MODELLING OF BREAKDOWN VOLTAGE OF WHITE MINILEX PAPER IN THE PRESENCE OF VOIDS USING FUZZY LOGIC

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology
In
Electrical Engineering

By

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Under the Guidance of

Prof. Sanjeeb Mohanty

Department of Electrical Engineering

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National Institute of Technology
Rourkela

Certificate

This is to certify that the thesis entitled “**Modelling of Break Down Voltage of White Minilex Paper in the presence of voids using Fuzzy Logic**” submitted by Shri Anumula Pavan Sandeep, Shri P. V. Balakrishna, Shri Deshpande Chaitanya Arvind in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Electrical Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date :
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It is our pleasure to refer “Microsoft Word” exclusive of which the compilation of this report would have been impossible. Also it would not have been possible to complete the project without the simulation software ”MATLAB” .

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Anumula Pavan Sandeep

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ABSTRACT

Occluded gaseous cavities within the insulating materials are potential sources of electrical trees which can lead to continuous deterioration and breakdown of materials. To determine the suitability of use and to acquire the data for the dimensioning of electrical insulation systems breakdown voltage of insulators should be determined. In this project, Fuzzy Logic (FL) method is used to model breakdown voltages of White Minilex Paper samples based on experimental data generated in the laboratory. Two models are proposed with triangular and trapezoidal shape of the membership functions for the FL under both dc and ac voltage conditions. The cavities are created artificially with different dimensions. Low values of mean absolute errors of the estimated breakdown voltage of the test data show the effectiveness of such models.

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Chapter 1

INTRODUCTION

1.1 Introduction

In industrial insulation systems, aging can be mainly related to technological micro defects present in the bulk of insulation since manufacturing. The changes in micro defect numbers and sizes makes the aging process critical and difficult to determine particularly as the insulation samples were both thermally and electrically aged. Breakdown voltage tests are widely used to test for general degradation of insulation or insulation systems .

The breakdown of solid dielectrics is an event that is sudden and catastrophic[1]. The insulation cannot withstand the service voltage following it. It occurs in a time duration which is very much less than a second. The breakdown can be due to various causes such as intrinsic, electromechanical, thermal, micro discharges in the cavities[2] . Due to the application of the voltage, while in service, the electrical stress experienced by the cavities entrapped into the insulation initiate discharges when the stress value exceeds a certain critical value. At a given voltage, these discharges produce a deterioration of the insulating properties in diverse ways depending on geometrical factors and the nature of the dielectric. These eventually cause the material degradation and lead to final breakdown. Since, breakdown by discharges is so important industrially, it is worthwhile examining the factors which control the discharges.

In recent times, the modeling of breakdown voltage using soft computing techniques, such as, Artificial Neural Network (ANN)[3] and FL[4] has been gaining popularity. The advantage of using a soft computing model is that it is highly flexible[5-8] and a model can be improved simply by providing additional training data. Moreover, this kind of model can be developed in a shorter time as well as more accurately. In our work FL techniques have been proposed to model breakdown voltage for White Minilex Paper (potentially used solid dielectric materials in the industry) under ac and dc condition. As a diagnostic tool, FL techniques have been exploited for breakdown voltage estimation under artificially created air cavities of different sizes.

1.2 Objectives and organization of thesis

In this work an attempt has been made to predict the breakdown voltage under AC and DC conditions. Chapter 2 has given the basic Fuzzy Logic (FL) theory which has been used to calculate the MAE for White Minilex under AC and DC conditions. Chapter 3 has provided the results and discussions. Chapter 4 has concluded by giving scope for future work.

Chapter 2

Proposed Fuzzy Logic Theory

The breakdown voltage of White Minilex Paper under dc and ac conditions has been modeled using FL Technique. 45 sets of input-output data are used for modeling purpose for both dc and ac conditions, out of which 38 sets are used as training data and remaining 7 sets for the testing purpose. The breakdown voltage, V is a function of the thickness of the paper, t , thickness of the void t_1 and the diameter of the void, d, that is V = f (t, t_1, d). The relationship between the linguistic values and the actual values for t, t_1, d and V are presented in Table 1 and Table 2.

Table 1: Relationship between the linguistic values and the actual values for t, t_1 and d

Linguistic Values	t (mm)	t_1(mm)	d (mm)
Low	0-0.13	0-0.07	1.0-3.0
Medium Low	0.05-0.18		1.7-3.7
Medium	0.10-0.23		2.4-4.4
Medium High	0.15-0.28		3.1-5.1
High	0.20-0.33	0.08-0.15	3.8-5.8

Table 2: Relationship between the linguistic values and the actual values for V_{dc} and V_{ac}

Linguistic Values	V_{dc} (kV)	V_{ac} (kV)
Low	17-21	1.9-2.1
Medium Low	19-23	2.0-2.2
Medium	21-25	2.1-2.3
Medium High	23-27	2.2-2.4
High	26-30	2.3-2.5

The set of linguistic values assigned to t, d and V are given by

Ł= {Low (L), Medium Low (ML), Medium (M), Medium High (MH), High (H)}(1)

The Membership Functions (MFs) for t, t_1, d and V are μ_t, μ_{t1}, μ_d and μ_V respectively. Since, t and d can have five linguistic values and t_1 has 2 linguistic values, the rule base can be created with a maximum of 50 rules from the experimentally generated data. Also, μ_t, μ_d , and μ_V would be having five components corresponding to each linguistic value and μ_{t1} would be having 2 components

$$\mu_t = \{\mu_{tL}, \mu_{tML}, \mu_{tM}, \mu_{tMH}, \mu_{tH}\} \quad (2)$$

$$\mu_{t1} = \{\mu_{t1L}, \mu_{t1H}\} \quad (3)$$

$$\mu_d = \{\mu_{dL}, \mu_{dML}, \mu_{dM}, \mu_{dMH}, \mu_{dH}\} \quad (4)$$

$\mu_V = \{\mu_{VL}, \mu_{VML}, \mu_{VM}, \mu_{VMH}, \mu_{VH}\}$ (5)

The Mamdani Rule Based Inferencing (MRBI) is computationally very efficient and saves a lot of memory. Hence, it is a very popular method and has been used here to evaluate the modeled value of the breakdown voltage.

2.1 Breakdown Voltage Modeling Under dc condition:

Corresponding to the 38 training sets, 38 ‘if then’ rules are formulated under dc conditions. Out of these 38 rules, 34 rules have been used to form the rule base and the rest 4 rules could not be considered. This is because these 4 rules satisfied the inconsistency property of the if-then rules [9]. Since 7 sets of input output data have been used for testing purpose, the number of crisp input output pairs are 7 in number. The 34 rules have been presented in Table 3. The 7 sets of crisp input for the thickness of the paper and the diameter of the void, fire each of the 34 rules given in Table 3.

A typical clipped fuzzified MFs obtained by firing a rule is as follows:

$\mu_{VM1} = \text{minimum}_4\ (\mu_t^*\ , \mu_{t1}^*, \mu_d^*\ , \mu_{VM})$ (6)

Where μ_t^*, μ_{t1}^* , μ_d^* are the MFs corresponding to the crisp inputs for the thickness of the paper, thickness of the void and the diameter of the void respectively.

Similarly the other fuzzified MFs obtained by firing the rest 33 rules are $\mu_{VMH1}, \mu_{VH1}, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots, \mu_{VM10}, \mu_{VML6}$. All the 34 clipped fuzzified MFs are aggregated to form the aggregated fuzzified MFs.

The aggregated fuzzified MFs is given by

$\mu_{A1}(V) = \text{maximum}_{34}\ (\mu_{VMH1}, \mu_{VH1}, \ldots\ldots\ldots\ldots\ldots\ldots, \mu_{VM10}, \mu_{VML6})$ (7)

Table 3 has been generated from Table 4 which shows the experimentally generated data for White Minilex under DC condition.

Equations 6) and 7) have been implemented in MATLAB 7.1 environment by writing suitable codes for it. The defuzz function in the fuzzy toolbox was used to compute the defuzzified or the modeled value of the breakdown voltage V_{b2} from $\mu_{A1}(V)$

Table 3: Rule Base under dc Condition (WHITE MINILEX)

IF Input parameters			THEN Output parameters
Thickness, t	Thickness of void, t_1	Diameter of the void, d	Breakdown Voltage, V
H	L	L	M
H	H	ML	MH
MH	L	L	H
H	H	L	M
M	L	M	ML
ML	H	ML	MH
L	L	L	L
ML	H	L	L
M	L	ML	ML
MH	H	H	M
ML	L	ML	MH
M	H	ML	M
H	L	M	H
H	H	MH	MH
H	L	H	M
MH	H	ML	ML
L	L	MH	L
M	H	H	H
ML	L	L	M
M	H	MH	ML
L	L	H	L
L	H	MH	M
L	L	ML	ML
M	H	L	MH
ML	L	H	MH
ML	H	MH	M
M	L	L	MH
MH	H	L	MH
MH	L	ML	H
H	H	H	MH
H	L	MH	M
MH	L	MH	MH
ML	H	H	M
L	H	M	ML

Table 4: Experimental Results under DC conditions for t, t_1, d and V(White Minilex)

Thickness, t	Thickness of void, t1	Diameter of the void, d	Breakdown Voltage, V
0.26	0.025	1.5	19
0.26	0.125	2	20
0.22	0.025	1.5	19
0.26	0.125	1.5	20
0.18	0.025	3	23
0.155	0.125	2	26
0.125	0.025	1.5	19
0.155	0.125	1.5	20
0.125	0.025	2	24
0.22	0.125	5	23
0.155	0.125	2	26
0.18	0.025	2	24
0.26	0.025	3	20
0.26	0.125	4	26
0.26	0.025	5	19
0.22	0.125	2	24
0.22	0.125	2	24
0.125	0.025	4	20
0.18	0.125	5	20
0.155	0.025	1.5	19
0.125	0.025	5	23
0.125	0.125	4	24
0.125	0.025	2	23
0.18	0.125	1.5	23
0.155	0.025	5	19
0.155	0.125	4	19
0.18	0.025	1.5	24
0.22	0.125	1.5	26
0.22	0.025	2	23
0.26	0.125	5	20
0.26	0.025	4	23
0.22	0.025	4	20
0.22	0.125	5	19
0.125	0.125	3	20

The Mean Absolute Error (MAE) is a good performance measure for judging the accuracy of the Fuzzy System .The MAE under dc conditions expressed in percentage is given by

$$MAE_{dc}= (1/s)* \mid (\sum_{s} (V_{b1}(s) - V_{b2}(s))/(V_{b1}(s))\mid *100 \qquad (8)$$

Where V_{b1} is the experimental or the crisp value for the breakdown voltage under dc condition and s in this case is 7.

2.2 Breakdown Voltage Modeling Under AC condition:

Similarly under ac conditions corresponding to the 38 training sets, 38 ‘if then’ rules are formulated. Out of these 38 rules, 34 rules were used to form the rule base and the rest 4 rules could not be considered as explained in Section 2.1. The 34 rules have been presented in Table 4. The 7 sets of crisp input for the thickness of the paper and the diameter of the void, fire each of the 34 rules given in Table 5.

