right] >$$

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If the components are supposed to be in parallel as shown in Fig.4, the reliability $\tilde{R}_p^i$ of the parallel system can be defined by using the expression

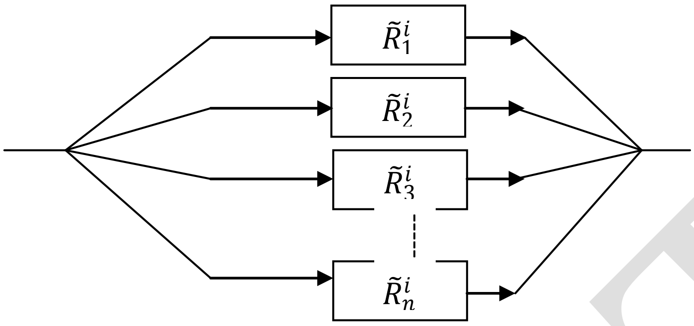

Fig. 4 Parallel System

$$\tilde{R}_p^i = 1 - \prod_{i=1}^{n}\left(1 - \tilde{R}_1^i\right) =$$
$$< \left[\left(1 - \prod_{i=1}^{n}(1 - a_{1i}), 1 - \prod_{i=1}^{n}(1 - a_{2i}), 1 - \prod_{i=1}^{n}(1 - a_{3i})\right) : \min_{j=1\ldots n} \mu_{\tilde{A}_j}(x)\right], \left[\left(1 - \prod_{i=1}^{n}(1 - a_{1i}), 1 - \prod_{i=1}^{n}(1 - a_{2i}), 1 - \prod_{i=1}^{n}(1 - a_{3i})\right) : \max_{j=1\ldots n} v_{\tilde{A}_j}(x)\right] >$$

PARALLEL-SERIES SYSTEM

Consider a parallel-series system consisting of 'm' branches connected in parallel and each branch contains 'n' components as shown in Fig.5. The fuzzy reliability $\tilde{R}PS = 1 \ominus \otimes_{k=1}^{m} (1 \ominus \otimes_{i=1}^{n} \tilde{R}ki))$ of the parallel-series system shown in Fig.5 can be evaluated using the algorithm proposed in section 3 for multiplication and subtraction. where $\tilde{R}ki$ represents the reliability of the ith component at kth branch.

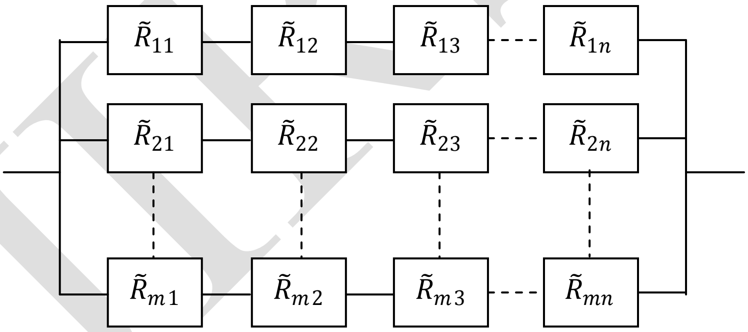

Fig.5. Parallel-Series System

Consider a series-parallel system consisting of 'n' stages connected in series and each stage contains 'm' components as shown in Fig.6. The fuzzy reliability $\tilde{R}SP = \otimes_{k=1}^{n} (1 \ominus \otimes_{i=1}^{m} (1 \ominus \tilde{R}ik))$ of the series-parallel system shown in Fig.6 can be evaluated using the algorithm proposed in section 3 for multiplication and subtraction. where $\tilde{R}ik$ represents the reliability of the ith component at kth stage.

