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AN INTELLIGENT METHOD TO ESTIMATE THE FLASHOVER OF HIGH VOLTAGE INSULATORS

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***Abstract**. In this work we tried to contribute in solving the problem of flashover in polluted high voltage insulators. For this purpose, metaheuristic methods, namely fireflies algorithm, have been used to solve the Obenaus equation which is practically the only mathematical model that simulates this phenomenon. The results obtained demonstrate the high precision of the approach used.*

Keywords: Flashover, High voltage insulator, Fireflies algorithm (FFA), Critical voltage, ESDD.

1. INTRODUCTION

Insulators are among the most important components of overhead electrical energy transport and distribution networks since they provide both the mechanical support of the parts brought to high voltage and the electrical insulation of the latter, with grounded or energized other components [1-2].

Indeed, a disturbance of the electrical insulation provided by the insulator can lead, in certain circumstances, to its bypassing and therefore a major risk to the reliability and operation of the overhead electrical energy transmission system. Several causes are at the origin of the electrical flashover such as transient overvoltage on the electrical networks (lightning, interlocking and openings of lines), freezing atmospheric precipitation in cold regions or even atmospheric pollution deposits [3].

This research work is particularly interested in atmospheric pollution deposits and its impact on the reliability of the isolator. For this we used an artificial intelligence technique to try to define new values of the constants of the arc of the famous model of Obenaus. And indeed we have been able to demonstrate that the fireflies algorithm method is very effective in achieving good results.

Fig. 1– Attractiveness of fireflies

2. THE FIREFLIES ALGORITHM

Collective intelligence has become a widely used medium for constructing nature-inspired methods to solve very complicated problems [4]. The firefly algorithm is a metaheuristic method inspired by the behavior of fireflies insects [5].

Fireflies are flying insects that emit light in order to ward off enemy insects and attract other fireflies to move together.

That is to say the medium of communication between these insects is light, the less luminescent firefly moves to the more luminescent firefly and so on [6].

It should be noted that as it is evident, the intensity of the light is inversely proportional to the distance between the two fireflies Fig. 1.

This method aims to simulate this behavior and thus model it in the form of mathematical equations for later use in optimization problems.

3. MATHEMATICAL MODEL

It should be noted that fireflies are unisex so the attractiveness does not depend on the sex of the insect; however it strongly depends on the degree of brightness which can be considered as an objective function to be optimized.

The intensity of light is inversely proportional to the distance, so we can write:

$$I \quad \frac{1}{r^2} \qquad (1)$$

I: intensity of the emitted light.

r: the distance between two fireflies.

In a given environment we must define a coefficient γ which we will call the absorption coefficient and the light intensity will therefore be calculated by:

$$I = I_0 e^{-\gamma r} \qquad (2)$$

I_0: the intensity of the light at zero distance.

γ: absorption coefficient.

Since light intensity is strongly related to attractiveness, then the latter can be calculated in the same way and it is called β.

$$\beta = \beta_0 e^{-\gamma r} \qquad (3)$$

β_0: attractiveness when r=0

The distance between two fireflies is given by the following formula [7]:

$$r_{ij} = \left| x_i - x_j \right| = \sqrt{\sum_{k=1}^{d} \left(x_{ik} - x_{jk} \right)^2} \qquad (4)$$

Finally the displacement of a firefly is given by [7]:

$$x_{i\,new} = x_i + \beta_0 e^{-\gamma r_{ij}^2} \left(x_j - x_i \right) + \alpha (rand - \frac{1}{2}) \qquad (5)$$

$x_{i\,new}$: the new position of the firefly i.

x_i: the current position of the firefly i.

r_{ij}: the distance between firefly i and firefly j.

x_j: the current position of the firefly j.

