

Investigation of the Breakdown Thresholds Air Gap from AC Voltage by Central Composite Face and Double Centered Composite Method

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Abstract

When an electrically insulating material is exposed to a high voltage, it abruptly transforms into an electrical conductor and allows current to flow through it. This process is known as dielectric breakdown. A controlled current flow is caused by an excessive electric field intensity in the region where the current flow is referred to as an electric breakdown. As a result, electrons will accelerate and collide with other molecules or atoms with enough force to release additional electrons from the affected molecules or atoms. The current work examines the Central Composite Face Method for modelling the AC breakdown voltage in point-to-plane air gaps with barriers in section one. The investigation was done for varying sizes and positions. The barrier in use was positioned between the electrodes vertically. The research outcomes presented in this study were obtained at Biskra University's High Voltage Laboratory, focusing on the dielectric strength of air in the peak-barrier system. In section two, a novel method based on the double-centred composite plane model was applied for the varying radius of tip and electrode distance curvate. A comparison was made between the experimental results and the results of numerical simulations. The computed and experimental results exhibited a high level of agreement.

Keywords: Electric breakdown, Air gaps discharge, Central Composite Face Method, Insulating Barrie, Factors.

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1. Introduction

The discharge is too weak to be visible and depends on an external source. This is not a self-sustaining plasma; increasing the voltage further, then the electron impact on atoms will eventually lead to ionization. Therefore, the discharge current will increase above the saturation current because each electron can create a strong avalanche of electron-ion pairs accelerated in the electric field. This repeat causes breakdown. Breakdown causes an arc whose current is limited only by the impedance of the external circuit [1–4]. An electric discharge is called the release and transmission of electrons and ions that build a bridge between two points influenced by an electric field, where one side has a different potential. The investigation has been done simulated and experimentally in a solid dielectric barrier. When operating at different voltages, solid dielectric materials are utilized in all devices and electrical circuits to separate one current-carrying component from another. A good dielectric should have a minimal dielectric loss, high mechanical strength, be free

of gaseous inclusions, and not contain any moisture. It should also be resistant to chemical deterioration and thermal. Research on the breakdown of solid dielectrics is essential for insulation investigations [5- 10].

During breakdown, solids are irreversibly destroyed, whereas liquids and gases partially and fully recover their dielectric strength after removing the applied electric field [11- 14].

The factors influencing the breakdown voltage are the thickness and homogeneity, frequency and waveform of the voltage applied, frequency of cavities and moisture, ambient medium mechanical force, and nature of the field.

For example, solid insulating materials can occasionally have voids or cavities in the medium or boundaries between the electrodes and dielectric [15- 21]. The voids possess a dielectric constant of unity and a lower dielectric strength, resulting in a reduced electric field strength across the dielectric compared to the voids. Consequently, if the electric field strength within the voids surpasses its breakdown threshold, breakdown may transpire even under normal operating voltages. [22- 27].

Each time a discharge occurs, heat will be lost in the voids, which will cause the surface of the voids to carbonize and the material to deteriorate. The gradual deterioration of the material and the resulting loss of thickness eventually lead to breakdown [28-33]. Thermal breakdown results from a little current passing locally via weak dielectric areas. As the field strength increases, this current rise produces more heat locally, which creates point defects. As ionic conductivity develops, more heat is generated locally, raising the temperature further [34- 38].

A statistical tool called "Central Composite Face Method" or "CCF" is used to organize and carry out experiments and analyze and interpret the data they generate.

The aim here is to make a product or process less variables, a more robust interface of variation over which we have little or no control. Central Composite Face Method applies to problem areas such as, the development of new products and processes, enhancement of existing of important factors, the Principle of this methodology is to organized approach which rationally connects experiments, estimates the influence of and interactions between all elements, and evaluates outcomes in the context of variability[39]. Design is a body of knowledge and technique that assist the experimenter in product experiments economically, analyze the data, and make the connections between the conclusion from the analysis and the original objective of the investigation.

It is essential to define the objectives, which involves determining a range of variability for each variable and selecting the factors and their corresponding levels. [40].Consequently, to be chosen based on the number of responses that can be supported[41].Typically, all variables have the same number of levels, however, can be a choice of experimental design type and perform her experiments, analyzing the results and confirming the predicted results.

In this study, an experimental design methodology is employed to model the AC breakdown voltage in point-plane gaps featuring a barrier. The experimental results encompass various factors influencing breakdown phenomena, such as the relative position of the barrier, its width and hole, and the plane's radius of curvature.

2. Materials and methods

A. Section 1

a. Materials

The breakdown test equipment in the laboratory is capable of supplying the sample, it is important to understand and recognize that electrode style and size will influence the breakdown strength and must be accounted for when comparing results. [42]

The experiment that was carried out showed how the electrodes and insulating barrier are arranged, with the point-plane electrode configuration being vertically oriented.

The high-voltage electrodes comprise 300 conical-shaped copper and steel needle points. A round steel plate with a diameter and length of 30 cm serves as the grounded plane electrode.

The glass barriers are squares of various widths 10cm, 15cm, and 20cm, and various holes 10mm, 15mm, and 20mm, and its thickness is 1mm. The barriers are oriented vertically between the electrodes, and the surface is examined after each breakdown, as in Fig. 1.

