FUZZY MODEL OF CORONA CURRENT SIGNALS FOR EHV LINES

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Abstract:Corona generated currents change with atmospheric condition and with the terrain which themselves are uncertain and ambiguous in nature. This results that the corona models available presently are not defined accurately and are ambiguous. The authors in this paper have presented the Fuzzy Model of the Corona currents due to EHV lines assuming triangular fuzzy functions. It takes into accounts the ambiguity and uncertainties of earlier models. Fuzzy models related to fuzzification of voltage gradient and excitation function have been developed. The results have been compared with the conventional model.

1. Introduction : The ionization of air surrounding the conductor due to electrostatic field of EHV lines generate corona currents in the form of pulses. It depends upon various factors such as atmospheric conditions, size of conductors, conductor configuration and voltage gradient etc. The corona generated currents change with the atmospheric conditions and also with the terrain, which can not be defined accurately and are uncertain in nature. To deal with such signals it is appropriate to represent them with Fuzzy-logic model, as it takes into account the uncertainties of the parameters. The authors in this paper have applied this approach to develop the mathematical model of corona current signals. Since the corona current is the function of voltage gradient, which is the function of line parameters, earth resistivity and environment conditions, we have, therefore, computed the voltage gradient, g, taking into account the uncertainties of the parameters using fuzzy-logic functions. From this we have calculated the corona generated currents and voltages.

2. Excitation Function [1,2]: The excitation function Γ, can be visualized as an emf generated between the conductor surface and region very close to conductor surface. For single conductor per phase, under rainy condition, excitation function,Γ is given by equation (1)

$$\Gamma = 155.\log_{10}(g/11.5) + 11.5r \; db/\mu A/m^{1/2} \tag{1}$$

where g is the surface gradient in kV(rms)/cm, r is the radius of conductor in cm. For bundle conductor, the excitation function, Γ_b is given by equation (2).

$$\Gamma_b = \Gamma(g,r) + (11.5 + \log_{10} n^2).r_s - B(n) \tag{2}$$

where r_s is the radius of sub conductor in cm, n is the number of sub conductors in a bundle, B(n) represents correction due to number of conductors in one bundle

B(n) = 0 for single conductor/phase

B(n) = 5 for twin sub conductor/phase

The value of g is computed using following equation

$$g = \frac{V}{m.\delta.r.\log(2h/r)} \tag{3}$$

where, m is the irregularity factor whose value varies from 0.8 to 1.0 and δ is the air density factor whose values varies from 0.9 to 1.1, and h is the height of conductor above ground.

For twin bundle conductor, voltage gradient, g_b can be given as

$$g_b = 2\left[\frac{1}{2r} + \frac{1}{s}\right] \cdot \frac{V/m\delta}{\log_e \frac{4h^2}{rs}} \tag{4}$$

where s is the spacing between the sub conductors.

3. Corona Current : The corona currents propagates in transverse as well as radial direction. But in this paper we have considered only transverse mode. However, the radial mode will interfere with TV and communication signals. The corona injected current i per unit length can be computed using the equation (5).

$$i = \frac{\varpi C}{2\pi\varepsilon_0}\Gamma \qquad (5)$$

where C is the capacitance per unit length of the line and depends upon the geometry of conductors, ω is the angular frequency of injected corona current, and Γ is the excitation function.

The spectral density of the linear noise current density i_{sd} in such a case can be obtained by multiplying corona current by the circumference of conductor.

$$i_{sd} = 2\pi r.i \qquad (6)$$

Once the corona inject current is computed, the corona voltage v is given as

$$[v] = [Z_0].[i] \qquad (7)$$

where Z_0 is the surge impedance of the transmission line.

4. Fuzzy Model [4,5]: Conventionally the corona currents are computed by defining the excitation function, associated voltage and atmospheric parameters. However, there exists a large element of uncertainty and vagueness due to the complex relationship between the voltage gradient, atmospheric parameters and excitation currents. The uncertainty may also occurs due to

(i) variation of earth resistivity

(ii) inaccuracies due to air density factor i.e. due to atmospheric humidity pressure etc..

(iii) insufficient knowledge of surface condition of the conductor.

Fuzzy logic model can accommodate the ambiguities of these variations and measurements. It consists of 3 steps. (i) Fuzzification (ii) Inferencing and (iii) Defuzzification. Fig.(1) shows the block diagram of fuzzy logic modeling scheme.

4.1 Fuzzification: Fuzzification is the transformation of crisp data into a corresponding Fuzzy set. Before the data can be fuzzified, however, they should be first normalized to meet the range of universe of discourse.