α: random number

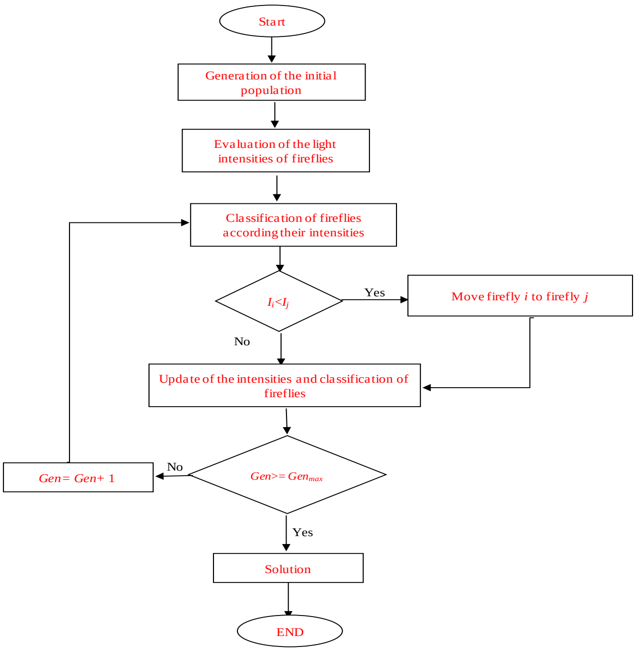

Fig. 2– Flowchart of the FFA method

4. THE MECHANISM OF FLASHOVER IN POLLUTED INSULATORS

Several studies have proposed certain criteria for arc development and flashover. The first quantitative criterion was proposed by Obenaus [8] which is known as the extinction theory. The flashover process is modeled as an arc, in series with a resistance, which represents the wet portion of the pollution layer (Fig. 3).

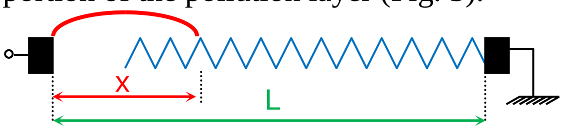

Fig. 3 – Physical model of the development of the electric arc

The voltage across this model is given by the following equation:

$$U = xAI^{-n} + (L-x) R_p I \qquad (6)$$

Where:

xAI^{-n}: is the arc voltage.

$(L-x)\ RpI$: is the voltage in the pollution layer.

x: The length of the arc.

L: The model's leakage line.

R_p: The resistance per unit length of the pollution layer.

I: The leakage current.

But this formula is very simplified, in reality the critical voltage *Uc* (in V), which is the voltage applied across the insulator when the partial arc is developed into a full flashover, is given by the following formula [9]:

$$U_c = \frac{A(L+\pi DFkn)}{n+1}\left(\pi D\sigma_p A\right)^{\frac{-n}{n+1}} \quad (7)$$

Where:

L: is the leakage line of the insulator (in cm).

D: the maximum diameter of the insulating disc (in cm).

F: is the form factor of the insulator.

A and *n*: are the arc constants.

σ_p: the conductivity of the pollution layer (in Ω^{-1}).

$$\sigma_p = (369.05C + 0.42)10^{-6} \quad (8)$$

C: the equivalent salt deposition density (ESDD) in mg/cm^2.

k: The coefficient of resistance of the pollution layer in cap-and-pin insulators which is added by Wilkins [10] to validate relation (6) at the critical moment of the flashover.

$$k = 1 + \frac{L}{2\pi Fn} Ln \frac{L}{2\pi FR} \quad (9)$$

R: is the radius of the arc step and is given by:

$$R = 0.469(\pi D\sigma_p A)^{\frac{1}{2(n+1)}} \quad (10)$$

Obviously the critical voltage can be calculated after determining the arc constants. These are the unknown parameters of the model and the subject of several studies which resulted in the great divergence in the results given [11-15].