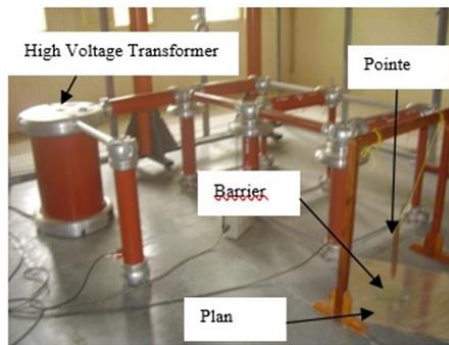


Fig. 1. Scheme of the test cell discharge with barrier



Fig. 2. Photography of a slippery discharge with barrier



Fig. 3. Photography of a slippery discharge without barrier

Figures 2 and 3 showed images of a slippery discharge with and without a barrier, illustrating the dynamics of gas breakdown in a fast-pulse electric field. The discharge current is calculated by deducting the displacement current from the total discharge current.

The discharge advances through three main phases: surface barrier discharge propagation, streamer breakdown of the electrode gap, and streamer to diffuse transition.

The strong electric field produces a primary streamer, initially traveling from the needle electrode to the plate electrode. Once the first streamer has spread across the dielectric plate's surface, the

conductive streamer channel can remove the memory charges that have accumulated there. [43-50].

When the electric field in the electrode gap and on the dielectric plate surface is lowered, a secondary streamer channel can form and move down the dielectric plate [56- 64].

However, the gas gap volume discharge is weakening, and the pulse voltage is declining. Space charges are then engaged in the development of the induced field at the streamer head as well as the propagation of the streamer. [51 55]

b. Method

The core concept of the technical CCF is to simultaneously change the levels of one or more parameters (which can be continuous, discrete, or variable) in each test.

It will help to reduce the number of testing that must be done considerably. As the number of elements being researched rises, it becomes more crucial to understand their interactions and their optimum relative response, or a value that can be used as standard and easily modelling results.

Four (04) steps make up the typical process for an experimental design:

Step 1:Preparation study

(Characterization of Objective -Related Responses)

Our objective is to quantify the influence of the parameters (R in cm, H in mm, and W in cm):

The relative position, the hole of the barrier and the width of the barrier respectively.

Step 2: The selection of parameters and experimental domain

The aims of the experiment and the basic knowledge about the physical phenomenon under study must be considered while choosing the field of study. Additionally, reducing the number of tests required for the study is important to keep costs down. Finally, we should remember that the study's findings will only apply to the whole range of variation among the variables examined. The following are the primary Factors in this plan's experiments:

Table 1: Levels Examined for the Factors

Factors	R(cm)	H(mm)	W(cm)
Level-1	2	10	10
Level 0	4	15	15
Level+1	6	20	20

Step 3: The model proposed

Our preferred approach for studying response surfaces is to utilize face-centred composite designs. These designs involve defining two starting points on each axis based on specific parameters, resulting in a comprehensive evaluation.

The quadratic terms in the polynomial model offer valuable insights into the curvature of the response surface.

NThe total number of experiments required for the study depends on two factors: K (the number of factors under investigation, in this case, K=3) and (n_0) (the number of iterations at the centre of the domain).

$$N = 2^K + 2.K + n_0 \quad (1)$$

$$N = 2^3 + 2.3 + 3 = 17 \quad (n_0 = 3) \quad (2)$$

Table 2 : Designing a Composite Plan Centred on Three Factors

Experiments No	Factors			U _c (kV)
	R(cm)	H(mm)	W(cm)	
1	-1	-1	-1	61,21
2	-1	1	-1	58,69
3	-1	-1	1	58,65
4	-1	1	1	54,45
5	1	-1	-1	68,22
6	1	1	-1	66,25
7	1	-1	1	66,78
8	1	1	1	63,32
9	0	-1	0	63,32
10	0	1	0	61,82
11	0	0	1	61,98
12	0	0	1	64,38
13	-1	0	0	60,56
14	1	0	0	67,72
15	0	0	0	63,25
16	0	0	0	63,22
17	0	0	0	63,18

To ensure specific properties for the matrix experiments, the last three rows of Table 2 represent a test centre that functions as an experimental field and needs to be replicated n_0 times.

To ensure that the experimental range's variance is almost constant and that it complies with the criteria for uniform precision.

Whether the model coefficients vector that was searched after analytically. The following is a description of the analytical model's coefficients vector:

$$b = (X^t X)^{-1} X^t y$$

X, X^t and y are the transpose matrix, the transpose matrix experiment and the breakdown voltage (the response) respectively.

The formula below can be used to calculate (b_i) (The number of polynomial's unknown parameters)

$$b = \frac{(K+2)!}{k! 2!} \Rightarrow b = \frac{(3+2)!}{3! 2!} = 10 \quad (4)$$

In conclusion, the model is expressed as follows:

$$y = b_0 + \sum_{i=1}^3 b_i \cdot X_i + \sum_{i=1}^3 b_{ii} \cdot X_i^2 + \sum_{i=1}^2 \left[\sum_{j=i+1}^3 b_{ij} \cdot X_i \cdot X_j \right] \quad (5)$$

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{11} x_1^2 + b_{22} + b_{33} x_3^2 + b_{12} x_{12} + b_{13} x_{13} + b_{23} x_{23} \quad (6)$$

Step 4: Mathematical models

We utilized the Matlab software to estimate the model coefficients, which provides an analytical version of the response surface and can be derived using equ.3 (Table 3).