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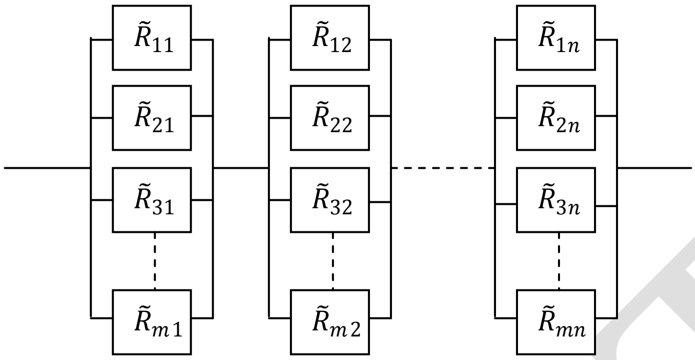

Fig.6 Series-Parallel System

VI. FUZZY FAULT TREE OF THERMAL POWER PLANT

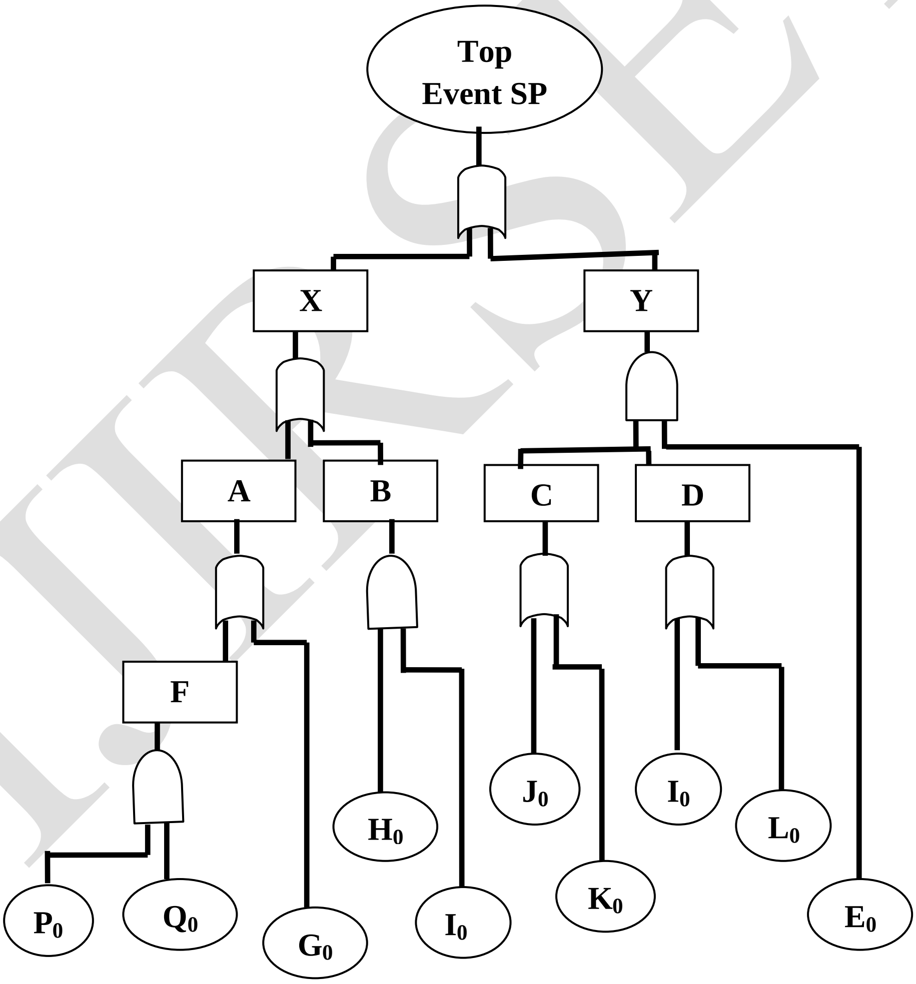

Fig.7 Fault tree of Nuclear Power Plant

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A Thermal power plant model is considered. Develop a fault tree for the desired event (i.e. top event): Each fault event in the fault tree diagram is considered as Triangular Interval Type-2 Fuzzy Number (TIT2FN) & Trapezoidal Interval Type-2 Fuzzy Number (TrIT2FN). Using series parallel components formula and fuzzy fault tree Fig.7, the reliability of thermal power plant can be investigated as below.