A typical clipped fuzzified MFs obtained by firing a rule is as follows:

$$\mu_{VM1} = \text{minimum}_4 (\mu_t^* , \mu_{t1}^* ,\mu_d^* , \mu_{VM}) \qquad (9)$$

Where μ_t^* , μ_{t1}^* , μ_d^* are the MFs corresponding to the crisp inputs for the thickness of paper , thickness of void and the diameter of the void respectively.

Similarly the other fuzzified MFs obtained by firing the rest 33 rules are

$\mu_{VM2,}$ $\mu_{VM3,}$ ………………………., $\mu_{VM23,}$ $\mu_{VMH8.}$ All the 34 clipped fuzzified MFs are aggregated to form the aggregated fuzzified MFs.

The aggregated fuzzified MFs is given by

$$\mu_{A2}(V) = \text{maximum}_{34} (\mu_{VM1,}\ \mu_{VM2,}\ \mu_{VM3}\ ………………., \mu_{VM23,}\ \mu_{VMH8}) \qquad (10)$$

The defuzz function has been used to compute the defuzzified or the modeled value of the breakdown voltage V_{b4} from $\mu_{A2}(V)$

The MAE under ac conditions expressed in percentage is given by

$$MAE_{ac}= (1/s)* \mid (\sum_{s} (V_{b3}(s) - V_{b4}(s))/(V_{b3}(s))\mid *100 \qquad (11)$$

Where V_{b3} is the experimental or the crisp value for the breakdown voltage under ac condition and s is 7.

Table 5 has been obtained from Table 6 for the experimentally generated data under AC conditions for White Minilex.

Table 5: Rule Base under ac Condition (WHITE MINILEX)

IF Input parameters			THEN Output parameters
Thickness, t	Thickness of void, t_1	Diameter of the void, d	Breakdown Voltage, V
H	L	L	M
H	H	ML	M
MH	L	L	M
H	H	L	MH
M	L	M	H
ML	H	ML	M
L	L	L	M
ML	H	L	MH
M	L	ML	H
MH	H	H	M
ML	L	ML	M
M	H	ML	M
H	L	M	M
H	H	MH	M
H	L	H	M
MH	H	ML	M
L	L	MH	M
M	H	H	M
ML	L	L	MH
M	H	MH	H
L	L	H	M
L	H	MH	M
L	L	ML	M
M	H	L	M
ML	L	H	MH
ML	H	MH	M
M	L	L	MH
MH	H	L	M
MH	L	ML	MH
H	H	H	M
H	L	MH	MH
MH	L	MH	M
ML	H	H	MH
L	H	M	M

Table 6: Experimental Results under AC conditions for t, t_1, d and V(White Minilex)

Thickness, t of paper (mm)	Thickness of void, t1(mm)	Diameter of the void, d	Breakdown Voltage, V
0.26	0.025	1.5	2
0.26	0.125	3	2.1
0.26	0.025	1.5	2
0.26	0.125	2	2.1
0.18	0.025	3	2.2
0.125	0.125	3	2.4
0.125	0.025	1.5	2
0.125	0.125	1.5	2.1
0.125	0.025	3	2.3
0.18	0.125	5	2.2
0.18	0.025	3	2.4
0.18	0.125	2	2.3
0.26	0.025	3	2.1
0.26	0.125	5	2.4
0.26	0.025	5	2
0.26	0.125	2	2.3
0.125	0.025	5	2.3
0.18	0.125	2	2.1
0.18	0.025	4	2.1
0.18	0.125	5	2
0.125	0.025	5	2.3
0.125	0.125	2	2.2
0.18	0.025	3	2.2
0.18	0.125	5	2
0.125	0.025	4	2
0.26	0.125	1.5	2.3
0.18	0.025	1.5	2.4
0.26	0.125	2	2.2
0.26	0.025	4	2.1
0.18	0.125	4	2.2
0.125	0.025	1.5	2.1
0.125	0.125	4	2
0.125	0.025	2	2.1

Chapter 3
Results and Discussions

The μ_t, μ_{t1} μ_d and μ_V given in eqns. (2), (3) ,(4) and (5) have assumed two different closed shapes which are defined as given below.

Triangular MF

The triangular curve is a function of a vector, `x`, and depends on three scalar parameters *a*, *b*, and *c*, as given by

$$f(x;a,b,c)=\left\{\begin{matrix} 0, & x\le a \\ \dfrac{x-a}{b-a}, & a\le x\le b \\ \dfrac{c-x}{c-b}, & b\le x\le c \\ 0, & c\le x \end{matrix}\right\} \qquad (12)$$

Or, more compactly, by

$$f(x;a,b,c)=\max\left(\min\left(\frac{x-a}{b-a},\frac{c-x}{c-b}\right),o\right)$$

The parameters *a* and *c* locate the "feet" of the triangle and the parameter *b* locates the peak.

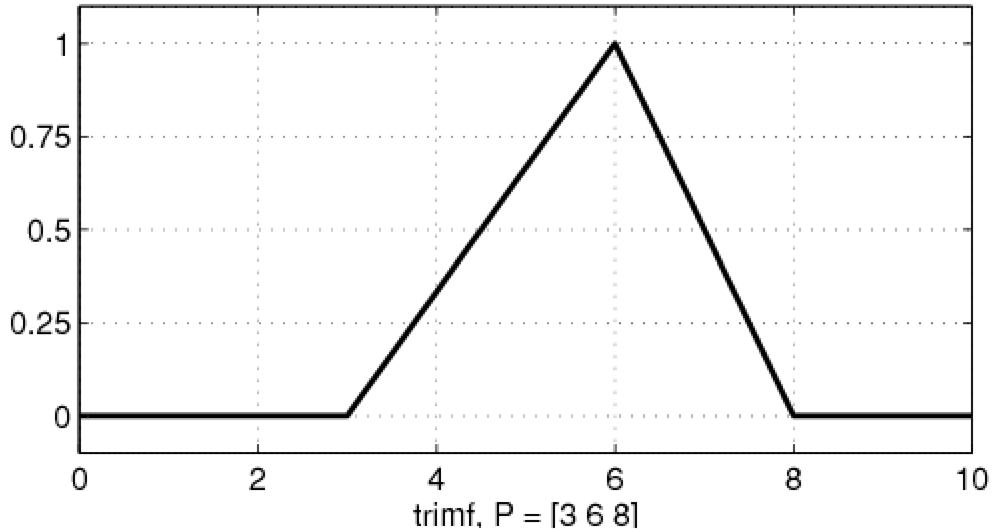

Figure 1: Triangular MF

Trapezoidal MF

The trapezoidal curve is a function of a vector, `x`, and depends on four scalar parameters a, b, c, and d, as given by

$$f(x;a,b,c,d)=\begin{Bmatrix} 0, & x\le a \\ \dfrac{x-a}{b-a}, & a\le x\le b \\ 1, & b\le x\le c \\ \dfrac{d-x}{d-c}, & c\le x\le d \\ 0, & d\le x \end{Bmatrix} \tag{13}$$

Or, more compactly, by

$$f(x;a,b,c,d)=\max\left(\min\left(\frac{x-a}{b-a},1,\frac{d-x}{d-c}\right),o\right)$$

The parameters *a* and *d* locate the "feet" of the trapezoid and the parameters *b* and *c* locate the "shoulders.

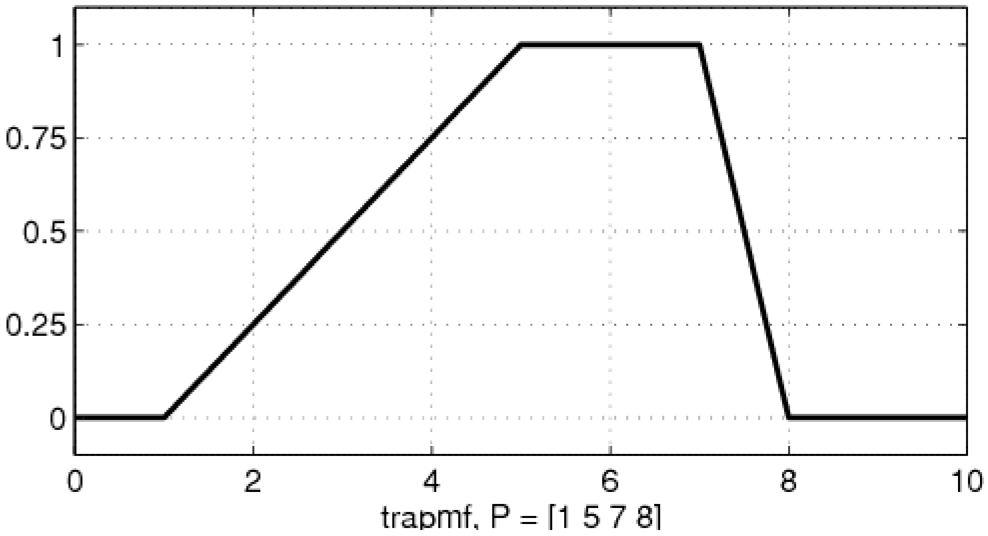

Figure 2: Trapezoidal MF

3.1 Results under DC conditions

a) **MAE with Triangular MFs**: A combination of b_{tL} (corresponding to μ_{tL}),b_{dL} (corresponding to μ_{dL}) and b_{t1L} (corresponding to μ_{tL1})b_{VL} (corresponding to μ_{VL}) was varied 16 times to obtain 16 different values of MAE . The MAE turned out to be minimum at 2.4981% when b_{tL}= 0.05, b_{dL}=1.6, b_{t1L}= 0.03 ,and b_{VL}=18.

b) **MAE with Trapezoidal MFs :** A combination of b_{tL} ,c_{tL}(corresponding to μ_{tL}), b_{tL1} ,c_{tL1}(corresponding to μ_{tL1}), b_{dL} ,c_{dL}(corresponding to μ_{dL}) and b_{VL} ,c_{VL}(corresponding to μ_{VL}) was varied 20 times to obtain 20 different values of MAE. The MAE turned out to be minimum at 3.6797% when b_{tL}=0.05, c_{tL1}=0.05, c_{tL}=0.10, b_{dL}=1.4, b_{tL1}=0.04, c_{dL}=2.4, b_{VL}=19 and c_{VL}=20.

Table 7 shows the comparison of the experimental with the modeled value of the breakdown voltage with the Triangular MFs under DC conditions and Figure 3 shows all the 7 aggregated fuzzified outputs using (7).

Similarly ,Table 8 shows the comparison of the experimental with the modeled value of the breakdown voltage with the Trapezoidal MFs under DC conditions and Figure 4 shows all the 7 aggregated fuzzified outputs using (7).