The voltage gradient, corresponding to various parameters affecting it, are converted into fuzzy variables by considering the suitable fuzzy function. Suppose the air density factors lies between 0.9 to 1.1, it can be considered as belonging to the sets VS, S, N, H, VH. If the usual deterministic approach is employed, these five sets are separate and hence variable air density factor can belong to only one of them at a time. In the fuzzy set approach, it can belong to more than one set according to a given membership function $\mu_m(\delta)$, whose value range is normalized in the range of 0 to 1. This function determines the membership grade that the fuzzy variable δ assumes in the corresponding fuzzy sets. In the measurement considered in fig. (2) the variable $\delta = 0.925$ belong to normal with a membership grade $\mu_m(\delta) = 0.25$ and in low with a membership grade $\mu_m(\delta) = 0.75$. Of course it belongs to all other sets with a membership grade zero. Therefore, fuzzy set $\mu_m(\delta) \Rightarrow [\ 0,\ 0.75,\ 0.25,\ 0,\ 0] \Rightarrow$ [VL, L,N,H,VH]. Similarly from fig(3) fuzzy membership for m = 0.85 is [0,0.5,0.5,0,0]

4.1.a Criteria For the Selection Of Membership Function : The choice of number range and shape of membership function depend upon the design choice and the accuracy desired in the resultant value. Following points should be kept in mind while selecting the membership value

(i)Symmetrically distribute the fuzzy set across the defined universe of discourse.

(ii)Use an odd number of fuzzy set for each value, this ensures that some fuzzy set will be in the middle. 5 or 7 fuzzy sets for each system variable is fairly typical.

(iii)Overlap adjacent fuzzy sets to ensure that no crisp value fails to correspond to any set and to help in ensuring that more than one rule is involved in determining the output.

(iv)Use triangular or trapezoidal membership functions, as these require less computation time than other types.

System variable with 5 to 7 fuzzy sets with 15% to 25% overlap of adjacent fuzzy sets tend to work fairly well. It is important to clearly distinguish between the input and output values which are usually crisp numbers with many permitted levels in an allowed range, are the system variables or fuzzy parameters which are essentially linguistic, taking values that correspond to fuzzy set.

4.2 Compositional Rule of Inference : The basic function of inference in Fuzzy-logic are the adaptation of classical principles to the Fuzzy domain. The basic information unit representing assertions and fuzzy rule is a proportion of the type

The <Attribute> is <Value> i.e. p : x is A

where x is the linguistic variables and A is its value.

Typically, a Fuzzy rule has the following general format of a conditional proposition, p : if antecedent then consequent

where antecedent and consequent are fuzzy propositions.

The Bechus-Naur Form (BNF) notation for a generalized Fuzzy rule is given below :

< if – then – else > :: = if<proposition> then < proposition>

<proposition> :: = < disfunction> {and <disjunction>}

<disjunction> :: = <variable> {or <variables> }

<variable> :: =<attribute> is <value>

It may be noted that the Demantics of Fuzzy Rule is that the statement of the form if x is A then y is B describes a relation between the Fuzzy variable x and y.

4.3 Defuzzification : Defuzzification is the process of obtaining crisp value from the processed fuzzy set values. It has two functions :

(i) conversion of a fuzzy set into crisp value

(ii) selection of one of several possible value.

If the final fuzzy set represent only one single value, the second task is superfluous. It is sufficient to determine an appropriate crisp value from the given fuzzy set. The defuzzification strategies Mean of Maxima method and Centre of Gravity method work under this presumption. If in contrast the fuzzy set represents a set of several elements both tasks (i) and (ii) have to be solved. In this case the order in which they are carried out is important.

If we complete task (ii) we have to choose from a fuzzy set representing a set of several elements a fuzzy subset, representing only a single fuzzy element. This fuzzy set can be defuzzified into a crisp value by applying strategy like Mean of Maxima method or Centre of Gravity method. We have calculated the corona current using the Centre of Gravity method for getting the crisp value.

(i) COG (Centre of Gravity) method :

In this method the output or crisp value can be given as

$$Output = \frac{\int \mu(x).\, x.\, dx}{\int \mu(x).\, dx} \tag{8}$$

where μ(x) is the membership function of variable x. This method is commonly employed with control application as the result move more smoothly with observational changes.

(ii) MOM (Mean of Maxima) Method :

In this method the crisp value or output is given as

$$Out\ Put = \frac{\int \mu_{out}(x).\, x.\, dx}{\int \mu_{out}(x).\, dx} \tag{9}$$

such that $\mu_{out}(x)$ is maximum. This method is used in the real time implementation of fuzzy logic control.