Table 3: Coefficients of mathematical model.

Response	Breakdown voltage U _c (kV)
	Experimental design domain
Constant	63.7911
R	3.873
H	-1.365
W	-1.28855
R.H	0.16125
R.W	0.30375
H.W	-0.39625
R ²	-0.08189
H ²	-1.65189
W ²	0.24666

Thus, the following is how the mathematical model (experimental domain) might be expressed:

$$U_c = 63,7911 + 3,873.R - 1,365.H - 1,28855.W + 0,1612.R.H + 0,30375.R.W - 0,39625.H.W - 0,08189.R^2 - 0,08189.H^2 + 0,24666.W^2(7)$$

To compare the measured and estimated responses, the collected data may be plotted. It is crucial to plot the model's adequacy.

The measured responses are plotted on the abscissa, while the estimated responses are plotted on the ordinate in Figure 4. The cloud points align closely with the $y=x$ line, indicating a high level of accuracy in the model.

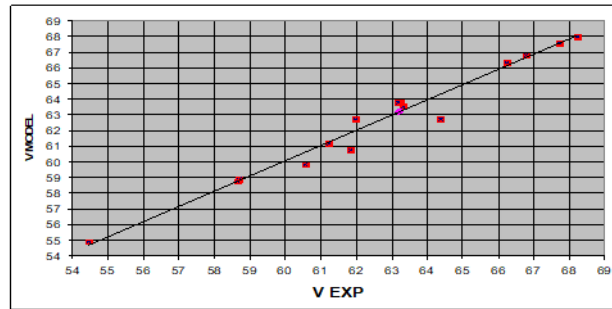


Fig .4. Graph model adequacy

Although the model's descriptive quality is shown here, this result will need to be verified by a second analysis of variance.

a. Statistical analysis of the model

Implementing statistical tests should involve making a decision based on the results obtained. The regression analysis table is built during this step of the statistical analysis and the descriptive model's quality is assessed. The total variation of the response is determined by calculating the sum of squared residuals between the test results and their average. This information is further explained through regression analysis. The statistical analysis is complemented by:

$$STCE(U_c) = SCEL + SCER = 197,88 \quad (8)$$

STCE: Total Squared Sum is independent of the proposed model.

SCEL: Squared Sum associated with the model,

SCER: Squared Sum associated with Residuals.

$$SCER(U_c) = \sum_{i=1}^{17} (Y_i - y_{ipr})^2 = 6.34 \quad (9)$$

$$SCEL(U_c) = \sum_{i=1}^{17} (Y_{ipr} - y_{moy})^2 = 191.54 \quad (10)$$

With:

Y_i, y_{moy} and y_{moy} : responses experimental, responses calculated by the models and average of response respectively.

statistical test is based on comparing the fraction of two variances to a predetermined value.

The statistic value F_{SV} is defined by:

$$F_{SV} = \frac{SCEL/P-1}{S^2} \quad (10)$$

$$S^2 = \frac{1}{N-P} \sum e_i^2 \quad (11)$$

$$e_i^2 = (Y_i - y_{ipr})^2 \quad (12)$$

S, N, P and e_i^2 : Variance of residues, Number of experiences realized, Number of coefficients and residues, respectively.

We chose $\alpha = 5\%$: (Fisher risk), for a significance level,.

$F_{crit} = (\alpha, df_M, df_R)$,

df_M : The freedom degrees number of model,

df_R : The freedom degrees number of residual.

The various steps taken to calculate this probability are listed in Table 4 of the regression analysis.

Table 4 :Table of regression analysis

Source	STCE	df_M	mean square	FSV
Model	191.54	09	21.282713	23.5123354
Residual	6.34	07	0.9051722	
Total	197.88	16		

The regression analysis table can be used to calculate the coefficient of determination R^2 , R_{ajus}^2 and Q^2

$$R^2 = \frac{SCE_L}{STCE} \quad (14)$$

$$R_{ajus}^2 = 1 - \frac{SCER/N-P}{STCE/N-1} \quad (15)$$

$$Q^2 = 1 - \frac{PRESS}{STCE} \quad (16)$$

The residual predictive squared sum:

$$PRESS = \sum_{i=1}^{17} \frac{(Y_i - y_{ipr})^2}{(1 - h_i)^2} \quad (17)$$

h_i : The matrix's i th diagonal component.

Table 5 presented the results obtained

Table5: Coefficients for determining the model's descriptive quality

R^2	R_{ajus}^2	Q^2
0,96798	0,98386	0,986

The Coefficients R^2 , R_{ajus}^2 and Q^2 are all over 0.9 (around unity), which indicates that the model is of high quality.

$N - P = 17 - 10 = 7$ with a risk of $\alpha = 5\%$

Coming from the student table:

$$t_{crit} = (0,05, 7) = 2.37 \quad (18)$$

If ($t_i > 2.37$), the effect will be significant at a risk of 5%.