5. FORMULATION OF THE PROBLEM

The program used maximizes the functions to be optimized. In our case the function to be solved is that of equation (7). To do this, we relied on previous work to build a database for the critical flashover voltage *Uc* and the ESDD "*C*" to calculate the values of "*A*" and "*n*" which best fit this base of data. For this we must try to adapt our function to the program used. The function to be maximized will therefore be:

$$F = 1 - \sum_{i=1}^{14}\sum_{j=1}^{14}\left|Uc_{ij} - f_{ij}(A,n)\right| \quad (11)$$

It is clear that the maximum of this function corresponds to the minimum of the term $\sum_{i=1}^{14}\sum_{j=1}^{14}\left|Uc_{ij} - f_{ij}(A,n)\right|$ which is our objective.

The database is built from 14 types of insulators whose characteristics are mentioned in table (1) and whose data are published in previous works [16-20], 14 values were taken for each type.

Table 1 Characteristics of the insulators of the database

Type	*D* (cm)	*L* (cm)	*F*
1	26.8	33	0.79
2	26.8	40.6	0.86
3	25.4	43.2	0.9
4	25.4	31.8	0.72
5	29.2	47	0.92
6	27.9	36.8	0.76
7	32.1	54.6	0.96
8	28	37	0.8
9	25.4	30.5	0.74
10	20	40	1.29
11	25.4	27.9	0.68
12	25.4	30.5	0.70
13	25.4	43.2	0.92
14	22.9	43.2	1.38

Finally to validate our results, we used the available experimental data which are grouped together in table (2) [10].

Table 2 Experimental values for 4 types of insulators

Type	*L* (cm)	*D* (cm)	*F*	*C* (mg/cm^2)	*Uc* (KV)
Type 1	27.9	25.4	0.68	0.13	12
	27.9	25.4	0.68	0.16	11.1
	27.9	25.4	0.68	0.23	8.7
	27.9	25.4	0.68	0.34	7.5
	27.9	25.4	0.68	0.49	6.2
	27.9	25.4	0.68	0.55	6.1
Type 2	30.5	25.4	0.70	0.02	22
	30.5	25.4	0.70	0.05	16
	30.5	25.4	0.70	0.1	13
	30.5	25.4	0.70	0.16	11
	30.5	25.4	0.70	0.22	10
Type 3	43.2	25.4	0.92	0.05	19
	43.2	25.4	0.92	0.1	15
	43.2	25.4	0.92	0.16	13
	43.2	25.4	0.92	0.22	12
	43.2	25.4	0.92	0.3	10.5
Type 4	43.2	22.9	1.38	0.02	23.5
	43.2	22.9	1.38	0.03	20.9
	43.2	22.9	1.38	0.04	19.4
	43.2	22.9	1.38	0.05	18.3
	43.2	22.9	1.38	0.06	16.9
	43.2	22.9	1.38	0.1	15.8
	43.2	22.9	1.38	0.2	13.6

6. APPLICATION AND RESULTS

The program of the FFA method is configured as follows: the number of iterations is 20, the number of fireflies is 100, the random number "α" is 0.4, the reduction of the random number is 0.6, the absorption coefficient is 0.7, the population of the variable "A" is chosen in the interval [94, 154] and that of the variable "n" is chosen in the interval [0.1, 0.6].

By launching the program the following results were obtained:

After the first generation we see that the fireflies have chosen random solutions as shown in figure (4).

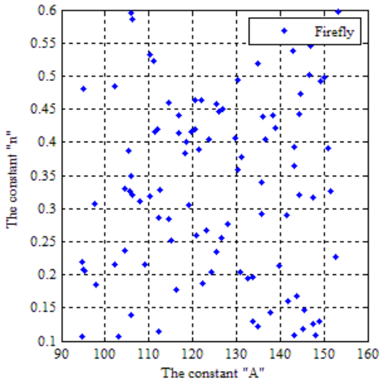

Fig. 4 – The solution given by the FFA after the 1st generation

From the 5th generation we see that the fireflies start to converge towards the optimal solutions as shown in figure (5).

