ISSN 0974 - 9373

Vol. 18 No.3 (2014) **Journal of International Academy of Physical Sciences** pp. 231-240

Vague Reliability Analysis for Fault Diagnosis in Power Transformers

M. K. Sharma
Department of Mathematics,
R.S.S. (PG), Pilkhuwa, (Hapur) U.P. – India-245304
drmukeshsharma@gmail.com

D. Pandey
Department of Mathematics
Ch. Charan Singh University, Meerut

(Received March 28, 2014)

Abstract: Due to information transmission mistakes as well as arisen errors while processing data in surveying and monitoring state information of any system, uncertain and incomplete information may be produced. Based on these points, present paper extends our study for the development of a vague scheme for fault tree analysis of any general system. The functioning of the developed vague scheme is demonstrated for diagnosis of fault in power transformers using vague fault tree analysis (VFTA) and beta distribution for failure possibility estimation. By using these techniques we have proposed herein the vague numbers to give a realistic estimate of failure possibility of a basic event in VFTA. Further, it explains a new approach based on Euclidean distance between vague numbers, to rank the basic events in accordance with their Vague Importance Index (VII).

Keywords: Vague Fault Tree, Power Transformer, Vague Sets, Expert Systems, Vague Importance Index (VII), Vague Fault Tree Analysis (VFTA)

1. Introduction

The involvement of a very large number of variables and their multiple inter relations make the design of a power transformer very complicated. This complicacy in design of a power system and variations in operating conditions cause uncertain and random occurrence of faults. Fault Tree Analysis (FTA) has been proved to be a very effective tool to predict probability of hazard, caused by a sequence and combinations of faults and failure events. With the availability of the concept of fuzzy sets given by Zadeh [1] in 1965. In 1983, Tanaka et al. [2] used fuzzy set theory to replace a crisp number by fuzzy number for better estimation of failure possibility of top event. In 1990, Singer [3,4] presented fuzzy set theoretic approach and fuzzy logic to fault tree analysis. In 1994 & 1996, Chen [5, 6] used arithmetic of fuzzy numbers to evaluate system reliability, in 2003, he [7] gave the concept of reliability analysis of the system using vague sets. In 1998, Chandra et al. [8] gave an approach to reliability analysis to transmission expansion planning using fuzzy fault tree model. In 1995, Yang [9] constructed a fuzzy approach to fault diagnosis which is used in fuzzy fault tree analysis to represent knowledge of the causal relationships in the process operation and control system. Fuzzy set theoretic approach for estimating failure rate parameters was developed by Pandey et.al [10] in 2007, which provided the comprehensive results in estimation of variety of parameters involving human judgment, vague operating conditions, etc. In 2009, they [11] further developed a technique that proved successful in other area of knowledge, fuzzy reasoning and in the evaluation and assessment of equipment failure modes etc. In 2006, Chang et al. [12] gave the concept of vague fault tree analysis in the reliability analysis of fault diagnosis in weapons system. In 2010, Sharma et al. [13] showed the usefulness of the extensions of vague sets in fault tree analysis and constructed the vague fault tree. In 2007, Tong Wu et al [14] also introduced a method for fault diagnosis of power transformer. In 1996 , P. V. Suresh et al. [15] proposed another method to evaluate an importance measure called fuzzy importance measure (FIM).

Accurate failure statistics is crucial requirement for reliability estimation in power transformer failure in a situation where failure data may not be obtained accurately due to various reasons. Since a power transformer may be installed under different operating conditions, it is impractical to assign a single vague number to the failure possibility of the basic events in fault tree analysis. To overcome this problem, we have categorized the operating conditions of a power transformer as "Worst Case Condition", "Conducive Environment" and "Highly Conducive Environment" for a power transformer to work. In our work in this paper, we have also proposed a very precise and realistic approach based on PERT method to get a single vague number for each basic event. Our approach uses vague numbers and generalizes the PERT method to evaluate the failure possibility of each basic event to enable us to give more realistic estimates of failure possibility of basic events. Therefore, in this paper we have also extended the work of Pandey et al. [16] by using the vague sets and proved that our results are more realistic and if we neglect the non-membership function then the results match with their results.