Additionally, t_i is determined by:

$$t_i = \frac{|b_i|}{s_i} \quad (19)$$

Table 6 :Significance testing of the coefficients.

Factors	Effect	t_i = 2.37	results
Constants	63.791	276.45	significant
R	3.873	16.78	significant
H	-1.365	5.92	significant
W	- 1.2885	5.58	significant
R.H	0.1613	0.70	not significant
R.W	0.3038	1.32	not significant
H.W	- 0.3962	1.72	not significant
R2	- 0.0819	0.35	not significant
H2	- 1.6519	7.16	significant
W2	0.2467	1.07	not significant

Only the coefficients that provide the model's descriptive quality will be maintained from Table.6.

The reduced model equation becomes:

$$U_c = 63,791 + 3,873.R - 1,365.H - 1,2885.W - 1,6519.H^2 \quad (20)$$

In this situation, the confidence interval for an effect is provided as follows:

Lower limit: $[b_i - 1.96 * 0.189]$

Higher limit: $[b_i + 1.96 * 0.189]$

a. Results and discussion

The purpose of validating the model's output is to ensure that the presumptions underlying the findings of experiments have been thoroughly examined. In addition, the model behaviour identified by the experimental design can be validated by doing complementary experiments outside of the testing plan tests. In this case study, the constructed test was utilized to look at how the parameters impacted the outcomes. Along with assessing the experimental strategy. In Figures 5, 6, and 7, the outcomes of these tests are compared with those of the mathematical model.

Impact of the Relative Position Barrier on Breakdown Voltage

Figure 5 illustrates the relationship between the relative position of the barrier and the experimental and predicted breakdown voltage for three varying barrier widths (10, 15, and 20 cm).

Studies were done at various point-to-barrier separations (2 cm to 6 cm).

The breakdown voltage is significantly affected by the insertion of the barrier, with the predicted values falling within the range of the two 5% risk area limits. This observation suggests that the model established through the experimental design method is highly accurate.

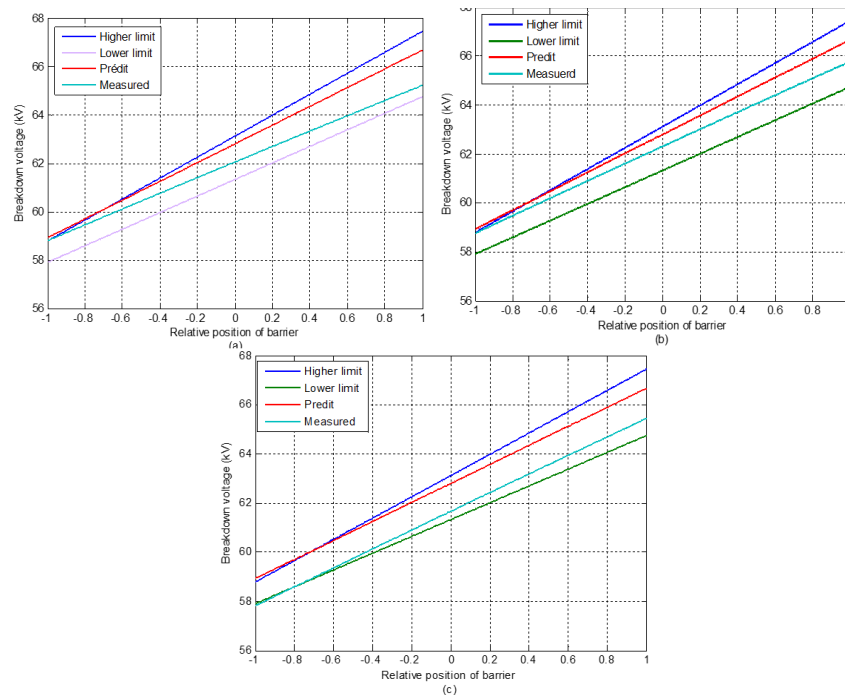


Fig. 5. Effect of Barrier relative position on Breakdown Voltage in AC Voltage: Comparative Analysis of (a) 10cm, (b) 15cm and (c) 20cm Widths with a Fixed Hole Diameter of 5mm.

Impact of the Barrier Hole on Breakdown Voltage

The barrier's central holes in this test range in size from 10mm to 15mm to 20mm. The barrier's relative position values for 10, 15, and 20cm widths. Reviewing the figures, we see that the breakdown voltage falls off as the number of holes in the middle of the barrier rises.

This result can be attributed to the reduced electrical charge that passes through the hole. When the diameter of the hole increases, a significant portion of the charging area also passes through the hole.

This observation supports the understanding that increasing the hole diameter results in the predicted values falling within the boundaries of the 5% risk area.