Table 7: Comparison of the Crisp (V_{b1}) and modeled values (V_{b2}) of the Breakdown Voltage with Triangular MF for White Minilex under dc condition

t (mm)	t_1(mm)	d (mm)	Breakdown Voltage V_{b1} (kV)	Breakdown Voltage V_{b2} (kV)	MAE (%)
0.26	0.025	3	24	22.3600	2.4981
0.26	0.125	2	20	20.0628	
0.125	0.025	3	26	26.0219	
0.18	0.125	5	23	21.8182	
0.18	0.025	3	24	23.9194	
0.26	0.125	5	19	19.4324	
0.26	0.025	2	23	23.5761	

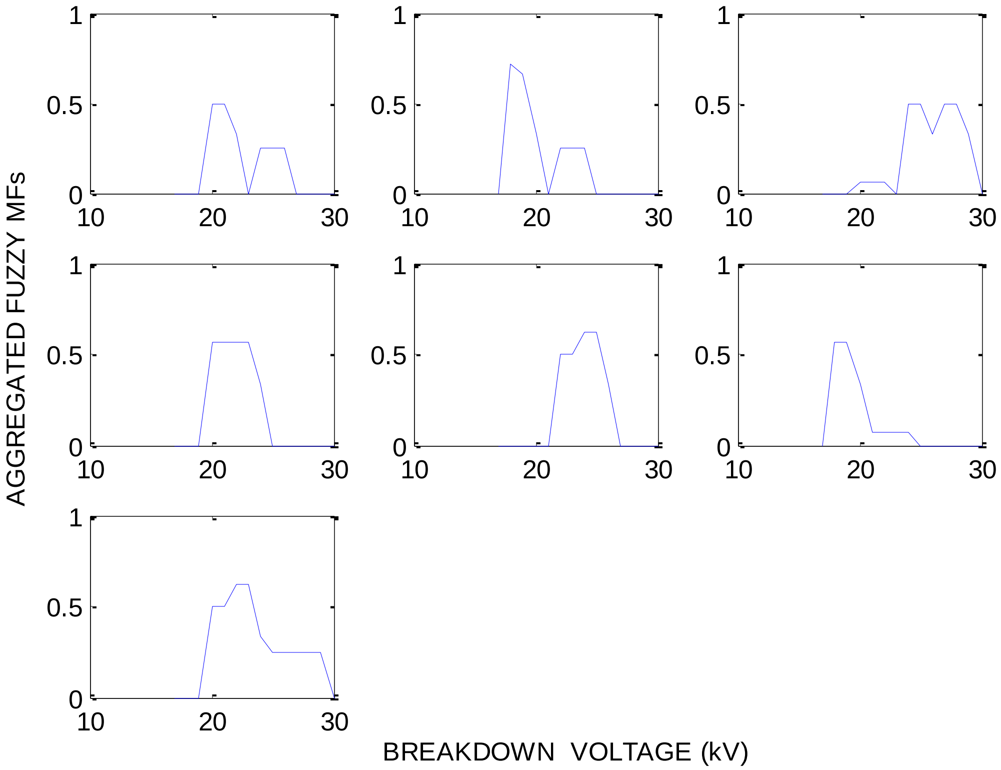

Figure 3: Aggregated Fuzzy MFs for all the 7 Crisp Inputs with MAE =2.4981% (Triangular MFs for White Minilex under DC conditions)

Table 8: Comparison of the Crisp (V_{b1}) and modeled values (V_{b2}) of the Breakdown Voltage with Trapezoidal MF for WHITE MINILEX under dc condition

t (mm)	t_1(mm)	d (mm)	Breakdown Voltage V_{b1} (kV)	Breakdown Voltage V_{b2} (kV)	MAE (%)
0.26	0.025	3	24	22.3750	3.6797
0.26	0.125	2	20	20.5556	
0.18	0.025	3	26	25.7059	
0.125	0.125	5	23	21.4615	
0.125	0.025	3	24	23.5618	
0.26	0.125	5	19	19.6512	
0.125	0.025	2	23	23.7213	

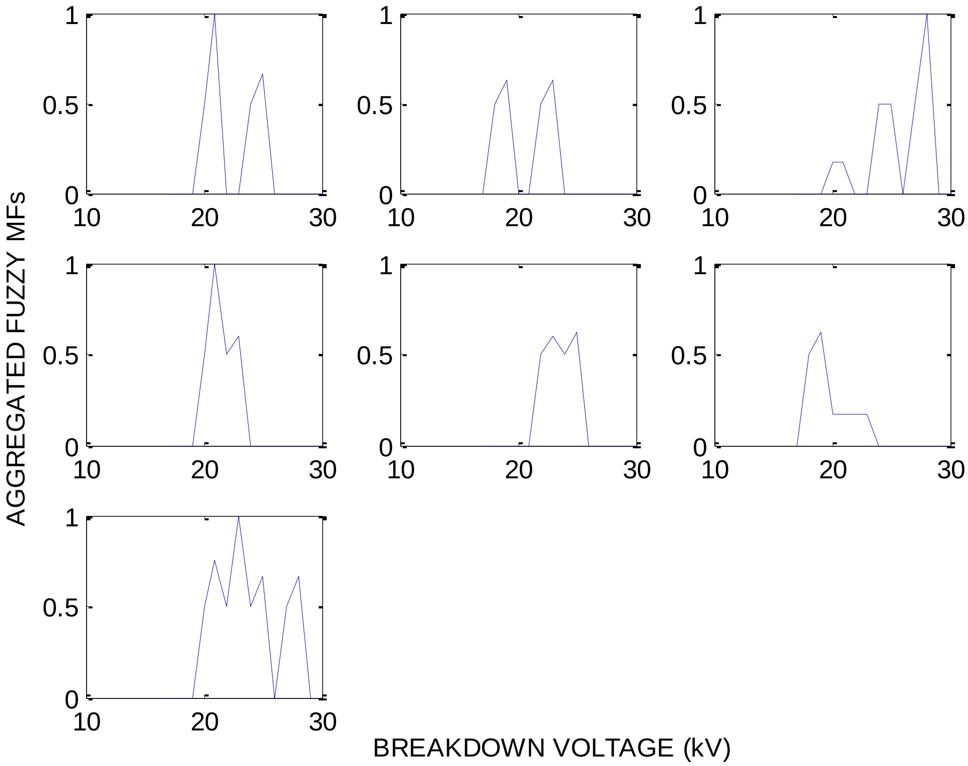

Figure 4: Aggregated Fuzzy MFs for all the 7 Crisp Inputs with MAE =3.6797% (Trapezoidal MFs for White Minilex under DC conditions)

3.2 Results under AC conditions

a) **<u>MAE with Triangular MFs</u>**: A combination of b_{tL} (corresponding to μ_{tL}),b_{dL} (corresponding to μ_{dL}) and b_{t1L} (corresponding to μ_{tL1})b_{VL} (corresponding to μ_{VL}) was varied 15 times to obtain 15 different values of MAE . The MAE turned out to be minimum at 1.4031% when b_{tL}= 0.03, b_{dL}=1.6, b_{t1L}= 0.02 ,and b_{VL}=2.0.

b) **<u>MAE with Trapezoidal MFs :</u>** A combination of b_{tL} ,c_{tL}(corresponding to μ_{tL}), b_{tL1} ,c_{tL1}(corresponding to μ_{tL1}), b_{dL} ,c_{dL}(corresponding to μ_{dL}) and b_{VL} ,c_{VL}(corresponding to μ_{VL}) was varied 25 times to obtain 25 different values of MAE. The MAE turned out to be minimum at 1.4997% when b_{tL}=0.02, c_{tL1}=0.05, c_{tL}=0.08, b_{dL}=1.4, b_{tL1}=0.02, c_{dL}=2.3, b_{VL}=1.92 and c_{VL}=2.00.

Table 9 shows the comparison of the experimental with the modeled value of the breakdown voltage with the Triangular MFs under AC conditions and Figure 5 shows all the 7 aggregated fuzzified outputs using (10).

Similarly ,Table 10 shows the comparison of the experimental with the modeled value of the breakdown voltage with the Trapezoidal MFs under AC conditions and Figure 6 shows all the 7 aggregated fuzzified outputs using (10).

Table 9: Comparison of the Crisp (V_{b1}) and modeled values (V_{b2}) of the Breakdown Voltage with Triangular MF for WHITE MINILEX under ac condition

t (mm)	t_1(mm)	d (mm)	Breakdown Voltage V_{b1} (kV)	Breakdown Voltage V_{b2} (kV)	MAE (%)
0.26	0.025	3	2.2	2.2286	1.4031
0.26	0.125	2	2.2	2.2222	
0.18	0.025	3	2.3	2.3000	
0.125	0.125	5	2.2	2.2125	
0.125	0.025	3	2.4	2.3000	
0.26	0.125	5	2.2	2.2111	
0.125	0.025	2	2.2	2.2500	

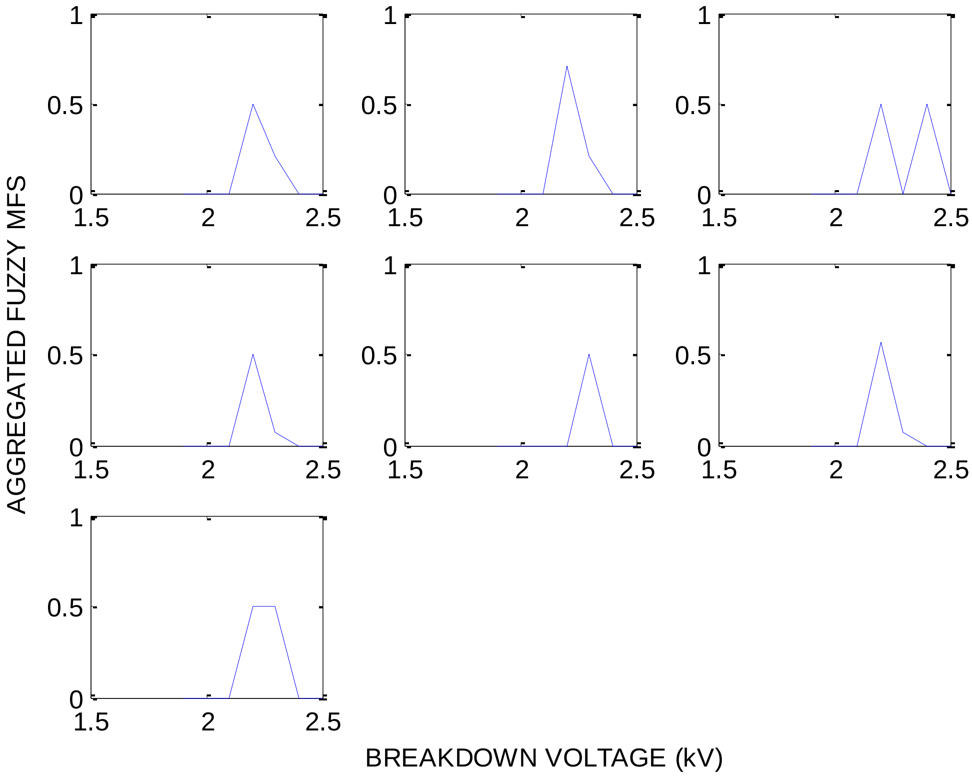

Figure 5: Aggregated Fuzzy MFs for all the 7 Crisp Inputs with MAE =1.4031% (Triangular MFs for White Minilex under AC conditions)