2. Proposed Algorithm To Evaluate Failure Possibility of Basic Events

In the proposed algorithm, vague numbers have been used instead of crisp/fuzzy numbers to represent failure possibility of occurrence of each basic event in fault tree analysis. For the sake of simplicity, triangular vague numbers are used to define the failure of the basic events. Since a triangular vague number is capable to capture the impreciseness of experts' assessments, the vagueness of unreliable data is easy to compute.

Step 1: First identify an undesirable top event (Hazard), intermediate events and the basic events leading to top event by exploring history concerned with the failure of that event. Further connect these events using logical gates "AND" and "OR" to get the pictorial representation of occurrence of top event.

Step 2: Since the basic events follow different statistical properties of sampled data collected for a particular event, so the data for the occurrence of the basic events must be collected by different experts, which in the present case is three, say A, B and C. Further the observations be taken under the prescribed category of operating conditions, classified as "Worst –Case Conditions", "Conducive Environment and "Highly Conducive Environment" respectively.

Step 3: Using sampled data collected by the experts A, B and C the possibility of occurrence of basic events are assigned different vague numbers.

Step 4: It is a well known fact that mostly a system is operated under "Conducive Environment". So it is assumed that the data collected for the failure of a basic event follows a skewed beta distribution. Thus a PERT method based technique is used to find a single vague number to the failure possibility of a basic event. If $\tilde{p}_w(\tilde{E}_i)$, $\tilde{p}_c(\tilde{E}_i)$ and $\tilde{p}_h(\tilde{E}_i)$ are vague numbers assigned to a basic event $\tilde{E}_i$ by Expert A, B and C taking observations in "Worst Case Condition", "Conducive Environment" and "Highly Conducive Environment" respectively, then the failure possibility of the basic event E_i may be given as

$$\tilde{p}(\tilde{E}_i) = \frac{\tilde{p}_w(\tilde{E}_i) + 4\tilde{p}_c(\tilde{E}_i) + \tilde{p}_h(\tilde{E}_i)}{6}$$

Step 5: The vague number thus obtained for different basic events are used to compute failure possibility of top event.

3. Failure Possibility of Fault in Power Transformer

Fault Tree Analysis of Fault:

The fault tree of Fault in power transformer is taken as an analytical example to explain the proposed algorithm of fault diagnosis process. The fault tree of Fault in power transformer is shown in Fig. 3

We use following codes' for basic and intermediate events of power transformer.

Top event $\tilde{T}$: Fault; **Intermediate Events:**

$\tilde{M}_1$: Cannula Overheating; $\tilde{M}_2$: Inside Discharging;

$\tilde{M}_3$: Outer Insulated Flashover; $\tilde{M}_4$:Deterioration of Insulation;

$\tilde{M}_5$: High Contact Resistance; $\tilde{M}_6$:Abnormal Overvoltage;

Basic Events:

$\tilde{E}_1$:Over loading; $\tilde{E}_2$:Natural Aging; $\tilde{E}_3$:Insulated Damping;

$\tilde{E}_4$:Connector Loosening; $\tilde{E}_5$:Interface Oxygenating; $\tilde{E}_6$:Nicer less Encapsulation; $\tilde{E}_7$:Outer Short Circuit; $\tilde{E}_8$:Copper Pole Contact Cable; $\tilde{E}_9$:Nicer less dipping; $\tilde{E}_{10}$:unshielded & imperfect grounding; $\tilde{E}_{11}$:Structure unreasonable; $\tilde{E}_{12}$:Lightning Conductor Failure; $\tilde{E}_{13}$:Near Lightning Spot; $\tilde{E}_{14}$:High Energy Lightning; $\tilde{E}_{15}$: Annimal; $\tilde{E}_{16}$: Dumping Flashover Murry; $\tilde{E}_{17}$:Overvoltage by Human Error; $\tilde{E}_{18}$: Human Error Fault;

The Boolean expression corresponding to this fault tree can be given as below.