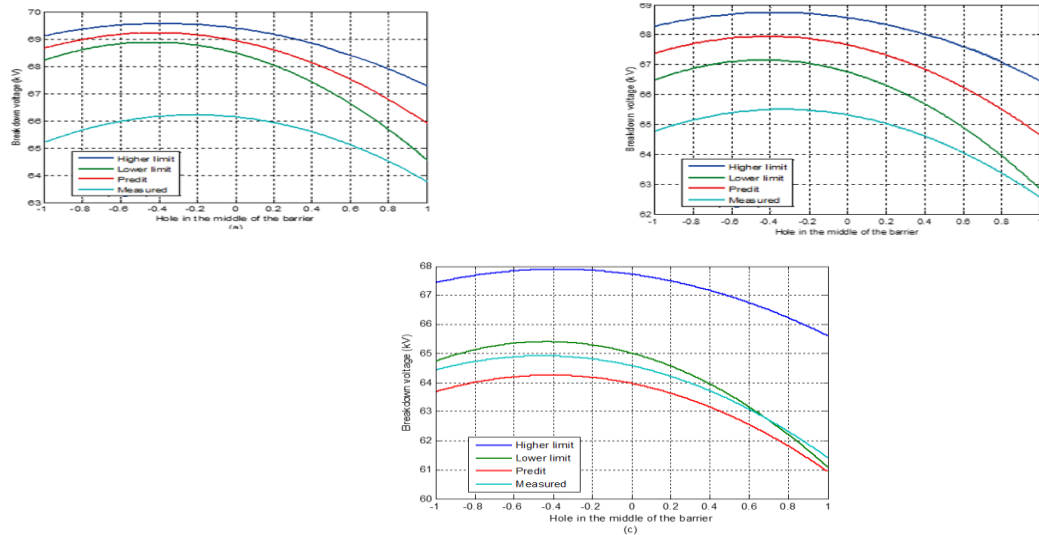


Fig. 6. Impact of Central Hole in Barrier on Breakdown Voltage: Comparative Analysis of (a)10cm ,(b)15 cm and (c) 20cm Widths in AC Voltage

Impact of Barrier Width on Breakdown Voltage

In this test, there are three different distances between the electrodes and the barrier (2 cm, 4cm, and 6cm) as well as a hole in the centre of the barrier (10 mm) and three different barrier widths(10cm , 15cm and 20cm).

We can clearly see that the breakdown voltage increases with rising large barrier widths and decreases with decreasing barrier widths. The presence of geometric impediments on the screen can be used to explain this.

In Figure 7, it is shown that the breakdown voltage decreases as the barrier widths increase.

Moreover, the predicted values fall within the boundaries of the 5% risk zone, indicating that the model generated through the experimental design process is perfect.

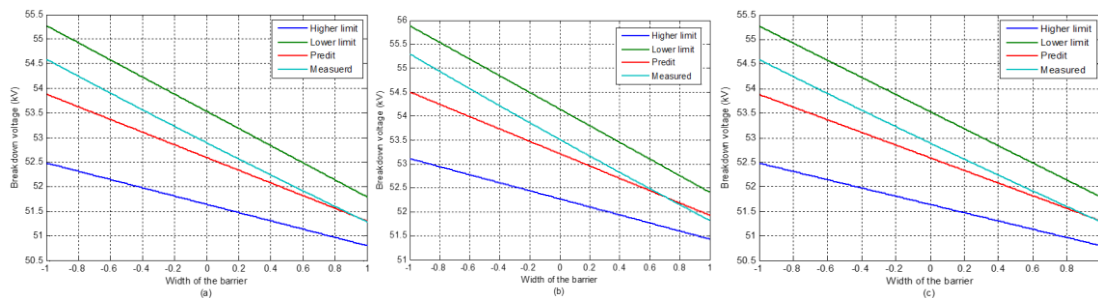


Fig. 7. Effect of Barrier Width on Breakdown Voltage: Comparative Analysis of Different Barrier relative Positions in AC Voltage

We can state that the results are satisfactory and well within the 5% confidence interval when we consider the experimental conditions that we worked under and the approximations we made in the numerical model.

Verification experiments should be conducted as part of the experiments design method to ascertain the ideal conditions and compare them to experimental data.

The validation experiments conducted in this study confirm that all values fall within the established confidence intervals.

B. Section B

In this section, we study the threshold of an electric breakdown in the air, based on the results obtained in the literature. According to the research work of the researcher H. Mohseni represented in the published article entitled "The field of rod-plane electrodes and partial discharge inception voltage in air" during the international symposium on high voltage engineering for this purpose, we applied the methodology experimental plans.

Most experiment realizations require access to prior, specialized information in the field of application.

The objective initially set in our work is to apply a novel strategy based on the design of experiments methodology to determine and predict the point-plane air gap breakdown voltage.

R: The radius of curvature of the tip (variable)

d: The inter-electrode distance (variable)

a. Modelling the breakdown voltage

The plane used in this work is:

• Double centred composite plane.

This modelling aims to model the variation of the point-plane distance (d) and the point-plane air gap tension as a function of radius (R). In the phase of model development for experiments based on experimental designs, the experimental results of references are employed as the basis of the data.

b. Modelling by the double centred composite plane

The numerous tables that illustrate the modelling results of the point-plane air breakdown voltage are shown in this section. In addition, we detail the results of the experimental tests used to concretize the composite plan's double-centred design in Table 7.