Steam pressure release (low) is assumed to be a hazard and treated as the top event in fault tree analysis. The Steam pressure release may be caused due to the occurrence of some events, and these events may again occur due to some other events as shown in Fig.7

The interval type-2 set operations corresponding to this Fuzzy fault tree is given below:
$SP=X \cup Y$, $X=A \cup B$, $Y=C \cap D \cap E_0$, $A= F \cup G_0$, $F=P_0 \cap Q_0$, $B=H_0 \cap I_0$, $C=J_0 \cup K_0$, $D=I_0 \cup L_0$, where

SP denotes Steam Pressure Low in turbine
Y = unwanted shaft vibration
B = thermal damage to the rotor
D = stress present
F=mechanical damage to the turbine
P_0= safety signal fails
H_0= insufficient thermal generation
J_0 =control circuit of alarm system fails
X = formation of corrosion product due to turbine blade corrosion
L_0= high premise temperature
A= physical damage to the rotor
C = alarm system fails
E_0= breach of physical boundary
G_0 = explosive damage to the boiler
Q_0 =power fails
I_0= Safety Valve not working
K_0 = sensor fails

On replacing the Boolean operators with fuzzy logic operators FNOT, ORF and ANF, we get the possibility of the top event in form of a fuzzy number. It is also assumed that each basic event is fuzzzified by assigning three fuzzy numbers to each basic event following the decision of three experts. The Triangular and trapezoidal fuzzy numbers assigned to these basic events are listed in Table 1 and Table 2.

Table 1. Triangular Interval Type-2 Fuzzy Numbers (Basic Events)

Event E_0			
Expert	**$a_{1(UMF,LMF)}$**	**$a_{2(UMF,LMF)}$**	**$a_{3(UMF,LMF)}$**
1	0.006,0.008	0.009,0.01	0.014,0.016
2	0.024,0.026	0.028,0.03	0.032,0.036
3	0.018,0.02	0.024,0.026	0.028,0.032
Event G_0			
Expert	**$a_{1(UMF,LMF)}$**	**$a_{2(UMF,LMF)}$**	**$a_{3(UMF,LMF)}$**
1	0.030,0.033	0.040,0.043	0.051,0.54
2	0.042,0.045	0.051,0.055	0.052,0.056
3	0.032,0.035	0.041,0.046	0.042,0.046
Event P_0			
Expert	**$a_{1(UMF,LMF)}$**	**$a_{2(UMF,LMF)}$**	**$a_{3(UMF,LMF)}$**
1	0.071,0.076	0.076,0.008	0.078,0.082
2	0.042,0.046	0.051,0.055	0.051,0.056
3	0.061,0.066	0.071,0.076	0.072,0.078
Event J_0			
Expert	**$a_{1(UMF,LMF)}$**	**$a_{2(UMF,LMF)}$**	**$a_{3(UMF,LMF)}$**
1	0.042,0.046	0.052,0.056	0.054,0.06
2	0.055,0.059	0.061,0.065	0.063,0.067
3	0.036,0.04	0.044,0.048	0.052,0.056

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Event L_0			
Expert	$a_{1(UMF,LMF)}$	$a_{2(UMF,LMF)}$	$a_{3(UMF,LMF)}$
1	0.041,0.045	0.12,0.15	0.14,0.18
2	0.15,0.19	0.24,0.28	0.32,0.36
3	0.16,0.21	0.21,0.25	0.22,0.26

Table 2. Trapezoidal Fuzzy Number (Basic Events)