Table 10: Comparison of the Crisp (V_{b1}) and modeled values (V_{b2}) of the Breakdown Voltage with Trapezoidal MF for WHITE MINILEX under ac condition

t (mm)	t_1(mm)	d (mm)	Breakdown Voltage V_{b1} (kV)	Breakdown Voltage V_{b2} (kV)	MAE (%)
0.26	0.025	3	2.2	2.2286	1.4999
0.26	0.125	2	2.2	2.2286	
0.18	0.025	3	2.3	2.3000	
0.125	0.125	5	2.2	2.2125	
0.125	0.025	3	2.4	2.3000	
0.26	0.125	5	2.2	2.2125	
0.125	0.025	2	2.2	2.2571	

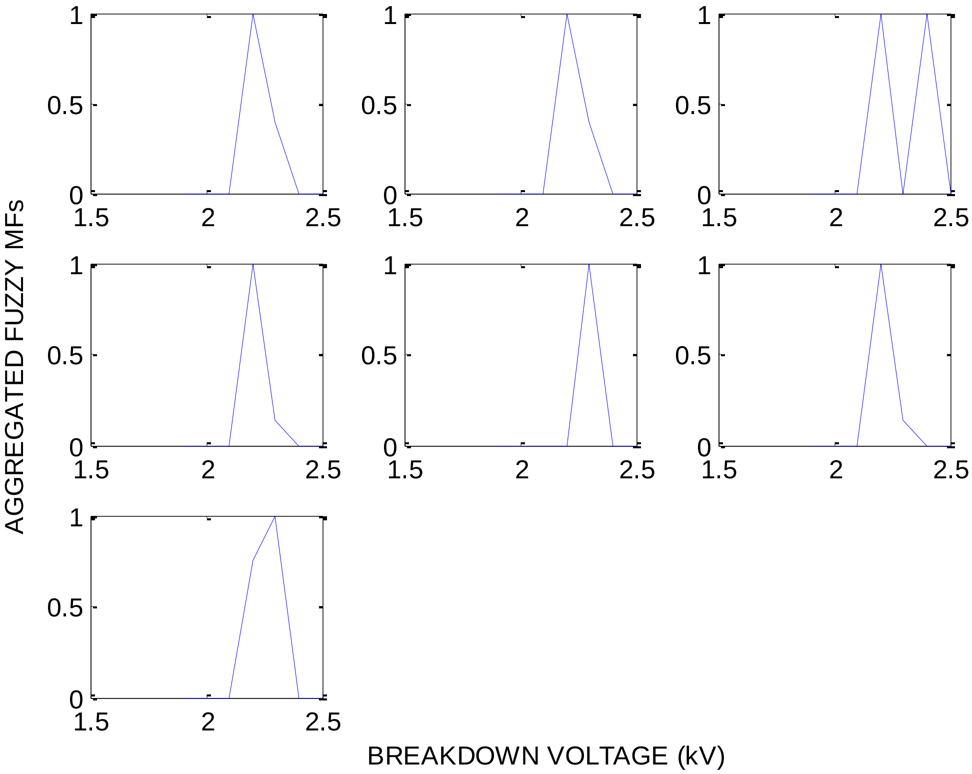

Figure 6: Aggregated Fuzzy MFs for all the 7 Crisp Inputs with MAE =1.4999% (Trapezoidal MFs for White Minilex under AC conditions)

Table 11 and Table 12 summarizes the minimum value of MAE obtained using Triangular and Trapezoidal MF for White Minilex under DC and AC conditions respectively.

Table 11: Summary of minimum value of MAE for two different shapes of MFs for t, t_1, d and V for White Minilex Paper under dc condition

Shape of MFs	MAE (%)
Triangular	2.4981
Trapezoidal	3.6797

Table 12: Summary of minimum value of MAE for two different shapes of MFs for t, t_1, d and V for White Minilex Paper under ac condition

Shape of MFs	MAE (%)
Triangular	1.4031
Trapezoidal	1.4999

Table 11 and Table 12 clearly shows that the breakdown voltage of White Minilex under DC and AC conditions can be effectively modeled using Mamdani Fuzzy Logic Technique.

On the whole it can be inferred that the FL modeling is a very effective way of modeling the breakdown by discharges of any solid dielectric material under both dc and ac conditions as it predicts the breakdown voltage quiet accurately and also requires less computational burden . Thus, the dielectric behaviour can be analyzed at negligible computing cost.

Chapter 4
Conclusions and Future Work

The breakdown voltage of insulating samples of White Minilex Paper of various thicknesses with artificially created void was modeled using two different shapes of the MFs under both ac and dc conditions. The results suggest the effectiveness of FL in modeling the breakdown voltage of insulating samples. An immediate advantage of this work is that the dielectric behaviour can be analyzed at a virtually negligible computing cost.

In this work the Triangular and Trapezoidal shape of the MFs was used to predict the breakdown voltage of White Minilex under DC and AC conditions. The work can be easily extended to by assuming Gaussian, Generalized Bell , Pi shaped MF for all the input and Output MFs.

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APPENDIX

Appendix 1

Matlab Code for BDV of White Minilex under DC conditions using fuzzy logic and triangular membership function

```
clear all;
% Three Inputs (thickness t of material, thickness of void and diameter of
% void)
% To model the BDV of White Minilex under DC conditions using fuzzy logic
% and triangular membership function(Mamdani Rule Based Inference with max
% min composition & Centroid Defuzzification)

% Membership function of the thickness t of the dielectric
 t= (0:0.005:0.33)';
 at=0.05;
utL=trimf(t,[0 at 0.13]);
utML=trimf(t,[0.05 at+0.05 0.18]);
utM=trimf(t,[0.10 at+0.10 0.23]);
utMH=trimf(t,[0.15 at+0.15 0.28]);
utH=trimf(t,[0.20 at+0.20 0.33]);
ut=[utL,utML,utM,utMH,utH];
% Membership function of the thickness t1 of the void
 t1= (0:0.005:0.15)';
 at1=0.03;
ut1L=trimf(t1,[0 at1 0.07]);
ut1H=trimf(t1,[0.08 at1+0.08 0.15]);
ut1=[ut1L,ut1H];
% Membership function of the diameter d of the void
d= (1.0:0.1:5.8)';
ad=1.6;
udL=trimf(d,[1.0 ad 3.0]);
udML=trimf(d,[1.7 ad+0.7 3.7]);
udM=trimf(d,[2.4 ad+1.4 4.4]);
udMH=trimf(d,[3.1 ad+2.1 5.1]);
udH=trimf(d,[3.8 ad+2.8 5.8]);
ud=[udL,udML,udM,udMH,udH];
% Membership function of the breakdown voltage B
B= (17:1:30)';
a1=18;
uBL=trimf(B,[17 a1 21]);
uBML=trimf(B,[19 a1+2 23]);
uBM=trimf(B,[21 a1+4 25]);
uBMH=trimf(B,[23 a1+6 27]);
uBH=trimf(B,[26 a1+9 30]);
uB=[uBL,uBML,uBM,uBMH,uBH];
% Program for testing the Fuzzy Logic System to evaluate the mean absolute error
% The input testing data (Crisp Input)(Thickness of material)
 t3=[0.26;0.26;0.125;0.18;0.18;0.26;0.26];
 % The input testing data(Crisp Input) (Thickness of void)
t4=[0.125;0.025;0.125;0.125;0.025;0.025;0.125];
 % The input testing data (Crisp Input)(Diameter of the void)
 d3=[3;2;3;5;3;5;2];
 % The output testing experimental data (Breakdown voltage)
 bve1=[24;20;26;23;24;19;23];
```

```
%Fuzzification of crisp input (thickness of material)
for z=1:7
utL1(z)=trimf(t3(z),[0 at 0.13]);
utML1(z)=trimf(t3(z),[0.05 at+0.05 0.18]);
utM1(z)=trimf(t3(z),[0.10 at+0.10 0.23]);
utMH1(z)=trimf(t3(z),[0.15 at+0.15 0.28]);
utH1(z)=trimf(t3(z),[0.20 at+0.20 0.33]);
%Fuzzification of crisp input (thickness of void)
ut1L1(z)=trimf(t4(z),[0 at1 0.07]);
ut1H1(z)=trimf(t4(z),[0.08 at1+0.08 0.15]);
%Fuzzification of crisp input (diameter of void)
udL1(z)=trimf(d3(z),[1.0 ad 3.0]);
udML1(z)=trimf(d3(z),[1.7 ad+0.7 3.7]);
udM1(z)=trimf(d3(z),[2.4 ad+1.4 4.4]);