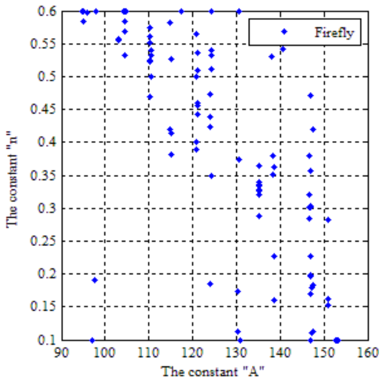

Fig. 5–The solution given by the FFA after the 5th generation

And at the end of the 20th generation the fireflies came together in the optimal solutions which are given in figure (6).

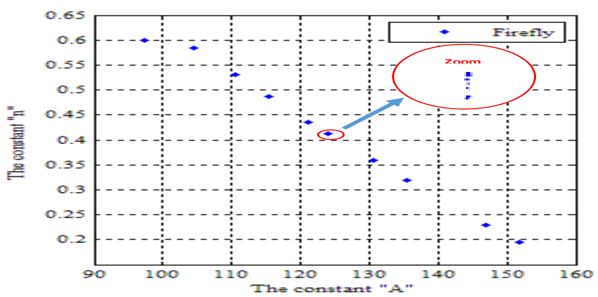

Fig. 6 – The solution given by the FFA after the 20th generation

7. VALIDATION

To validate our results we had recourse to the experimental values, and as we see in the figures (11, 12, 13, and 14) where we compared the results given by the FFA algorithm to the available experimental values, we see that these results correspond differently with the 4 types of which we dispose.