Event Q_0				
Expert	$a_{1(UMF,LMF)}$	$a_{2(UMF,LMF)}$	$a_{3(UMF,LMF)}$	$a_{4(UMF,LMF)}$
1	0.070, 0.074	0.078, 0.082	0.084,0.088	0.091,0.095
2	0.053,0.057	0.061,0.065	0.072,0.077	0.074,0.078
3	0.044,0.047	0.051,0.055	0.054,0.057	0.062,0.068
Event H_0				
Expert	$a_{1(UMF,LMF)}$	$a_{2(UMF,LMF)}$	$a_{3(UMF,LMF)}$	$a_{4(UMF,LMF)}$
1	0.011,0.015	0.021,0.026	0.023,0.027	0.031,0.035
2	0.021,0.025	0.031,0.035	0.035,0.038	0.044,0.048
3	0.034,0.038	0.04,0.044	0.042,0.046	0.046,0.052
Event I_0				
Expert	$a_{1(UMF,LMF)}$	$a_{2(UMF,LMF)}$	$a_{3(UMF,LMF)}$	$a_{4(UMF,LMF)}$
1	0.068,0.072	0.12,0.016	0.14,0.018	0.15,0.019
2	0.17,0.021	0.22,0.026	0.21,0.025	0.23,0.027
3	0.23,0.027	0.24,0.028	0.26,0.032	0.28,0.034
Event K_0				
Expert	$a_{1(UMF,LMF)}$	$a_{2(UMF,LMF)}$	$a_{3(UMF,LMF)}$	$a_{4(UMF,LMF)}$
1	0.12,0.16	0.14,0.18	0.16,0.20	0.18,0.22
2	0.15,0.19	0.21,0.25	0.22,0.27	0.25,0.29
3	0.28,0.32	0.3,0.34	0.33,0.37	0.35,0.39

Using the approximation method discussed earlier, a single fuzzy number is obtained by which suits with all the three experts' decision for each basic event. The triangular fuzzy numbers thus obtained for each basic event are listed in Table 3.

Table 3. Approximated Triangular Fuzzy Numbers (Basic Events)

Basic Event	$a_{1(UMF,LMF)}$	$a_{2(UMF,LMF)}$	$a_{3(UMF,LMF)}$
E_0	.0162,.0166	.02,.024	.0234,.0238
G_0	.0378,.0382	.044,.048	.0520,.056
P_0	.0702,.0708	.074,.078	.0796,.080
J_0	.044,.048	.052,.056	.058,.062
L_0	.110,.114	.174,.178	.238,.242

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Table 4. Approximated Trapezoidal Fuzzy Numbers (Basic Events)

Basic Event	$a_{1(UMF,LMF)}$	$a_{2(UMF,LMF)}$	$a_{3(UMF,LMF)}$	$a_{4(UMF,LMF)}$
Q_0	.058,.062	.064,.068	.068,.072	.074,.078
H_0	.022,.026	.030,.034	.033,.037	.041,.045
I_0	.152,.156	.174,.178	.194,.198	.216,.220
K_0	.192,.196	.224,.228	.244.248	.274,.278

FII OF BASIC EVENTS IN THERMAL POWER PLANT

The fuzzy importance of each basic event can be obtained in the form of fuzzy importance index (FII) for all basic events. We calculate the possibility of top event RR using fuzzy operators and possibilities of basic events. The possibility of top event is resulted as trapezoidal fuzzy number ([.044,.048], [.054,.058], [.056,.060, [.064,.068]) given by the following expression.

$$\underline{P}\,T= \begin{cases} \frac{x-.044}{.01} & \text{if } .044\le x \le .054 \\ 1 & \text{if } .054\le x \le .056 \\ \frac{.064-x}{.012} & \text{if } .056\le x \le .064 \end{cases} \qquad \overline{P}T= \begin{cases} \frac{x-.048}{.01} & \text{if } .048 \le x \le .058 \\ 1 & \text{if } .058 \le x \le .060 \\ \frac{.068-x}{.012} & \text{if } .060 \le x \le .068 \end{cases}$$

Here PTi's for different events i= E0, G0, P0, J0, L0, Q0, H0, I0 and K0 obtained as triangular and trapezoidal fuzzy numbers are listed in Table 5.