Table 7: Data table

N Experiments	R = x2(cm)	d=x1(cm)	y exp(kv)
1	0.12	20	140
2	0.12	40	210
3	2	20	180
4	2	40	280
5	1.06	20	160
6	1.06	40	245
7	0.12	30	160
8	2	30	230
9	1.06	30	195
10	1.06	30	195
11	1.06	30	195
12	0.12	20	140
13	0.12	40	210
14	2	20	180
15	2	40	280
16	1.06	20	160
17	1.06	40	245
18	0.12	30	160
19	2	30	230
20	1.06	30	195
21	1.06	30	195
22	1.06	30	195

a) Estimation of the coefficients of the model developed

The mathematical model of the dual centred composite plane

is given by:

$$y = a_0 + a_1x_1 + a_2x_2 + a_{11}x_1^2 + a_{22}x_2^2 + a_{12}x_1x_2 \quad (21)$$

Table 8 : Table of the values of the coefficients of the mathematical model

a_0	a_1	a_2	a_{11}	a_{22}	a_{12}
194.67	42.50	29.30	8.32	-0.91	7.50

By the use of the MATLAB software we found the coefficients of the mathematical model of double centred composite plane, from the equation (21) we obtained the values of the coefficients given in the table (8).

Thus, the following is how the mathematical model (experimental domain) might be expressed:

$$y = 194,67 + 42,50.x_1 + 29,30.x_2 + 8,32.x_1^2 - 0,91.x_2^2 + 7,50.x_1x_2 \quad (22)$$

The table (9) gives the matrix of experiments

Table 9: Matrix of experiments

N Experiments	d= x_1 (cm)	R= x_2 (cm)	y exp(kv)	Ymod(kv)
1	-1	-1	140	137.78
2	1	-1	210	207.78
3	-1	1	180	181.38
4	1	1	280	281.38
5	-1	0	160	160.49
6	1	0	245	245.49
7	0	-1	160	164.46
8	0	1	230	223.06
9	0	0	195	194.67
10	0	0	195	194.67
11	0	0	195	194.67
12	-1	-1	140	137.78
13	1	-1	210	207.78
14	-1	1	180	181.38
15	1	1	280	281.38
16	-1	0	160	160.49
17	1	0	245	245.49
18	0	-1	160	164.46
19	0	1	230	223.06
20	0	0	195	194.67
21	0	0	195	194.67
22	0	0	195	194.67

a. Statistical analyses and interpretation of the results obtained

In this section of work, we give a statistical analysis of the results obtained by the developed mathematical model and in the end we end this section with interpretations of the results obtained. Significance test of the coefficients e_i are the residues of order i observed during the experiments. They are defined by eq. 13

Table 10: Values of absolute errors and their squares

N Experiments	y exp(kv)	Ymod(kv)	e_i	e_i^2
1	140	137.78	2.22	4.9284
2	210	207.78	2.22	4.9284
3	180	181.38	-1.38	1.9044
4	280	281.38	-1.38	1.9044

5	160	160.49	-0.49	0.2401
6	245	245.49	-0.49	0.2401
7	160	164.46	-4.46	19.8916
8	230	223.06	6.94	48.1636
9	195	194.67	0.33	0.1089
10	195	194.67	0.33	0.1089
11	195	194.67	0.33	0.1089
12	140	137.78	2.22	4.9284
13	210	207.78	2.22	4.9284
14	180	181.38	-1.38	1.9044
15	280	281.38	-1.38	1.9044
16	160	160.49	-0.49	0.2401
17	245	245.49	-0.49	0.2401
18	160	164.46	-4.46	19.8916
19	230	223.06	6.94	48.1636
20	195	194.67	0.33	0.1089
21	195	194.67	0.33	0.1089
22	195	194.67	0.33	0.1089

We are trying to test the non-influence of a variable on the response. We choose a risk of 5%. The variance of the residuals is (eq. 12)

$$s^2 = \frac{1}{22-6} \cdot 165,07 = 10,32$$

n: number of experiments carried out

p: number of coefficients

The common variance of the model coefficient estimators is:

$$s_i^2 = \frac{s^2}{n} \quad (23)$$

$$s_i^2 = \frac{s^2}{n} = \frac{10,32}{22} = 0,47$$

The Student table gives, for a risk of 5% with $\theta = n - p = 22 - 6 = 16$: $t_{crit}(0.05;16) = 2.12$

An effect will therefore be significant at the 5% risk if " t_i " is greater than 2.12. We get the following table:

Table 11: Significance test

Variable	Effect	Interval	
		Lower bound	Upper bound
Constant	194.67	192.92	196.42
x_1	42.5	40.75	44.25
x_2	29.3	27.55	31.05
x_1^2	8.3212	6.57	10.08
x_1x_2	7.5	5.75	9.25

This table shows that only the variables x_1 , x_2 and the interaction x_1^2 , x_1x_2 are significant. Therefore, a model of the form should be retained:

$$y = 194,67 + 42,50 \cdot x_1 + 29,30 \cdot x_2 + 8,32 \cdot x_1^2 + 7,50 \cdot x_1x_2 \quad (24)$$

We will determine a confidence interval, at 5% risk, for the coefficients a_1, a_2 and a_{11}, a_{12} . Remember that this interval is calculated with: 5% risk:

$[a_i - 0.69 * 1.96 ; a_i + 0.69 * 1.96]$

Table 12: Confidence interval

Variable	Effect	Interval	
		Lower bound	Upper bound
Constant	194.67	193.34	196.00
x_1	42.5	41.17	43.83
x_2	29.3	27.97	30.63
x_1^2	8.3212	6.99	9.65
$x_1 x_2$	7.5	6.17	8.83