$$\tilde{T} = \tilde{M}_1 \cup \tilde{E}_{18} \cup \tilde{M}_2 \cup \tilde{M}_3, \quad \tilde{M}_1 = \tilde{E}_1 \cup \tilde{M}_4 \cup \tilde{E}_6 \cup \tilde{E}_7 \cup \tilde{M}_5 \cup \tilde{E}_8$$

$$\tilde{M}_2 = \tilde{E}_9 \cup \tilde{E}_3 \cup \tilde{E}_{10} \cup \tilde{E}_8, \quad \tilde{M}_3 = \tilde{E}_{11} \cup \tilde{M}_6 \cup \tilde{E}_{15} \cup \tilde{E}_{16},$$

$$\tilde{M}_4 = \tilde{E}_2 \cup \tilde{E}_3, \quad \tilde{M}_5 = \tilde{E}_4 \cup \tilde{E}_5, \quad \tilde{M}_6 = \tilde{E}_{17} \cup \tilde{E}_{12} \cup \tilde{E}_{13} \cup \tilde{E}_{14}$$

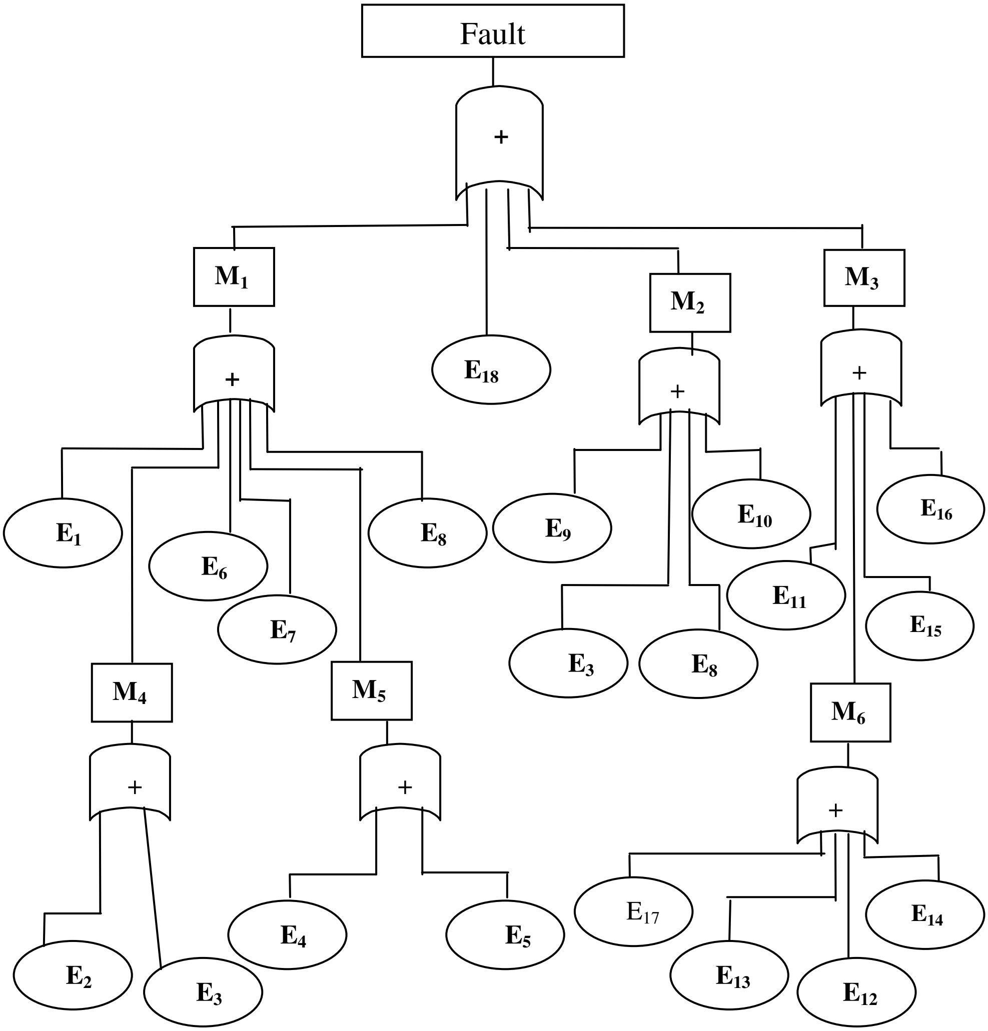

Fig. 1: Fault Tree of Fault

According to the data from [1], the accurate probability value of basic events in fault tree with statistical data is fuzzified. On employing the propose technique to evaluate the best vague number for failure possibility of each basic event we obtain a unique vague numbers for each basic event are listed in table 1