Table 5. Possibility of Top Event in absence of different basic events

Event (*i*)	Possibility of top event in absence of event i, (P_{Ti}) $_{(UMF,LMF)}$
E_0	([.044,.046], [.052,.056], [.054,.060], [.064,.068])
G_0	([.006,.008], [.012,.016], .014,.018], [.016,020])
P_0	([.042,.046], [.052,.056], [.053,.057],[.062,.066])
J_0	([.044,.048], [.054,.058], [.056,.06],[.068,.072])
L_0	([.045,.049], [.055,.059], [.057,.061],[.069,.073])
Q_0	([.040,.044],[.052,.056], [.054,.058],[.063,.067])
H_0	([.042,.046], [.052,.056],[.060,.064])
I_0	([.043,.047], [.053,.057],[.061,.065])
K_0	([.046,.050], [.056,.060], [.058,.062],[.070,.074])

First we evaluate $\overline{P_T - P_{T_i}}$, $\underline{P_T - P_{T_i}}$ and then MAX of these fuzzy events for i=1,2…n,. The distance of the fuzzy numbers $\overline{P_T - P_{T_i}}$, $\underline{P_T - P_{T_i}}$ from their MAX is obtained by using Hamming distance formula. Fuzzy importance index (FII) is thus obtained by the following expression. $P_T - P_{T_i} = [\overline{(PT - PTi\ )} + (\underline{P_T - P_{T_i}}\ )]/2$

$$\mathrm{FII(i)} = \frac{1}{1 + \text{Distance of fuzzy number } \left(P_T - P_{T_i}\right) \text{ from their MAX}}$$

Table 6. Fuzzy Importance Index of basic events

Event	G_0	I_0	E_0	Q_0	P_0	L_0	K_0	H_0	J_0
FII (*i*)	.9989	.9756	9638	.9628	.9626	.9621	.9618.	.9618	.9617

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VII.DISCUSSION

The techniques developed in this paper are demonstrated by taking the example of a Thermal power plant, and the following results are drawn:

All basic events E_0, Q_0, I_0 etc are assigned triangular/ trapezoidal interval type-2 fuzzy numbers (TIT2FN)/(TrIT2FN) by different experts under prescribed condition. Using technique developed in this paper, a single interval type-2 fuzzy number for each basic event is obtained, that tunes fine with all experts' judgments. In many situations, where the failure possibility of different basic events is collected from different experts under various operating conditions. It is more useful to adopt this realistic approach to get a single interval type-2 fuzzy number for this purpose.

Applying the method developed in our study for the importance of basic events, the fuzzy importance index (FII) of basic events is calculated. The basic events are listed in Table 6, in accordance with the descending order of their FII. It is observed that the basic event G_o is of higher sensitivity (greater importance) in comparison to other succeeding events.

Taking note of FII of basic events listed in Table 6, it is concluded that we should emphasize on basic event G_o rather than other succeeding events I_o, E_o etc. to improve the reliability of the Thermal power plant.

VIII.CONCLUSION

This paper presents reliability investigation of Series-Parallel and Components of thermal power plant using Interval Type-2 Fuzzy Set Theory. Applying the method developed in our study for the importance of basic events, the fuzzy importance index (FII) of basic events is calculated. The basic events are listed in Table 6, in accordance with the descending order of their FII. It is observed that the basic event G_o is of higher sensitivity (greater importance) in comparison to other succeeding events. Taking note of FII of basic events listed in Table 6, it is concluded that we should emphasize on basic event G_o rather than other succeeding events I_o, E_o etc. to improve the reliability of the Thermal power plant. Also arithmetic operation of proposed TIT2FN/TrIT2FN is evaluated. Here, a method to analyze system reliability which is based on interval type-2 fuzzy set theory has been presented, where the components of the system are represented by TIT2FN/TrIT2FN fuzzy number. By performing the techniques developed here early in design phase of various complex systems like nuclear power plant, potential deficiencies can be identified and averted to precipitate the occurrence of various basic events causing the happening of top event.