udMH1(z)=trimf(d3(z),[3.1 ad+2.1 5.1]);
udH1(z)=trimf(d3(z),[3.8 ad+2.8 5.8]);
  % Mamdani Rule Based Inference
 for k=1:size(B)
   % Firing of 1st rule
   uBM11(z,k,:)=[utH1(z),ut1L1(z),udL1(z),uBL(k)];
   uBM1(z,k)=min(uBM11(z,k,:));
  % Firing of 2nd rule
   uBMH11(z,k,:)=[utH1(z),ut1H1(z),udML1(z),uBML(k)];
   uBMH1(z,k)=min(uBMH11(z,k,:));
      % Firing of 3rd rule
   uBH11(z,k,:)=[utMH1(z),ut1L1(z),udL1(z),uBL(k)];
   uBH1(z,k)=min(uBH11(z,k,:));
      % Firing of 4th rule
   uBM21(z,k,:)=[utH1(z),ut1H1(z),udL1(z),uBM(k)];
   uBM2(z,k)=min(uBM21(z,k,:));
      % Firing of 5th rule
   uBML11(z,k,:)=[utM1(z),ut1L1(z),udM1(z),uBMH(k)];
   uBML1(z,k)=min(uBML11(z,k,:));
   % Firing of 6th rule
   uBMH21(z,k,:)=[utML1(z),ut1H1(z),udML1(z),uBH(k)];
   uBMH2(z,k)=min(uBMH21(z,k,:));
      % Firing of 7th rule
   uBL11(z,k,:)=[utL1(z),ut1L1(z),udL1(z),uBL(k)];
   uBL1(z,k)=min(uBL11(z,k,:));
     % Firing of 8th rule
   uBL21(z,k,:)=[utML1(z),ut1H1(z),udL1(z),uBML(k)];
   uBL2(z,k)=min(uBL21(z,k,:));
      % Firing of 9th rule
   uBML21(z,k,:)=[utM1(z),ut1L1(z),udML1(z),uBMH(k)];
   uBML2(z,k)=min(uBML21(z,k,:));
  % Firing of 10th rule
  uBM31(z,k,:)=[utMH1(z),ut1H1(z),udH1(z),uBM(k)];
   uBM3(z,k)=min(uBM31(z,k,:));
     % Firing of 11th rule
   uBMH31(z,k,:)=[utML1(z),ut1L1(z),udML1(z),uBH(k)];
   uBMH3(z,k)=min(uBMH31(z,k,:));
   % Firing of 12th rule
    uBM41(z,k,:)=[utM1(z),ut1H1(z),udML1(z),uBMH(k)];
   uBM4(z,k)=min(uBM41(z,k,:));
  % Firing of 13th rule
    uBH21(z,k,:)=[utH1(z),ut1L1(z),udM1(z),uBML(k)];
```

```
 uBH2(z,k)=min(uBH21(z,k,:));
   % Firing of 14th rule
 uBMH41(z,k,:)=[utH1(z),ut1H1(z),udMH1(z),uBH(k)];
 uBMH4(z,k)=min(uBMH41(z,k,:));
  % Firing of 15th rule
 uBM51(z,k,:)=[utH1(z),ut1L1(z),udH1(z),uBL(k)];
 uBM5(z,k)=min(uBM51(z,k,:));
   % Firing of 16th rule
  uBML31(z,k,:)=[utMH1(z),ut1H1(z),udML1(z),uBMH(k)];
 uBML3(z,k)=min(uBML31(z,k,:));
  % Firing of 17th rule
  uBL31(z,k,:)=[utL1(z),ut1L1(z),udMH1(z),uBML(k)];
 uBL3(z,k)=min(uBL31(z,k,:));
    % Firing of 18th rule
  uBH31(z,k,:)=[utM1(z),ut1H1(z),udH1(z),uBML(k)];
 uBH3(z,k)=min(uBH31(z,k,:));
  % Firing of 19th rule
  uBM61(z,k,:)=[utML1(z),ut1L1(z),udL1(z),uBL(k)];
 uBM6(z,k)=min(uBM61(z,k,:));
% Firing of 20th rule
  uBML41(z,k,:)=[utM1(z),ut1H1(z),udMH1(z),uBM(k)];
 uBML4(z,k)=min(uBML41(z,k,:));
   % Firing of 21st rule
 uBL41(z,k,:)=[utL1(z),ut1L1(z),udH1(z),uBM(k)];
 uBL4(z,k)=min(uBL41(z,k,:));
  % Firing of 22nd rule
 uBM71(z,k,:)=[utL1(z),ut1H1(z),udMH1(z),uBMH(k)];
 uBM7(z,k)=min(uBM71(z,k,:));
   % Firing of 23rd rule
  uBML51(z,k,:)=[utL1(z),ut1L1(z),udML1(z),uBM(k)];
 uBML5(z,k)=min(uBML51(z,k,:));
  % Firing of 24th rule
  uBMH51(z,k,:)=[utM1(z),ut1H1(z),udL1(z),uBM(k)];
 uBMH5(z,k)=min(uBMH51(z,k,:));
    % Firing of 25th rule
  uBMH61(z,k,:)=[utML1(z),ut1L1(z),udH1(z),uBL(k)];
 uBMH6(z,k)=min(uBMH61(z,k,:));
      % Firing of 26th rule
 uBM81(z,k,:)=[utML1(z),ut1H1(z),udMH1(z),uBM(k)];
 uBM8(z,k)=min(uBM81(z,k,:));
% Firing of 27th rule
 uBMH71(z,k,:)=[utM1(z),ut1L1(z),udL1(z),uBMH(k)];
 uBMH7(z,k)=min(uBMH71(z,k,:));
    % Firing of 28th rule
 uBMH81(z,k,:)=[utMH1(z),ut1H1(z),udL1(z),uBH(k)];
 uBMH8(z,k)=min(uBMH81(z,k,:));
    % Firing of 29th rule
 uBH41(z,k,:)=[utMH1(z),ut1L1(z),udML1(z),uBM(k)];
 uBH4(z,k)=min(uBH41(z,k,:));
    % Firing of 30th rule
 uBMH91(z,k,:)=[utH1(z),ut1H1(z),udH1(z),uBML(k)];
 uBMH9(z,k)=min(uBMH91(z,k,:));
 % Firing of 31st rule
 uBM91(z,k,:)=[utH1(z),ut1L1(z),udMH1(z),uBM(k)];
 uBM9(z,k)=min(uBM91(z,k,:));
    % Firing of 32nd rule
```

```
  uBMH101(z,k,:)=[utMH1(z),ut1L1(z),udMH1(z),uBML(k)];
  uBMH10(z,k)=min(uBMH101(z,k,:));
    % Firing of 33rd rule
  uBM101(z,k,:)=[utML1(z),ut1H1(z),udH1(z),uBL(k)];
  uBM10(z,k)=min(uBM101(z,k,:));
     % Firing of 34th rule
  uBML61(z,k,:)=[utL1(z),ut1H1(z),udM1(z),uBML(k)];
  uBML6(z,k)=min(uBML61(z,k,:));

    % Aggregated Output Membership function(taking the maximum of all 34
    % outputs for each value of input pattern & each value of

uB2(z,k,:)=[uBM1(z,k);uBMH1(z,k);uBH1(z,k);uBM2(z,k);uBML1(z,k);uBMH2(z,k);uBL1(z,k);uBL2(z,k);uBML2(z,k);uBM3(z,k);uBMH3(z,k);uBM4(z,k);uBH2(z,k);uBMH4(z,k);uBM5(z,k);uBML3(z,k);uBL3(z,k);uBH3(z,k);uBM6(z,k);uBML4(z,k);uBL4(z,k);uBM7(z,k);uBML5(z,k);uBMH5(z,k);uBMH6(z,k);uBM8(z,k);uBMH7(z,k);uBMH8(z,k);uBH4(z,k);uBMH9(z,k);uBM9(z,k);uBMH10(z,k);uBM10(z,k);uBML6(z,k)];
    uB3(z,k)= max(uB2(z,k,:));
 end;
 end;

  % Defuzzification(Centroid Method)
  for z=1:7
 bve2(z,:)= defuzz(B,uB3(z,:),'centroid');
  end;
 %  MAE
 MAE=0;
 for z=1:7
 MAE = MAE+abs((bve2(z,:)-bve1(z))/(bve1(z)))*(100/7);
 end;

        subplot(3,3,1); plot(B, [uB3(1,:) ]);
        subplot(3,3,2); plot(B, [uB3(2,:) ]);
        subplot(3,3,3); plot(B, [uB3(3,:) ]);
        subplot(3,3,4); plot(B, [uB3(4,:) ]);
        subplot(3,3,5); plot(B, [uB3(5,:) ]);
        subplot(3,3,6); plot(B, [uB3(6,:) ]);
        subplot(3,3,7); plot(B, [uB3(7,:) ]);
```