Table 1: Vague Numbers Approximated for Failure Possibility of Basic Events

Basic Event E1			Basic Event E7			Basic Event E13		
0.065	0.088	0.117	0.166	0.198	0.235	0.035	0.061	0.092
0.054	0.088	0.164	0.149	0.198	0.283	0.023	0.061	0.134
Basic Event E2			Basic Event E8			Basic Event E14		
0.06	0.088	0.116	0.07	0.108	0.145	0.05	0.08	0.117
0.048	0.088	0.158	0.058	0.108	0.214	0.038	0.08	0.165
Basic Event E3			Basic Event E9			Basic Event E15		
0.087	0.118	0.155	0.065	0.101	0.13	0.069	0.101	0.136
0.076	0.118	0.191	0.051	0.101	0.179	0.057	0.101	0.178
Basic Event E4			Basic Event E10			Basic Event E16		
0.068	0.1	0.137	0.065	0.088	0.137	0.17	0.203	0.237
0.056	0.1	0.181	0.053	0.088	0.179	0.157	0.203	0.279
Basic Event E5			Basic Event E11			Basic Event E17		
0.066	0.092	0.125	0.162	0.198	0.238	0.102	0.142	0.173
0.051	0.092	0.180	0.150	0.198	0.273833	0.092	0.142	0.218
Basic Event E6			Basic Event E12			Basic Event E18		
0.113	0.15	0.18	.04	.07	.10	0.242	0.282	0.318
0.101	0.15	0.223	0.029	0.07	0.1425	0.230	0.282	0.344

About 0.0933

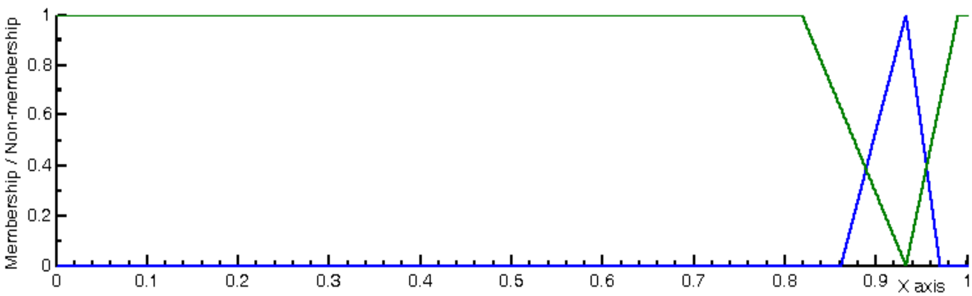

Fig. 2: Vague Failure Possibility of Fault

The approximated vague numbers listed in table 1 can also be represented in the failure possibility of the basic events in the form of membership functions.

The graphical presentation of vague failure possibility of fault in power transformer is shown in fig 2.

Table 2: Vague failure Possibility of top event when basic event E_i does not happen

Basic Event (E_i)	Possibility of top event when basic event E_i does not happen (P_{T_i})
E_1	< (0.852004, 0.926671, 0.96645) : (0.808464, 0.926671, 0.988246) >
E_2	< (0.852791, 0.926671, 0.966488) : (0.809671, 0.926671, 0.98833 >
E_3	< (0.833995, 0.914032, 0.95851) : (0.787775, 0.914032, 0.984987) >
E_4	< (0.851527, 0.925693, 0.965672) : (0.808058, 0.925693, 0.988002) >
E_5	< (0.851845, 0.926348, 0.966143) : (0.80907, 0.926348, 0.988017) >
E_6	< (0.843995, 0.921322, 0.963872) : (0.798451, 0.921322, 0.987354) >
E_7	< (0.834081, 0.916613, 0.961275) : (0.787082, 0.916613, 0.986296) >
E_8	< (0.840009, 0.915949, 0.959475) : (0.795808, 0.915949, 0.984095) >
E_9	< (0.852004, 0.92561, 0.965949) : (0.80907, 0.92561, 0.988032) >
E_{10}	< (0.852004, 0.926671, 0.965672) : (0.808666, 0.926671, 0.988032) >
E_{11}	< (0.834873, 0.916613, 0.961122) : (0.786832, 0.916613, 0.986469) >
E_{12}	< (0.855858, 0.92809, 0.967084) : (0.813396, 0.92809, 0.988541) >
E_{13}	< (0.856605, 0.928779, 0.967374) : (0.814542, 0.928779, 0.988654) >
E_{14}	< (0.854341, 0.927308, 0.96645) : (0.81165, 0.927308, 0.988232) >
E_{15}	< (0.851368, 0.92561, 0.965712) : (0.807855, 0.92561, 0.988046) >
E_{16}	< (0.833281, 0.91609, 0.961173) : (0.785062, 0.91609, 0.986372) >
E_{17}	< (0.845906, 0.922055, 0.964178) : (0.800448, 0.922055 0.987435) >
E_{18}	< (0.817445, 0.906857, 0.956562) : (0.764685, 0.906857, 0.985021) >