REFERENCES

1. Attanassov, K.T. (1986). "Intuitionistic fuzzy sets. Fuzzy Sets and Systems", Vol. 20, pp.87-96.
2. Attanassov, K.T. (1989). "More on intuitionistic fuzzy sets", Fuzzy Sets and Systems Vol. 33, Issue 1, 37-46.
3. Attanassov, K.T. (1999). "Intuitionistic Fuzzy Sets", Physica-Verlag, Heidelberg, New York.
4. Bowles, J.B. and Palaez, C.E. (1995). "Application of fuzzy logic to reliability engineering", Proceeding of the IEEE, Vol.83, No. 3, pp.435-449.
5. Cai, K. Y., Wen C. Y. and Zhang, M. L. (1993). "Fuzzy states as a basis for a theory of fuzzy reliability", Microelectronic Reliability, Vol. 33, pp. 2253-2263.
6. Cai, K. Y., Wen, C. Y. and Zhang, M. L. (1993). "Fuzzy variables as a basis for a theory of fuzzy reliability in the possibility context", Fuzzy Sets and Systems, Vol. 42, pp. 142-145.
7. Cai, K.Y. (1996). "System failure and fuzzy methodology: An introductory overview". Fuzzy Sets and Systems, Vol. 83, pp. 113-133.
8. Chen, S. M. (1994). "Fuzzy system reliability analysis using fuzzy number arithmetic operations", Fuzzy Sets and Systems, Vol. 64, pp. 31-38.
9. De, S.K., Biswas R. and Roy, A.R. (2000). "Some operations on intuitionistic fuzzy sets", Fuzzy Sets and Systems, Vol. 114, pp. 477–484.
10. De, S.K., Biswas R. and Roy, A.R. (2001). "An application of intuitionistic fuzzy sets in medical diagnosis", Fuzzy Sets and Systems, Vol. 117, pp. 209–213.
11. Deschrijver, G. and Kerre, E.E. (2002). "On the relationship between intuitionistic fuzzy sets and some other extensions of fuzzy set theory", Journal of Fuzzy Mathematics, Vol. 10, Issue 3, pp. 711–724.
12. Mitchell, H. B. (2004). "Ranking-Intuitionistic Fuzzy Numbers, International Journal of Uncertainty", Fuzziness and Knowledge-Based Systems, Vol. 12, Issue 3, pp. 377-386.

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ISSN: 2319-8753

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(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 11, November 2014