Appendix 2

Matlab Code for BDV of White Minilex under DC conditions using fuzzy logic and trapezoidal membership function

```
clear all;
% Three Inputs (thickness t of material, thickness of void and diameter of
% void)
% To model the BDV of White Minilex under DC conditions using fuzzy logic
% and trapezoidal membership function(Mamdani Rule Based Inference with max
% min composition & Centroid Defuzzification)

% Membership function of the thickness t of the dielectric
 t= (0:0.005:0.33)';
 at=0.05;
utL=trapmf(t,[0 at at+0.04 0.13]);
utML=trapmf(t,[0.05 at+0.04 at+0.09 0.18]);
utM=trapmf(t,[0.10 at+0.09 at+0.14 0.23]);
utMH=trapmf(t,[0.15 at+0.14 at+0.19 0.28]);
utH=trapmf(t,[0.20 at+0.19 at+0.24 0.33]);
ut=[utL,utML,utM,utMH,utH];
% Membership function of the thickness t1 of the void
 t1= (0:0.003:0.12:0.15)';
 at1=0.02;
ut1L=trapmf(t1,[0 at1 at1+0.03 0.07]);
ut1H=trapmf(t1,[0.08 at1+0.08 at1+0.11 0.15]);
ut1=[ut1L,ut1H];
% Membership function of the diameter d of the void
d= (1.0:0.1:5.8)';
ad=1.5;
udL=trapmf(d,[1.0 ad ad+1 3.0]);
udML=trapmf(d,[1.7 ad+0.7 ad+1.7 3.7]);
udM=trapmf(d,[2.4 ad+1.4 ad+2.4 4.4]);
udMH=trapmf(d,[3.1 ad+2.1 ad+3.1 5.1]);
udH=trapmf(d,[3.8 ad+2.8 ad+3.8 5.8]);
ud=[udL,udML,udM,udMH,udH];
% Membership function of the breakdown voltage B
B= (17:1:30)';
a1=18;
uBL=trapmf(B,[17 a1 a1+2 21]);
uBML=trapmf(B,[19 a1+2 a1+4 23]);
uBM=trapmf(B,[21 a1+4 a1+6 25]);
uBMH=trapmf(B,[23 a1+6 a1+8 27]);
uBH=trapmf(B,[25 a1+8 a1+10 30]);
uB=[uBL,uBML,uBM,uBMH,uBH];
% Program for testing the Fuzzy Logic System to evaluate the mean absolute error
% The input testing data (Crisp Input)(Thickness of material)
 t3=[0.26;0.26;0.125;0.18;0.18;0.26;0.26];
 % The input testing data(Crisp Input) (Thickness of void)
t4=[0.125;0.025;0.125;0.125;0.025;0.025;0.125];
 % The input testing data (Crisp Input)(Diameter of the void)
 d3=[3;2;3;5;3;5;2];
 % The output testing experimental data (Breakdown voltage)
```

```
 bve1=[24;20;26;23;24;19;23];
%Fuzzification of crisp input (thickness of material)
for z=1:7
utL1(z)=trapmf(t3(z),[0 at at+0.04 0.13]);
utML1(z)=trapmf(t3(z),[0.05 at+0.04 at+0.09 0.18]);
utM1(z)=trapmf(t3(z),[0.10 at+0.09 at+0.14 0.23]);
utMH1(z)=trapmf(t3(z),[0.15 at+0.14 at+0.19 0.28]);
utH1(z)=trapmf(t3(z),[0.20 at+0.19 at+0.24 0.33]);
%Fuzzification of crisp input (thickness of void)
ut1L1(z)=trapmf(t4(z),[0 at1 at1+0.03 0.07]);
ut1H1(z)=trapmf(t4(z),[0.08 at1+0.08 at1+0.11 0.15]);
%Fuzzification of crisp input (diameter of void)
udL1(z)=trapmf(d3(z),[1.0 ad ad+1 3.0]);
udML1(z)=trapmf(d3(z),[1.7 ad+0.7 ad+1.7 3.7]);
udM1(z)=trapmf(d3(z),[2.4 ad+1.4 ad+2.4 4.4]);
udMH1(z)=trapmf(d3(z),[3.1 ad+2.1 ad+3.1 5.1]);
udH1(z)=trapmf(d3(z),[3.8 ad+2.8 ad+3.8 5.8]);
  % Mamdani Rule Based Inference
 for k=1:size(B)
   % Firing of 1st rule
   uBM11(z,k,:)=[utH1(z),ut1L1(z),udL1(z),uBL(k)];
   uBM1(z,k)=min(uBM11(z,k,:));
  % Firing of 2nd rule
   uBMH11(z,k,:)=[utH1(z),ut1H1(z),udML1(z),uBML(k)];
   uBMH1(z,k)=min(uBMH11(z,k,:));
      % Firing of 3rd rule
   uBH11(z,k,:)=[utMH1(z),ut1L1(z),udL1(z),uBL(k)];
   uBH1(z,k)=min(uBH11(z,k,:));
      % Firing of 4th rule
   uBM21(z,k,:)=[utH1(z),ut1H1(z),udL1(z),uBM(k)];
   uBM2(z,k)=min(uBM21(z,k,:));
      % Firing of 5th rule
   uBML11(z,k,:)=[utM1(z),ut1L1(z),udM1(z),uBMH(k)];
   uBML1(z,k)=min(uBML11(z,k,:));
   % Firing of 6th rule
   uBMH21(z,k,:)=[utML1(z),ut1H1(z),udML1(z),uBH(k)];
   uBMH2(z,k)=min(uBMH21(z,k,:));
      % Firing of 7th rule
   uBL11(z,k,:)=[utL1(z),ut1L1(z),udL1(z),uBL(k)];
   uBL1(z,k)=min(uBL11(z,k,:));
     % Firing of 8th rule
   uBL21(z,k,:)=[utML1(z),ut1H1(z),udL1(z),uBML(k)];
   uBL2(z,k)=min(uBL21(z,k,:));
      % Firing of 9th rule
   uBML21(z,k,:)=[utM1(z),ut1L1(z),udML1(z),uBMH(k)];
   uBML2(z,k)=min(uBML21(z,k,:));
  % Firing of 10th rule
  uBM31(z,k,:)=[utMH1(z),ut1H1(z),udH1(z),uBM(k)];
   uBM3(z,k)=min(uBM31(z,k,:));
     % Firing of 11th rule
   uBMH31(z,k,:)=[utML1(z),ut1L1(z),udML1(z),uBH(k)];
   uBMH3(z,k)=min(uBMH31(z,k,:));
   % Firing of 12th rule
    uBM41(z,k,:)=[utM1(z),ut1H1(z),udML1(z),uBMH(k)];
   uBM4(z,k)=min(uBM41(z,k,:));
  % Firing of 13th rule
```

```
  uBH21(z,k,:)=[utH1(z),ut1L1(z),udM1(z),uBML(k)];
 uBH2(z,k)=min(uBH21(z,k,:));
   % Firing of 14th rule
 uBMH41(z,k,:)=[utH1(z),ut1H1(z),udMH1(z),uBH(k)];
 uBMH4(z,k)=min(uBMH41(z,k,:));
  % Firing of 15th rule
 uBM51(z,k,:)=[utH1(z),ut1L1(z),udH1(z),uBL(k)];
 uBM5(z,k)=min(uBM51(z,k,:));
   % Firing of 16th rule
  uBML31(z,k,:)=[utMH1(z),ut1H1(z),udML1(z),uBMH(k)];
 uBML3(z,k)=min(uBML31(z,k,:));
  % Firing of 17th rule
  uBL31(z,k,:)=[utL1(z),ut1L1(z),udMH1(z),uBML(k)];
 uBL3(z,k)=min(uBL31(z,k,:));
    % Firing of 18th rule
  uBH31(z,k,:)=[utM1(z),ut1H1(z),udH1(z),uBML(k)];
 uBH3(z,k)=min(uBH31(z,k,:));
  % Firing of 19th rule
  uBM61(z,k,:)=[utML1(z),ut1L1(z),udL1(z),uBL(k)];
 uBM6(z,k)=min(uBM61(z,k,:));
% Firing of 20th rule
  uBML41(z,k,:)=[utM1(z),ut1H1(z),udMH1(z),uBM(k)];
 uBML4(z,k)=min(uBML41(z,k,:));
   % Firing of 21st rule
 uBL41(z,k,:)=[utL1(z),ut1L1(z),udH1(z),uBM(k)];
 uBL4(z,k)=min(uBL41(z,k,:));
  % Firing of 22nd rule
 uBM71(z,k,:)=[utL1(z),ut1H1(z),udMH1(z),uBMH(k)];
 uBM7(z,k)=min(uBM71(z,k,:));
   % Firing of 23rd rule
  uBML51(z,k,:)=[utL1(z),ut1L1(z),udML1(z),uBM(k)];
 uBML5(z,k)=min(uBML51(z,k,:));
  % Firing of 24th rule
  uBMH51(z,k,:)=[utM1(z),ut1H1(z),udL1(z),uBM(k)];
 uBMH5(z,k)=min(uBMH51(z,k,:));
    % Firing of 25th rule
  uBMH61(z,k,:)=[utML1(z),ut1L1(z),udH1(z),uBL(k)];
 uBMH6(z,k)=min(uBMH61(z,k,:));
      % Firing of 26th rule
 uBM81(z,k,:)=[utML1(z),ut1H1(z),udMH1(z),uBM(k)];
 uBM8(z,k)=min(uBM81(z,k,:));
% Firing of 27th rule
 uBMH71(z,k,:)=[utM1(z),ut1L1(z),udL1(z),uBMH(k)];
 uBMH7(z,k)=min(uBMH71(z,k,:));
    % Firing of 28th rule
 uBMH81(z,k,:)=[utMH1(z),ut1H1(z),udL1(z),uBH(k)];
 uBMH8(z,k)=min(uBMH81(z,k,:));
    % Firing of 29th rule
 uBH41(z,k,:)=[utMH1(z),ut1L1(z),udML1(z),uBM(k)];
 uBH4(z,k)=min(uBH41(z,k,:));
    % Firing of 30th rule
 uBMH91(z,k,:)=[utH1(z),ut1H1(z),udH1(z),uBML(k)];
 uBMH9(z,k)=min(uBMH91(z,k,:));
 % Firing of 31st rule
 uBM91(z,k,:)=[utH1(z),ut1L1(z),udMH1(z),uBM(k)];
 uBM9(z,k)=min(uBM91(z,k,:));
```

```
      % Firing of 32nd rule
   uBMH101(z,k,:)=[utMH1(z),ut1L1(z),udMH1(z),uBML(k)];
  uBMH10(z,k)=min(uBMH101(z,k,:));
     % Firing of 33rd rule
   uBM101(z,k,:)=[utML1(z),ut1H1(z),udH1(z),uBL(k)];
   uBM10(z,k)=min(uBM101(z,k,:));
      % Firing of 34th rule
   uBML61(z,k,:)=[utL1(z),ut1H1(z),udM1(z),uBML(k)];
   uBML6(z,k)=min(uBML61(z,k,:));

     % Aggregated Output Membership function(taking the maximum of all 34
     % outputs for each value of input pattern & each value of

uB2(z,k,:)=[uBM1(z,k);uBMH1(z,k);uBH1(z,k);uBM2(z,k);uBML1(z,k);uBMH2(z,k);uBL1(z,k);uBL2(z,
k);uBML2(z,k);uBM3(z,k);uBMH3(z,k);uBM4(z,k);uBH2(z,k);uBMH4(z,k);uBM5(z,k);uBML3(z,k);uBL
3(z,k);uBH3(z,k);uBM6(z,k);uBML4(z,k);uBL4(z,k);uBM7(z,k);uBML5(z,k);uBMH5(z,k);uBMH6(z,k);u
BM8(z,k);uBMH7(z,k);uBMH8(z,k);uBH4(z,k);uBMH9(z,k);uBM9(z,k);uBMH10(z,k);uBM10(z,k);uBM
L6(z,k)];
     uB3(z,k)= max(uB2(z,k,:));
 end;
 end;

  % Defuzzification(Centroid Method)
  for z=1:7
 bve2(z,:)= defuzz(B,uB3(z,:),'centroid');
  end;
 %  MAE
 MAE=0;
 for z=1:7
 MAE = MAE+abs((bve2(z,:)-bve1(z))/(bve1(z)))*(100/7);
 end;


        subplot(3,3,1); plot(B, [uB3(1,:) ]);
        subplot(3,3,2); plot(B, [uB3(2,:) ]);
        subplot(3,3,3); plot(B, [uB3(3,:) ]);
        subplot(3,3,4); plot(B, [uB3(4,:) ]);
        subplot(3,3,5); plot(B, [uB3(5,:) ]);
        subplot(3,3,6); plot(B, [uB3(6,:) ]);
        subplot(3,3,7); plot(B, [uB3(7,:) ]);
```