Table 3: Vague Importance Index of Basic Events

Basic Event (E_i)	Vague Importance Index (VII)	Basic Event (E_i)	Vague Importance Index (VII)
E_1	0.0122303	E_{10}	0.0125017
E_2	0.0116086	E_{11}	0.0327691
E_3	0.0356175	E_{12}	0.0083313
E_4	0.0133893	E_{13}	0.0072848
E_5	0.012627	E_{14}	0.0101126
E_6	0.0221886	E_{15}	0.0135416
E_7	0.0333767	E_{16}	0.0343238
E_8	0.0296811	E_{17}	0.020198
E_9	0.0129839	E_{18}	0.0532211

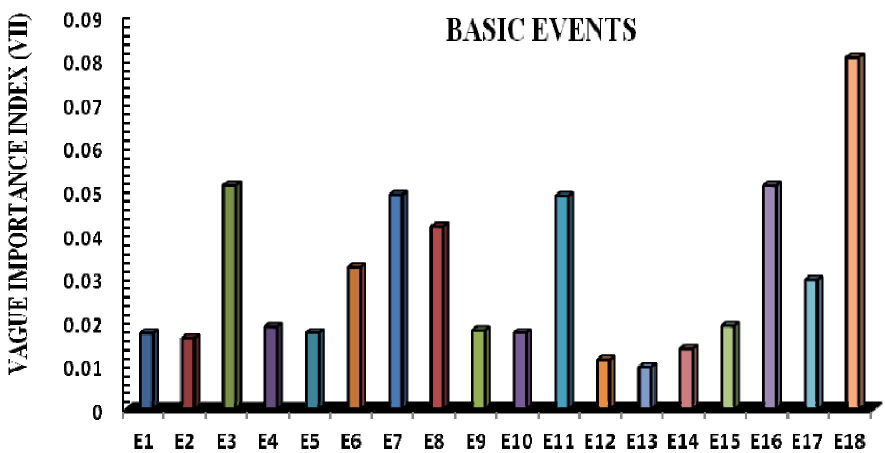

Fig. 3: Vague Importance Index of basic events

Vague Importance Index (VII) of Basic Events in Fault Diagnosis:

To illustrate proposed method of Vague Importance Index (VII), we implement it to the Fault Tree Analysis of Fault in power transformer. The vague failure possibility of top event calculated herein is,

$$<\left(0.861624,\ 0.933124,\ 0.970375\right):\left(0.818807,\ 0.933124,\ 0.990174\right)>.$$

The failure possibility of top event for each basic event E_i is listed in Table 2.

The Vague importance index for each basic event E_i, obtained by using the following expression is listed in Table 4 and shown in Fig. 3

$$\text{VII}\ (\tilde{E}_i) = \text{ED}\ (\tilde{p}_T, \tilde{p}_{T_i})$$

$$= \sqrt{(l-l^i)^2 + (m-m^i)^2 + (u-u^i)^2 + (v-v^i)^2 + (m-m^i)^2 + (w-w^i)^2}$$

Discussion and Conclusions

In this paper we have introduced a novel approach to approximate the failure possibility of basic events, if more than one vague number was assigned to a particular basic event by different experts. The possibilities of basic events were considered to be triangular vague numbers. Three vague numbers were assigned to each basic event by three Experts A, B and C. These experts collected data for failure of each component in three different operating conditions "Worst Case Conditions", "Conducive Environment" and "Highly Conducive Environment". Unlike previous techniques, here we deliberated over the operating conditions rigorously and assessed the weightage of each of them. Taking view of this, we generalized the PERT method for vague numbers to obtain the best choice of vague number to a basic event. The proposed method is observed to be very pragmatic and preclude of failure possibility for basic events.