13. Mong D.L. and Cheng C.H. (1994). "Fuzzy system reliability analysis for components with different membership functions", Fuzzy Sets and Systems, Vol. 64, pp. 145–157.
14. Pandey D. and Tyagi S. K. (2007). "Profust reliability of a gracefully degradable system Fuzzy Sets and Systems", Vol. 158, pp. 794-803.
15. Pandey D., Tyagi S. K. and Kumar V. (2009). "Failure mode screening using fuzzy set theory", International Mathematical Forum, Vol.16, Issue 4, pp. 779-794.
16. Singer D. (1990). "A fuzzy set approach to fault tree and reliability analysis", Fuzzy Sets and Systems, Vol. 34, pp. 145-155.
17. Stoyanova D. and Attanassov K.T. (1990). "Relations between operators, defined over intuitionistic fuzzy sets", IM-MFAIS, Vol. 1, pp. 46-49, Sofia, Bulgaria.
18. Zadeh L. A. (1965). "Fuzzy sets, Information Control", Vol.8, pp. 338-353.
19. Furuta H. and Shiraishi N. (1984). "Fuzzy importance in fault tree analysis". Fuzzy Sets and Systems, Vol. 12, pp. 205-213.
20. Gozaloz A. (1990). "A study of ranking function approach through mean values". Fuzzy Sets and Systems, Vol. 35, pp. 29-41.
21. Grogorzewek P. and Mrowka E. (2005). "Trapezoidal approximation of fuzzy numbers". Fuzzy Sets and Systems, Vol. 53, pp. 115-135.
22. Jackson P.S., Hockenbury R.W. and Yeater M.L. (1981). "Uncertainty analysis of system reliability and availability assessment". Nuclear Eng. Des., Vol. 68, pp. 5-29.
23. Klir G.J. and Yuan B.O. (1995). "Fuzzy sets and fuzzy logic, Theory and Applications". Prentice Hall, Upper Saddle River, NJ.
24. Pan Z.J. and Tau Y. (1988). "Variance importance of system components by Monte-Carlo", IEEE Trans. Reliability, Vol. 37, pp. 421-423.
25. Pandey D. and Tyagi S.K. (2009). "Failure mode screening using fuzzy set theory". International Mathematical Forum, Vol. 4, No. 13-16, pp. 779 – 794.
26. Singer D. (1990). "A fuzzy set approach to fault tree analysis". Fuzzy Sets and Systems, Vol. 34, pp.145-155.
27. Suresh P.V., Babar A.K. and Venkat Raj V. (1996). "Uncertainty in fault tree analysis: A fuzzy approach". Fuzzy Sets and Systems, Vol. 83, pp.135-141.
28. Tanaka H., Fan L.T., Lai F.S. and Toguchi K. (1983). "Fault-tree analysis by fuzzy probability". IEEE Trans. Reliability, Vol. 32, pp. 453-457.
29. Coupland S. and John R. (2007), "Geometric type-1 and type-2 fuzzy logic systems", IEEE Transactions on Fuzzy Systems Vol. 15, Issue 1, pp. 3–15.
30. Coupland S. and John R. (2008), "A fast geometric method for defuzzification of type-2 fuzzy sets", IEEE Transactions on Fuzzy Systems Vol. 16, Issue 4, pp. 929–941.
31. Zadeh L.A. (1975). "The concept of a linguistic variable and its application to approximate reasoning-1". Information Sciences, Vol. 8, pp. 99 – 249.
32. Mendel J.M. (2001). "Uncertain Rule-Based Fuzzy Logic Systems: Introduction and New Directions". Prentice Hall, Upper Saddle River, NJ.
33. John R.I. (1998). "Type-2 fuzzy sets:an appraisal of theory and applications". Uncertainty, Fuzziness and Knowledge-Based Systems, Vol. 6, pp. 563–576.
34. John R.I. and Coupland S., "Type-2 fuzzy logic a historical view". IEEE Computational Intelligence Magazine, Vol. 2, Issue 1, pp. 57–62, February 2007.
35. Mendel J. M., "Advances in type-2 fuzzy sets and systems". Information Sciences, Vol. 177, Issue 1, pp. 84-110, January 2007.
36. Dubois D. and Prade H. "Fuzzy Sets and Systems: Theory and Applications", volume 144. Academic Press INC, NY, USA, 1980.
37. Gorzalczany M.B. "A method of inference in approximate reasoning based on interval valued fuzzy sets". Fuzzy Sets and Systems, Vol. 21, pp.1–17, January 1987.
38. Mendel J.M., John R.I. and Liu F., "Interval type-2 fuzzy logic systems made simple". IEEE Transaction on Fuzzy Systems, Vol. 14, Issue 6, pp. 808–821, December 2006.
39. Hong D. H. and Lee S., "Some algebraic properties and a distance measure for interval valued fuzzy numbers". Information Sciences, Vol. 148, Issue (1-4), pp. 1–10, December 2002.
40. Wang G. and Li. X. (1998). "The applications of interval-valued fuzzy numbers and interval distribution numbers". Fuzzy Sets and Systems, Vol. 98, Issue 3, pp.331–335.
41. Mendel J. M. and John R.I. (2002). "Type-2 fuzzy sets made simple". IEEE Transaction on Fuzzy Systems, Vol. 10, Issue 2, pp. 117–127.
42. Karnik N.N. and Mendel J.M. (2001). "Operations on type-2 fuzzy set". Fuzzy Sets and Systems, Vol. 122, Issue 2, pp. 327–348.

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