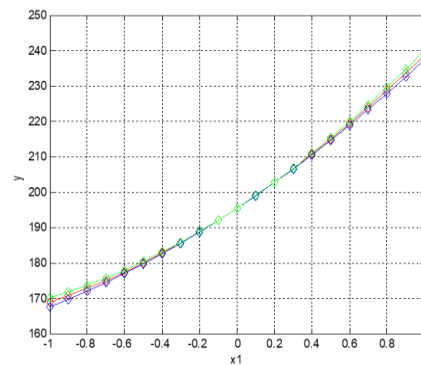


Fig .8. Confidence interval for a 5% risk of $y = f(x_1)$

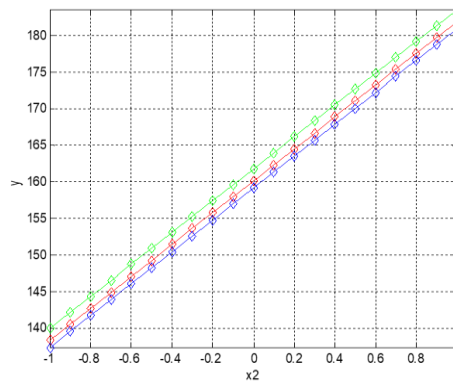


Fig .9. Confidence interval for a 5% risk of $y = f(x_2)$

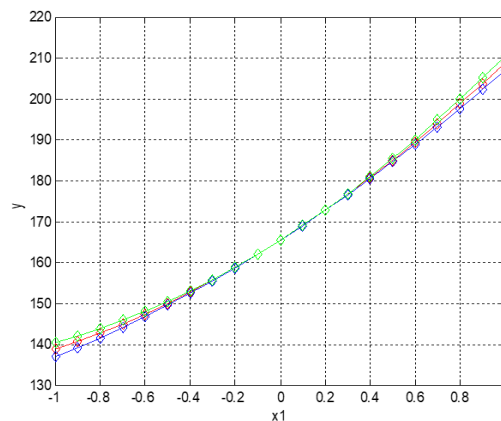
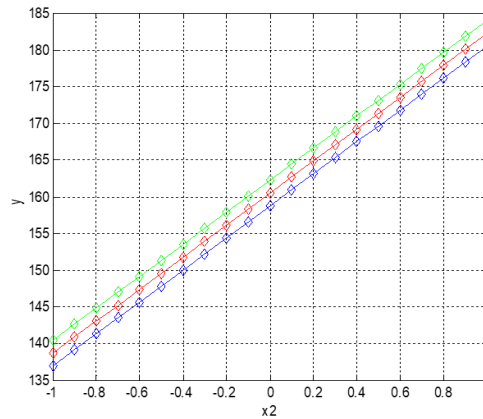


Fig.10. Confidence interval for a 1% risk of $y = f(x_1)$

Fig .11. Confidence interval for a 1% risk of $y = f(x_2)$

We will determine a confidence interval, at the risk of 1%, for the coefficients a_1 , a_2 and a_{11} , a_{12} . Remember that this interval is calculated with:

Risk 1%: $[a_i - 0.69 \cdot 2.58 ; a_i + 0.69 \cdot 2.58]$

Table 13 : Confidence interval

Factors	Effect	t=2,12	Results
Constant	194.6715	286.28	significant
x_1	42.5	62.50	significant
x_2	29.3	43.09	significant
x_1^2	8.3212	12.24	significant
x_2^2	-0.9124	-1.34	not significant
$x_1 x_2$	7.5	11.03	significant

a. Analysis of the results obtained

Fig12 presents the comparison between the experimental values and the values of the model developed:

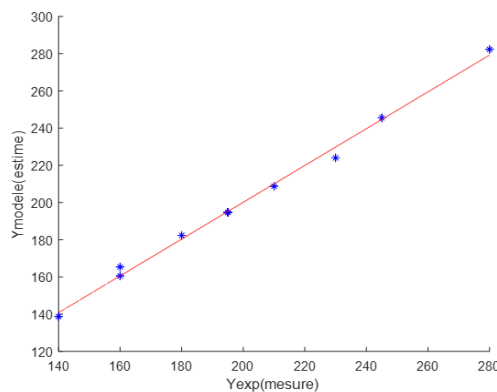


Fig.12. Model fit graph

This figure clearly shows that the results of the models developed are in good agreement with the experimental results, with a very acceptable error.

b. Analysis of variance

The sum of the squares of the deviations entirely attributable to the regression (therefore to the model) is compared with the sum of the squares of the residuals as part of the analysis of variance using the Fischer F test.