Further since, all basic events do not contribute equally in failure of a system that is, in the occurrence of top event, so it is important to assess the importance of each basic event. We have, in our work, employed a very effective and computationally easy technique to obtain vague important index. The implementation of proposed methods is demonstrated through the diagnosis of fault in power transformer. We classified eighteen basic events, which lead to the occurrence of top event, and also compare the result of failure possibility of vague numbers with the fuzzy numbers and calculate the fuzzy and vague impotence index. We finally reached to the conclusion that the reliability of Power Transformer may be improved by preventing occurrence of basic event E_{18}.

References

1. L. A. Zadeh, Fuzzy Sets, *Information and Control*, **8(3)** (1965) 338-353.
2. H. Tanaka, L. T. Fan, F. S. Lai, K. Toguchi, Fault-tree analysis by fuzzy Probability, *IEEE Reliability Society*, **32(5)** (1983) 453-457.

3. D. Singer, A fuzzy set approach to fault tree analysis, *Fuzzy Sets and Systems*, **34(2)** (1990) 145-155.

4. D. Singer, Fault tree analysis based on fuzzy logic, *Computers Ind. Engng.*, **14(3)** (1990) 259-266.

5. S. M. Chen, Fuzzy system reliability analysis using fuzzy number arithmetic operations, *Fuzzy Sets and Systems*, **64(1)** (1994) 31-38.

6. S. M. Chen, Evaluating weapon systems using fuzzy arithmetic operations, *Fuzzy Sets and Systems*, **77(3)** (1996) 265-276.

7. S. M. Chen, Analyzing Fuzzy System Reliability using Vague Set Theory, *International J. Applied Science and Engineering*, **1(1)** (2003) 82-88.

8. R. S. Chanda, P. K. Bhattacharjee, A reliability approach to transmission expansion planning using fuzzy fault-tree model, *Electric PowerSystem Research*, **45(2)** (1998) 101-108.

9. Z. X. Yang, Fuzzy fault diagnostic system based on fault tree analysis, *IEEE*, **l(1)** (1995) 165 -170.

10. D. Pandey, Sanjay Kumar Tyagi, "Profust reliability of a gracefully degradable system", *Fuzzy Sets and Systems*, **158(7)** (2007) 794-803.

11. D. Pandey, Sanjay kumar Tyagi and Vinesh Kumar, Failure mode screening using fuzzy set theory, *International Mathematical Forum*, **4(16)** (2009) 779-794.

12. J. R. Chang, K. H. Chang, S. H. Liao, C. H. Cheng, The reliability of general vague fault-tree analysis on weapon systems fault diagnosis, *Soft Computing*, **10(7)** (2006) 531-542.

13. M. K. Sharma and D. Pandey, Vague Set Theoretic Approach to Fault Tree Analysis, *Journal of International Academy of Physical Sciences*, **14(1)** (2010) 1-14.

14. Tong Wu. Guangya, Tu. Z. Q. Bo and A. Klimek, "Fuzzy set theory and fault tree analysis based method suitable for fault diagnosis of power transformer", *The 14th International Conference on Intelligent Systems Applications to Power Systems (ISAP 2007),* November 4-8, 2007, Kaohsiung, Taiwan, 487-491.

15. P. V. Suresh, A. K. Babar, V. Venkat Raj, Uncertainty in fault tree analysis: A fuzzy approach, *Fuzzy Sets and Systems*, **83(2)** (1996) 135-141.

16. D. Pandey, Sanjay Kumar Tyagi and Vinesh Kumar, Fuzzy fault tree analysis for fault diagnosis of cannula fault in power transformer, *An International Journal of Applied Mathematics (AM)*, **2(11)** (2011) 1346-1355.