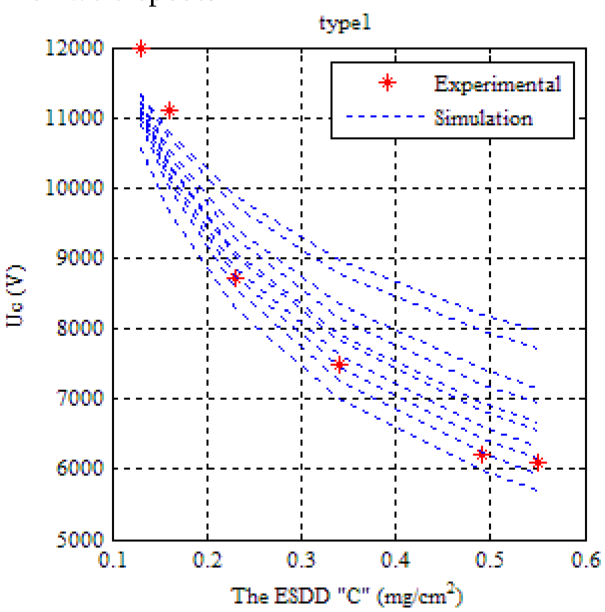

Fig. 7– Comparison between simulation and experimental for type 1 insulator

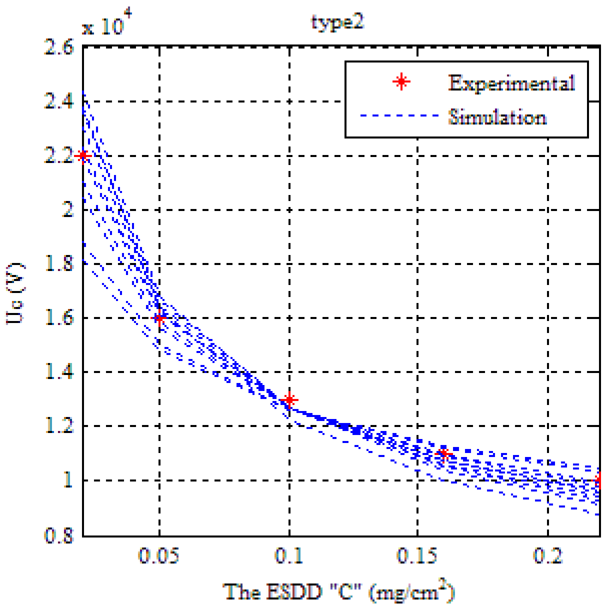

Fig. 8 – Comparison between simulation and experimental for type 2 insulator

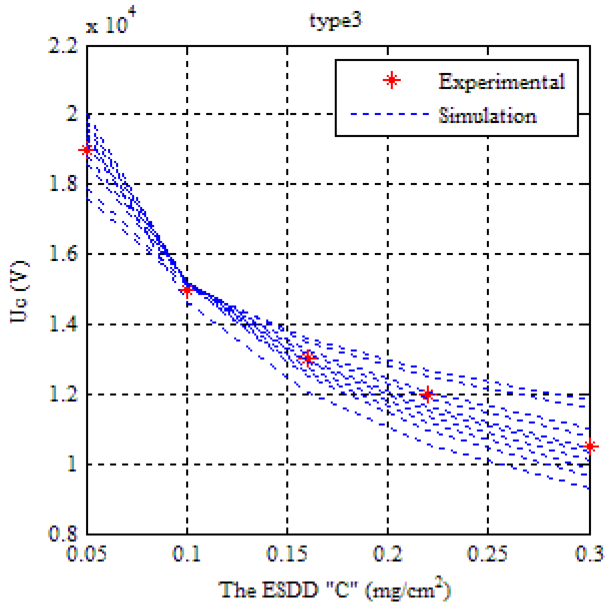

Fig. 9 – Comparison between simulation and experimental for type 3 insulator

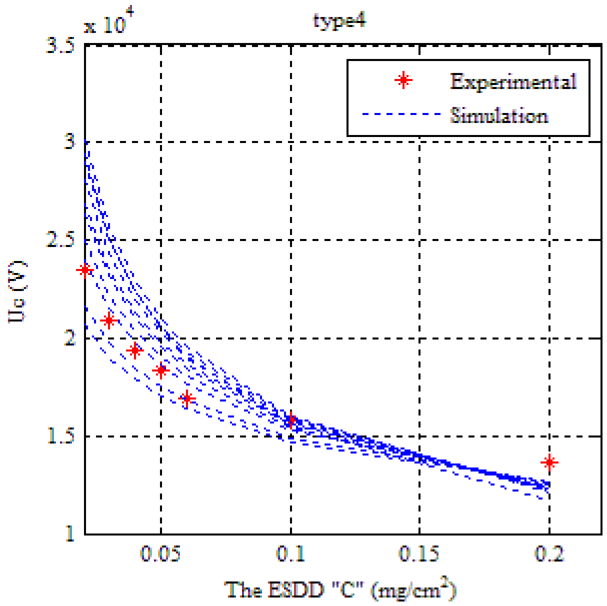

Fig. 10 – Comparison between simulation and experimental for type 4 insulator

We note that this method gives several solutions for the equation, hence the variation of the constant *A* from 97 to 152 and the constant *n* from 0.19 to 0.6 and if we compare them with the values given by other researchers, summarized in table 3, we can conclude that this method is very well suited to this kind of problem.

Table 3. Values of constants A and n according to different authors

Authors	*"A"*	*"n"*
Alston and Zoledziowski [21]	63	0.760
Wilkins [25]	63	0.76
Rahal [22]	220	0.31
Claverie [23]	100	0.5
Hampton [24]	530	0.24
Obenaus [8]	100	0.7
Renyu [26]	138	0.69
Farzaneh [13]	208.9	0.449
Gosh [14]	360	0.59
Topalis [27]	131.5	0.374

8. CONCLUSION

From the results we have reached, we can conclude that this proposed approach is very effective in solving the problem of the flashover in high voltage insulators. Thus estimating with great precision the critical flashover voltage and consequently contributing to the correct dimensioning of the chains of insulators, which has a positive economic impact. However it should be noted that the aim of the work in this direction is far from being achieved, it takes many experimental values to allow the programming to simulate reality well.

<u>Prospects:</u>

This method gave ten possible solutions to this problem, in comparison with the experimental values it can be seen that each solution is better suited to a particular type of insulator. The ideal is to find a single solution for all types. It is hoped that this work will be useful to fellow researchers in future work to achieve this aim.

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