Appendix 3

Matlab Code for BDV of White Minilex under AC conditions using fuzzy logic and triangular membership function

```
clear all;
% Three Inputs (thickness t of material, thickness of void and diameter of
% void)
% To model the BDV of White Minilex under AC conditions using fuzzy logic
% and triangular membership function(Mamdani Rule Based Inference with max
% min composition & Centroid Defuzzification)

% Membership function of the thickness t of the dielectric
 t= (0:0.005:0.33)';
 at=0.03;
utL=trimf(t,[0 at 0.13]);
utML=trimf(t,[0.05 at+0.05 0.18]);
utM=trimf(t,[0.10 at+0.10 0.23]);
utMH=trimf(t,[0.15 at+0.15 0.28]);
utH=trimf(t,[0.20 at+0.20 0.33]);
ut=[utL,utML,utM,utMH,utH];
% Membership function of the thickness t1 of the void
 t1= (0:0.005:0.15)';
 at1=0.02;
ut1L=trimf(t1,[0 at1 0.07]);
ut1H=trimf(t1,[0.08 at1+0.08 0.15]);
ut1=[ut1L,ut1H];
% Membership function of the diameter d of the void
d= (1.0:0.1:5.8)';
ad=1.6;
udL=trimf(d,[1.0 ad 3.0]);
udML=trimf(d,[1.7 ad+0.7 3.7]);
udM=trimf(d,[2.4 ad+1.4 4.4]);
udMH=trimf(d,[3.1 ad+2.1 5.1]);
udH=trimf(d,[3.8 ad+2.8 5.8]);
ud=[udL,udML,udM,udMH,udH];
% Membership function of the breakdown voltage B
B= (1.9:0.1:2.5)';
a1=2.0;
uBL=trimf(B,[1.9 a1 2.1]);
uBML=trimf(B,[2.0 a1+0.1 2.2]);
uBM=trimf(B,[2.1 a1+0.2 2.3]);
uBMH=trimf(B,[2.2 a1+0.3 2.4]);
uBH=trimf(B,[2.3 a1+0.4 2.5]);
uB=[uBL,uBML,uBM,uBMH,uBH];
% Program for testing the Fuzzy Logic System to evaluate the mean absolute error
% The input testing data (Crisp Input)(Thickness of material)
 t3=[0.26;0.26;0.125;0.18;0.18;0.26;0.26];
 % The input testing data(Crisp Input) (Thickness of void)
t4=[0.125;0.025;0.125;0.125;0.025;0.025;0.125];
 % The input testing data (Crisp Input)(Diameter of the void)
 d3=[3;2;3;5;3;5;2];
```

```
 % The output testing experimental data (Breakdown voltage)
 bve1=[2.2;2.2;2.3;2.2;2.4;2.2;2.2];
%Fuzzification of crisp input (thickness of material)
for z=1:7
utL1(z)=trimf(t3(z),[0 at 0.13]);
utML1(z)=trimf(t3(z),[0.05 at+0.05 0.18]);
utM1(z)=trimf(t3(z),[0.10 at+0.10 0.23]);
utMH1(z)=trimf(t3(z),[0.15 at+0.15 0.28]);
utH1(z)=trimf(t3(z),[0.20 at+0.20 0.33]);
%Fuzzification of crisp input (thickness of void)
ut1L1(z)=trimf(t4(z),[0 at1 0.07]);
ut1H1(z)=trimf(t4(z),[0.08 at1+0.08 0.15]);
%Fuzzification of crisp input (diameter of void)
udL1(z)=trimf(d3(z),[1.0 ad 3.0]);
udML1(z)=trimf(d3(z),[1.7 ad+0.7 3.7]);
udM1(z)=trimf(d3(z),[2.4 ad+1.4 4.4]);
udMH1(z)=trimf(d3(z),[3.1 ad+2.1 5.1]);
udH1(z)=trimf(d3(z),[3.8 ad+2.8 5.8]);
  % Mamdani Rule Based Inference
 for k=1:size(B)
   % Firing of 1st rule
   uBM11(z,k,:)=[utH1(z),ut1L1(z),udL1(z),uBM(k)];
   uBM1(z,k)=min(uBM11(z,k,:));
  % Firing of 2nd rule
   uBM21(z,k,:)=[utH1(z),ut1H1(z),udML1(z),uBM(k)];
   uBM2(z,k)=min(uBM21(z,k,:));
      % Firing of 3rd rule
   uBM31(z,k,:)=[utMH1(z),ut1L1(z),udL1(z),uBM(k)];
   uBM3(z,k)=min(uBM31(z,k,:));
      % Firing of 4th rule
   uBMH11(z,k,:)=[utH1(z),ut1H1(z),udL1(z),uBMH(k)];
   uBMH1(z,k)=min(uBMH11(z,k,:));
      % Firing of 5th rule
   uBH11(z,k,:)=[utM1(z),ut1L1(z),udM1(z),uBH(k)];
   uBH1(z,k)=min(uBH11(z,k,:));
   % Firing of 6th rule
   uBH21(z,k,:)=[utML1(z),ut1H1(z),udML1(z),uBH(k)];
   uBH2(z,k)=min(uBH21(z,k,:));
      % Firing of 7th rule
   uBMH21(z,k,:)=[utL1(z),ut1L1(z),udL1(z),uBMH(k)];
   uBMH2(z,k)=min(uBMH21(z,k,:));
     % Firing of 8th rule
   uBM41(z,k,:)=[utML1(z),ut1H1(z),udL1(z),uBM(k)];
   uBM4(z,k)=min(uBM41(z,k,:));
      % Firing of 9th rule
   uBMH31(z,k,:)=[utM1(z),ut1L1(z),udML1(z),uBMH(k)];
   uBMH3(z,k)=min(uBMH31(z,k,:));
  % Firing of 10th rule
  uBM51(z,k,:)=[utMH1(z),ut1H1(z),udH1(z),uBM(k)];
   uBM5(z,k)=min(uBM51(z,k,:));
     % Firing of 11th rule
   uBM61(z,k,:)=[utML1(z),ut1L1(z),udML1(z),uBM(k)];
   uBM6(z,k)=min(uBM61(z,k,:));
   % Firing of 12th rule
    uBM71(z,k,:)=[utM1(z),ut1H1(z),udML1(z),uBM(k)];
   uBM7(z,k)=min(uBM71(z,k,:));
```

```
% Firing of 13th rule
  uBM81(z,k,:)=[utH1(z),ut1L1(z),udM1(z),uBM(k)];
 uBM8(z,k)=min(uBM81(z,k,:));
   % Firing of 14th rule
 uBM91(z,k,:)=[utH1(z),ut1H1(z),udMH1(z),uBM(k)];
 uBM9(z,k)=min(uBM91(z,k,:));
  % Firing of 15th rule
 uBM101(z,k,:)=[utH1(z),ut1L1(z),udH1(z),uBM(k)];
 uBM10(z,k)=min(uBM101(z,k,:));
   % Firing of 16th rule
  uBMH41(z,k,:)=[utMH1(z),ut1H1(z),udML1(z),uBMH(k)];
 uBMH4(z,k)=min(uBMH41(z,k,:));
  % Firing of 17th rule
  uBM111(z,k,:)=[utL1(z),ut1L1(z),udMH1(z),uBM(k)];
 uBM11(z,k)=min(uBM111(z,k,:));
    % Firing of 18th rule
  uBM121(z,k,:)=[utM1(z),ut1H1(z),udH1(z),uBM(k)];
 uBM12(z,k)=min(uBM121(z,k,:));
  % Firing of 19th rule
  uBM131(z,k,:)=[utML1(z),ut1L1(z),udL1(z),uBM(k)];
 uBM13(z,k)=min(uBM131(z,k,:));
% Firing of 20th rule
  uBMH51(z,k,:)=[utM1(z),ut1H1(z),udMH1(z),uBMH(k)];
 uBMH5(z,k)=min(uBMH51(z,k,:));
   % Firing of 21st rule
 uBM141(z,k,:)=[utL1(z),ut1L1(z),udH1(z),uBM(k)];
 uBM14(z,k)=min(uBM141(z,k,:));
  % Firing of 22nd rule
 uBMH61(z,k,:)=[utL1(z),ut1H1(z),udMH1(z),uBMH(k)];
 uBMH6(z,k)=min(uBMH61(z,k,:));
   % Firing of 23rd rule
  uBH31(z,k,:)=[utL1(z),ut1L1(z),udML1(z),uBH(k)];
 uBH3(z,k)=min(uBH31(z,k,:));
  % Firing of 24th rule
  uBM151(z,k,:)=[utM1(z),ut1H1(z),udL1(z),uBM(k)];
 uBM15(z,k)=min(uBM151(z,k,:));
    % Firing of 25th rule
  uBM161(z,k,:)=[utML1(z),ut1L1(z),udH1(z),uBM(k)];
 uBM16(z,k)=min(uBM161(z,k,:));
      % Firing of 26th rule
 uBM171(z,k,:)=[utML1(z),ut1H1(z),udMH1(z),uBM(k)];
 uBM17(z,k)=min(uBM171(z,k,:));
% Firing of 27th rule
 uBM181(z,k,:)=[utM1(z),ut1L1(z),udL1(z),uBM(k)];
 uBM18(z,k)=min(uBM181(z,k,:));
    % Firing of 28th rule
 uBM191(z,k,:)=[utMH1(z),ut1H1(z),udL1(z),uBM(k)];
 uBM19(z,k)=min(uBM191(z,k,:));
    % Firing of 29th rule
 uBMH71(z,k,:)=[utMH1(z),ut1L1(z),udML1(z),uBMH(k)];
 uBMH7(z,k)=min(uBMH71(z,k,:));
    % Firing of 30th rule
 uBM201(z,k,:)=[utH1(z),ut1H1(z),udH1(z),uBM(k)];
 uBM20(z,k)=min(uBM201(z,k,:));
 % Firing of 31st rule
 uBMH81(z,k,:)=[utH1(z),ut1L1(z),udMH1(z),uBMH(k)];
```

```
  uBMH8(z,k)=min(uBMH81(z,k,:));
    % Firing of 32nd rule
  uBM211(z,k,:)=[utMH1(z),ut1L1(z),udMH1(z),uBM(k)];
  uBM21(z,k)=min(uBM21(z,k,:));
   % Firing of 33rd rule
  uBMH91(z,k,:)=[utML1(z),ut1H1(z),udH1(z),uBMH(k)];
  uBMH9(z,k)=min(uBMH91(z,k,:));
    % Firing of 34th rule
  uBM221(z,k,:)=[utL1(z),ut1H1(z),udM1(z),uBM(k)];
  uBM22(z,k)=min(uBM221(z,k,:));

   % Aggregated Output Membership function(taking the maximum of all 34
   % outputs for each value of input pattern & each value of

uB2(z,k,:)=[uBM1(z,k);uBM2(z,k);uBM3(z,k);uBMH1(z,k);uBMH1(z,k);uBH2(z,k);uBMH2(z,k);uBM4(z,k);uBMH3(z,k);uBM5(z,k);uBM6(z,k);uBM7(z,k);uBM8(z,k);uBM9(z,k);uBM10(z,k);uBMH4(z,k);uBM11(z,k);uBM12(z,k);uBM13(z,k);uBMH5(z,k);uBM14(z,k);uBMH6(z,k);uBH3(z,k);uBM15(z,k);uBM16(z,k);uBM17(z,k);uBM18(z,k);uBM19(z,k);uBMH7(z,k);uBM20(z,k);uBMH8(z,k);uBM21(z,k);uBMH9(z,k);uBM22(z,k)];
   uB3(z,k)= max(uB2(z,k,:));
 end;
 end;

  % Defuzzification(Centroid Method)
  for z=1:7
 bve2(z,:)= defuzz(B,uB3(z,:),'centroid');
  end;
 %  MAE
 MAE=0;
 for z=1:7
 MAE = MAE+abs((bve2(z,:)-bve1(z))/(bve1(z)))*(100/7);
 end;

      subplot(3,3,1); plot(B, [uB3(1,:) ]);
      subplot(3,3,2); plot(B, [uB3(2,:) ]);
      subplot(3,3,3); plot(B, [uB3(3,:) ]);
      subplot(3,3,4); plot(B, [uB3(4,:) ]);
      subplot(3,3,5); plot(B, [uB3(5,:) ]);
      subplot(3,3,6); plot(B, [uB3(6,:) ]);
      subplot(3,3,7); plot(B, [uB3(7,:) ]);
```