The analysis of variance table then looks like this table:

Table 14: Different values of the elements constituting the variance

N°exp	y exp	y model	Y moy	SCEL	SCER	STCE
1	140	138.69	199.09	3647.95	1.71	3491.75
2	210	208.69	199.09	92.19	1.71	119.01
3	180	182.29	199.09	282.18	5.26	364.47
4	280	282.29	199.09	6922.52	5.26	6546.27
5	160	160.49	199.09	1489.83	0.24	1528.11
6	245	245.49	199.09	2153.12	0.24	2107.64
7	160	165.37	199.09	1137.00	28.85	1528.11
8	230	223.97	199.09	619.04	36.34	955.37
9	195	194.67	199.09	19.53	0.11	16.74
10	195	194.67	199.09	19.53	0.11	16.74
11	195	194.67	199.09	19.53	0.11	16.74
12	140	138.69	199.09	3647.95	1.71	3491.75
13	210	208.69	199.09	92.19	1.71	119.01
14	180	182.29	199.09	282.18	5.26	364.47
15	280	282.29	199.09	6922.52	5.26	6546.27
16	160	160.49	199.09	1489.83	0.24	1528.11
17	245	245.49	199.09	2153.12	0.24	2107.64
18	160	165.37	199.09	1137.00	28.85	1528.11
19	230	223.97	199.09	619.04	36.34	955.37
20	195	194.67	199.09	19.53	0.11	16.74
21	195	194.67	199.09	19.53	0.11	16.74
22	195	194.67	199.09	19.53	0.11	16.74

Table 15: Analysis of variance

Variation	Sum of squares	DDL	Average square	F
Connection	SCEL	p-1=4	8201.22	872.4702
Residues	SCER	n-p =17	9.40	
Total	SCET	n-1=21	1589.61	

The Fischer-Snédecor table gives for $\vartheta_1 = 4$ and $\vartheta_2 = 17$, $F(\text{crit}) = 2.96$, for a risk of 5%. We have: $(F_{\text{obs}} = 872.4702) > (F_{\text{crit}} = 2.96)$ so we accept hypothesis H_1 of linearity of the model. This is in good agreement with the fact that all the coefficients are significant.

Coefficients of determination (R^2, R_{ajust}^2)

After calculation the values of the coefficients are as follows:

$$R^2 = 0.983$$

$$R_{ajust}^2 = 0.994$$

Coefficient Q^2 :The quality coefficient value is: $Q^2 = 0.999$

c. Discussion of results

TABLE I. In this section, we have given details of the values predicted by the two experimental designs developed for each trial and compared them with the experimental values by the relative errors:

Table 16: Experimental and predicted values

N°exp	R =x2	d=x1	Yexp	Ymod PCC	ER (%)	Ymod PCD	ER (%)
1	0,12	20	140	137.5	1.79	137.78	1.59
2	0,12	30	160	165	3.13	160.49	0.31
3	0,12	40	210	207.5	1.19	207.78	1.06
4	2	20	180	182.5	1.39	181.38	0.77
5	2	40	280	282.5	0.89	281.38	0.49
ER min					0.89	ER min	0.31
ER moy					1.68	ER moy	0.84
ER max					3.13	ER max	1.59

- PCC: centred composite plane.
- PCD: dual centred composite plane.
- ER: relative error.

In the table (17) we give the different values of R^2 , R_{ajust}^2 and Q^2 for each plane:

Table 17: Different values of (R^2, R_{ajust}^2) and Q^2

Centered composite planes		
R^2	R_{ajust}^2	Q^2
0.9955	0.988	0.996
Double centered composite planes		
R^2	R_{ajust}^2	Q^2
0.983	0.994	0.999

We compared the experimental results with from modelling.

Tables (16 and 17) compare the predicted and experimental voltage values.

After the results obtained, it is clear that the design of experiments methodology has great power in solving modelling problems.

The number of factors greatly influences the results and the accuracy of the modelling.

The results presented by the various tables show that we succeeded in implementing dedicated models for modelling the breakdown voltage.

3.Conclusions

a. For section 1

Research findings indicated that the Experimental Design Method is a helpful tool for searching parameters impacting the fixed and optimization of the objective. Experiment methodology provided direction on the effects of many factors. It entails fixing the search parameters that affect the target as a first stage. Because it enables the classification of parameter effects in terms of relevance, the approach response surface works incredibly well for this.

On one hand, the study investigates the impact of parameters, while on the other hand, it aims to narrow down the selection of factors for the desired model.

Thus, a model that adequately describes the system under study has been defined, which has improved system performance.

It has been looked at how to model the breakdown of the dielectric in a point-plan arrangement with an insulating barrier in the air interval.

We have suggested a design method for mathematical modelling based on experiments. It leads to the analysis of how the relative positions, diameter of the barrier, and distance between electrodes interact with one another.

This methodology has shown positive findings and aids in reducing the number of tests required for the study's cost.

It has been demonstrated that this methodology is particularly helpful for lifetime modelling and tracking the influential operating parameters on insulation dependability. We can conclude from this study that the Experiment Design Method exhibits good performance to investigations in the analysis of various discharge phases of the air interval.

b. For section 2

In this work, we have shown that the design of experiments method is a useful tool for modelling. An approach based on the use of experimental designs has been proposed to tackle these often complex problems.

It consists initially of researching the parameters that influenced the set objective. For this, the use of factorial plans proves to be very effective. Because they make it possible to classify the parameters in order of importance by testing the objective function a minimum of times. In addition, the use of statistical tools, such as the analysis of variance, gives the degree of confidence in the results obtained.

The second step is to use the influential parameters in the modelling. A direct optimization method by successive design of experiments has been developed and tested on a practical case.

Finally, the study of the sensitivity of the solution retained to achieve the fixed objective, can be carried out thanks to the use of a centred composite factorial plan which will provide a precise model author of the solution.

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