Appendix 4

Matlab Code for BDV of White Minilex under AC conditions using fuzzy logic and trapezoidal membership function

```
clear all;
% Three Inputs (thickness t of material, thickness of void and diameter of
% void)
% To model the BDV of White Minilex under AC conditions using fuzzy logic
% and trapezoidal membership function(Mamdani Rule Based Inference with max
% min composition & Centroid Defuzzification)

% Membership function of the thickness t of the dielectric
 t= (0:0.005:0.33)';
 at=0.03;
utL=trapmf(t,[0 at at+0.07 0.13]);
utML=trapmf(t,[0.05 at+0.05 at+0.12 0.18]);
utM=trapmf(t,[0.10 at+0.10 at+0.17 0.23]);
utMH=trapmf(t,[0.15 at+0.15 at+0.22 0.28]);
utH=trapmf(t,[0.20 at+0.20 at+0.27 0.33]);
ut=[utL,utML,utM,utMH,utH];
% Membership function of the thickness t1 of the void
 t1= (0:0.005:0.15)';
 at1=0.02;
ut1L=trapmf(t1,[0 at1 at1+0.03 0.07]);
ut1H=trapmf(t1,[0.08 at1+0.08 at1+0.11 0.15]);
ut1=[ut1L,ut1H];
% Membership function of the diameter d of the void
d= (1.0:0.1:5.8)';
ad=1.5;
udL=trapmf(d,[1.0 ad  ad+1 3.0]);
udML=trapmf(d,[1.7 ad+0.7 ad+1.7 3.7]);
udM=trapmf(d,[2.4 ad+1.4 ad+2.4 4.4]);
udMH=trapmf(d,[3.1 ad+2.1 ad+3.1 5.1]);
udH=trapmf(d,[3.8 ad+2.8 ad+3.8 5.8]);
ud=[udL,udML,udM,udMH,udH];
% Membership function of the breakdown voltage B
B= (1.9:0.1:2.5)';
a1=1.95;
uBL=trapmf(B,[1.9 a1 a1+0.1 2.1]);
uBML=trapmf(B,[2.0 a1+0.1 a1+0.2 2.2]);
uBM=trapmf(B,[2.1 a1+0.2 a1+0.3 2.3]);
uBMH=trapmf(B,[2.2 a1+0.3 a1+0.4 2.4]);
uBH=trapmf(B,[2.3 a1+0.4 a1+0.5 2.5]);
uB=[uBL,uBML,uBM,uBMH,uBH];
% Program for testing the Fuzzy Logic System to evaluate the mean absolute error
% The input testing data (Crisp Input)(Thickness of material)
 t3=[0.26;0.26;0.125;0.18;0.18;0.26;0.26];
 % The input testing data(Crisp Input) (Thickness of void)
t4=[0.125;0.025;0.125;0.125;0.025;0.025;0.125];
 % The input testing data (Crisp Input)(Diameter of the void)
 d3=[3;2;3;5;3;5;2];
 % The output testing experimental data (Breakdown voltage)
```

```
 bve1=[2.2;2.2;2.3;2.2;2.4;2.2;2.2];
%Fuzzification of crisp input (thickness of material)
for z=1:7
utL1(z)=trapmf(t3(z),[0 at at+0.07 0.13]);
utML1(z)=trapmf(t3(z),[0.05 at+0.05 at+0.12 0.18]);
utM1(z)=trapmf(t3(z),[0.10 at+0.10 at+0.17 0.23]);
utMH1(z)=trapmf(t3(z),[0.15 at+0.15 at+0.22 0.28]);
utH1(z)=trapmf(t3(z),[0.20 at+0.20 at+0.27 0.33]);
%Fuzzification of crisp input (thickness of void)
ut1L1(z)=trapmf(t4(z),[0 at1 at1+0.03 0.07]);
ut1H1(z)=trapmf(t4(z),[0.08 at1+0.08 at1+0.11 0.15]);
%Fuzzification of crisp input (diameter of void)
udL1(z)=trapmf(d3(z),[1.0 ad ad+1 3.0]);
udML1(z)=trapmf(d3(z),[1.7 ad+0.7 ad+1.7 3.7]);
udM1(z)=trapmf(d3(z),[2.4 ad+1.4 ad+2.4 4.4]);
udMH1(z)=trapmf(d3(z),[3.1 ad+2.1 ad+3.1 5.1]);
udH1(z)=trapmf(d3(z),[3.8 ad+2.8 ad+3.8 5.8]);
  % Mamdani Rule Based Inference
 for k=1:size(B)
   % Firing of 1st rule
   uBM11(z,k,:)=[utH1(z),ut1L1(z),udL1(z),uBM(k)];
   uBM1(z,k)=min(uBM11(z,k,:));
  % Firing of 2nd rule
   uBM21(z,k,:)=[utH1(z),ut1H1(z),udML1(z),uBM(k)];
   uBM2(z,k)=min(uBM21(z,k,:));
      % Firing of 3rd rule
   uBM31(z,k,:)=[utMH1(z),ut1L1(z),udL1(z),uBM(k)];
   uBM3(z,k)=min(uBM31(z,k,:));
      % Firing of 4th rule
   uBMH11(z,k,:)=[utH1(z),ut1H1(z),udL1(z),uBMH(k)];
   uBMH1(z,k)=min(uBMH11(z,k,:));
      % Firing of 5th rule
   uBH11(z,k,:)=[utM1(z),ut1L1(z),udM1(z),uBH(k)];
   uBH1(z,k)=min(uBH11(z,k,:));
   % Firing of 6th rule
   uBH21(z,k,:)=[utML1(z),ut1H1(z),udML1(z),uBH(k)];
   uBH2(z,k)=min(uBH21(z,k,:));
      % Firing of 7th rule
   uBMH21(z,k,:)=[utL1(z),ut1L1(z),udL1(z),uBMH(k)];
   uBMH2(z,k)=min(uBMH21(z,k,:));
     % Firing of 8th rule
   uBM41(z,k,:)=[utML1(z),ut1H1(z),udL1(z),uBM(k)];
   uBM4(z,k)=min(uBM41(z,k,:));
      % Firing of 9th rule
   uBMH31(z,k,:)=[utM1(z),ut1L1(z),udML1(z),uBMH(k)];
   uBMH3(z,k)=min(uBMH31(z,k,:));
  % Firing of 10th rule
  uBM51(z,k,:)=[utMH1(z),ut1H1(z),udH1(z),uBM(k)];
   uBM5(z,k)=min(uBM51(z,k,:));
     % Firing of 11th rule
   uBM61(z,k,:)=[utML1(z),ut1L1(z),udML1(z),uBM(k)];
   uBM6(z,k)=min(uBM61(z,k,:));
   % Firing of 12th rule
    uBM71(z,k,:)=[utM1(z),ut1H1(z),udML1(z),uBM(k)];
   uBM7(z,k)=min(uBM71(z,k,:));
  % Firing of 13th rule
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  uBM81(z,k,:)=[utH1(z),ut1L1(z),udM1(z),uBM(k)];
 uBM8(z,k)=min(uBM81(z,k,:));
   % Firing of 14th rule
 uBM91(z,k,:)=[utH1(z),ut1H1(z),udMH1(z),uBM(k)];
 uBM9(z,k)=min(uBM91(z,k,:));
  % Firing of 15th rule
 uBM101(z,k,:)=[utH1(z),ut1L1(z),udH1(z),uBM(k)];
 uBM10(z,k)=min(uBM101(z,k,:));
   % Firing of 16th rule
  uBMH41(z,k,:)=[utMH1(z),ut1H1(z),udML1(z),uBMH(k)];
 uBMH4(z,k)=min(uBMH41(z,k,:));
  % Firing of 17th rule
  uBM111(z,k,:)=[utL1(z),ut1L1(z),udMH1(z),uBM(k)];
 uBM11(z,k)=min(uBM111(z,k,:));
    % Firing of 18th rule
  uBM121(z,k,:)=[utM1(z),ut1H1(z),udH1(z),uBM(k)];
 uBM12(z,k)=min(uBM121(z,k,:));
  % Firing of 19th rule
  uBM131(z,k,:)=[utML1(z),ut1L1(z),udL1(z),uBM(k)];
 uBM13(z,k)=min(uBM131(z,k,:));
% Firing of 20th rule
  uBMH51(z,k,:)=[utM1(z),ut1H1(z),udMH1(z),uBMH(k)];
 uBMH5(z,k)=min(uBMH51(z,k,:));
   % Firing of 21st rule
 uBM141(z,k,:)=[utL1(z),ut1L1(z),udH1(z),uBM(k)];
 uBM14(z,k)=min(uBM141(z,k,:));
  % Firing of 22nd rule
 uBMH61(z,k,:)=[utL1(z),ut1H1(z),udMH1(z),uBMH(k)];
 uBMH6(z,k)=min(uBMH61(z,k,:));
   % Firing of 23rd rule
  uBH31(z,k,:)=[utL1(z),ut1L1(z),udML1(z),uBH(k)];
 uBH3(z,k)=min(uBH31(z,k,:));
  % Firing of 24th rule
  uBM151(z,k,:)=[utM1(z),ut1H1(z),udL1(z),uBM(k)];
 uBM15(z,k)=min(uBM151(z,k,:));
    % Firing of 25th rule
  uBM161(z,k,:)=[utML1(z),ut1L1(z),udH1(z),uBM(k)];
 uBM16(z,k)=min(uBM161(z,k,:));
      % Firing of 26th rule
 uBM171(z,k,:)=[utML1(z),ut1H1(z),udMH1(z),uBM(k)];
 uBM17(z,k)=min(uBM171(z,k,:));
% Firing of 27th rule
 uBM181(z,k,:)=[utM1(z),ut1L1(z),udL1(z),uBM(k)];
 uBM18(z,k)=min(uBM181(z,k,:));
    % Firing of 28th rule
 uBM191(z,k,:)=[utMH1(z),ut1H1(z),udL1(z),uBM(k)];
 uBM19(z,k)=min(uBM191(z,k,:));
    % Firing of 29th rule
 uBMH71(z,k,:)=[utMH1(z),ut1L1(z),udML1(z),uBMH(k)];
 uBMH7(z,k)=min(uBMH71(z,k,:));
    % Firing of 30th rule
 uBM201(z,k,:)=[utH1(z),ut1H1(z),udH1(z),uBM(k)];
 uBM20(z,k)=min(uBM201(z,k,:));
 % Firing of 31st rule
 uBMH81(z,k,:)=[utH1(z),ut1L1(z),udMH1(z),uBMH(k)];
 uBMH8(z,k)=min(uBMH81(z,k,:));
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     % Firing of 32nd rule
  uBM211(z,k,:)=[utMH1(z),ut1L1(z),udMH1(z),uBM(k)];
  uBM21(z,k)=min(uBM21(z,k,:));
    % Firing of 33rd rule
  uBMH91(z,k,:)=[utML1(z),ut1H1(z),udH1(z),uBMH(k)];
  uBMH9(z,k)=min(uBMH91(z,k,:));
     % Firing of 34th rule
  uBM221(z,k,:)=[utL1(z),ut1H1(z),udM1(z),uBM(k)];
  uBM22(z,k)=min(uBM221(z,k,:));

    % Aggregated Output Membership function(taking the maximum of all 34
    % outputs for each value of input pattern & each value of

uB2(z,k,:)=[uBM1(z,k);uBM2(z,k);uBM3(z,k);uBMH1(z,k);uBMH1(z,k);uBH2(z,k);uBMH2(z,k);uBM4(z
,k);uBMH3(z,k);uBM5(z,k);uBM6(z,k);uBM7(z,k);uBM8(z,k);uBM9(z,k);uBM10(z,k);uBMH4(z,k);uBM
11(z,k);uBM12(z,k);uBM13(z,k);uBMH5(z,k);uBM14(z,k);uBMH6(z,k);uBH3(z,k);uBM15(z,k);uBM16(z
,k);uBM17(z,k);uBM18(z,k);uBM19(z,k);uBMH7(z,k);uBM20(z,k);uBMH8(z,k);uBM21(z,k);uBMH9(z,k
);uBM22(z,k)];
    uB3(z,k)= max(uB2(z,k,:));
 end;
 end;

  % Defuzzification(Centroid Method)
  for z=1:7
 bve2(z,:)= defuzz(B,uB3(z,:),'centroid');
  end;
 %  MAE
 MAE=0;
 for z=1:7
 MAE = MAE+abs((bve2(z,:)-bve1(z))/(bve1(z)))*(100/7);
 end;

       subplot(3,3,1); plot(B, [uB3(1,:) ]);
       subplot(3,3,2); plot(B, [uB3(2,:) ]);
       subplot(3,3,3); plot(B, [uB3(3,:) ]);
       subplot(3,3,4); plot(B, [uB3(4,:) ]);
       subplot(3,3,5); plot(B, [uB3(5,:) ]);
       subplot(3,3,6); plot(B, [uB3(6,:) ]);
       subplot(3,3,7); plot(B, [uB3(7,:) ]);
```