5. Fuzzy Model Of Corona Currents : For a crisp value of irregularity factor, m and air density factor δ, fuzzy sets are formed. From these fuzzy sets (or fuzzified values of m and δ), the fuzzy value of voltage gradient, g is determined and from these, a set of fuzzy values of excitation function, Γ is determined using Min-Max method. Then the fuzzy set of excitation function is defuzzified using COA method and a crisp value of excitation function is determined. From the defuzzified or crisp value of excitation function, value of corona currents and corona voltages are determined. The value of corona currents and corona voltages, thus obtained are, then compared with the corresponding values of corona current and voltages which are determined by conventional method.

6. Numerical Results : In order to demonstrate the usefulness of fuzzy-logic modeling, the corona current signal generated on single conductor/phase in a 220 kV and twin bundle conductor in a 400 kV line has been considered. The details of the lines are given in Annexure – I.

To fuzzify the value of air density factor δ and irregularity factor m, the functions shown in fig.(2) & fig.(3), respectively are considered. Also defuzzification of fuzzy sets of voltage gradient g and excitation function Γ are shown in fig.(4) & fig.(5), respectively. Table 1 shows the results with different values of irregularity factor, m and air density factor δ on a single conductor/phase on a 220 kV line. Table 2 shows the results on a 400 kV line with twin bundle conductors.

Table 1

i) For m = 0.725, δ = 0.825

Variable	*Computed Values*	*Only 'g' fuzzified*	*Γ fuzzified*
g	22.938	22.638	--
Γ	60.6879	59.80	55
i μA	8.9393	8.8083	8.1015
i_{sd} μA	3.8251	3.769	3.466
v_{sd} μV	1632.5144	1608.742	1479.254

ii) For m = 0.825, δ = 0.925

Variable	*Computed Values*	*Only 'g' fuzzified*	*Γ fuzzified*
g	17.9787	19.7568	--
Γ	44.2993	50.63	42
i μA	6.5238	7.4578	6.1866
i_{sd} μA	2.7915	3.1912	2.6472
v_{sd} μV	1191.3842	1361.97	1129.7984

iii) For m = 0.95, $\delta = 0.85$

Variable	*Computed Values*	*Only 'g' fuzzified*	*Γ fuzzified*
g	16.99	70.168	--
Γ	40.4818	52.026	40
i μA	5.9629	7.6634	5.892
i_{sd} μA	2.5515	3.2791	2.5211
v_{sd} μV	1088.95	1399.487	1075.98

iv) For m = 0.95, $\delta = 1.125$

Variable	*Computed Values*	*Only 'g' fuzzified*	*Γ fuzzified*
g	12.8368	12.75	--
Γ	21.6126	21.150	17
i μA	3.1835	3.1154	2.5024
i_{sd} μA	1.3622	1.333	1.0707
v_{sd} μV	581.3733	568.911	456.984

Table 2

i) For m = 0.725, $\delta = 0.825$

Variable	*Computed Values*	*Only 'g_b' fuzzified*	*Γ_b fuzzified*
g_b	22.62	22.3245	--
Γ_b	59.707	58.822	55
i μA	11.595	11.4232	8.1015
i_{sd} μA	662.1286	652.169	462.63
v_{sd} mV	223.65	220	156

ii) For m = 0.825, $\delta = 0.925$

Variable	*Computed Values*	*Only 'g_b' fuzzified*	*Γ_b fuzzified*
g_b	17.7297	19.4832	--
Γ_b	43.31	49.6586	42
i μA	8.4108	9.6437	8.1564
i_{sd} μA	480.29	550.7	465.7685
v_{sd} mV	162.234	186.015	157.327

iii) For m = 0.95, $\delta = 0.85$

Variable	*Computed Values*	*Only 'g_b' fuzzified*	*Γ_b fuzzified*
g_b	16.7554	19.8887	--
Γ_b	39.5054	51.045	40
i μA	7.6719	9.9129	7.768
i_{sd} μA	438.1013	566.075	443.589
v_{sd} mV	147.981	191.208	149.835

In both the cases, it has been found that the computed value of corona currents & voltages and the value of corona currents and voltages determined using fuzzy-logic technique are comparable. This invices that fuzzy set theory provides a machinery for modeling corona current signal when available information is uncertain and imprecise.

7. Conclusion : The fuzzy logical concept has been explored for developing the mathematical model of corona currents first time in this paper. The uncertainties due to line parameters, earth resistivity and environmental conditions can best be taken into account by fuzzy modeling. The natural language which is the matter of degree has been used for inferencing the information from the fuzzy membership values. These studies, therefore, shall be useful to the tele-protection and communication engineers.

8. References :

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Annexure-I

Details of Lines

(i) Single conductor/phase :

Voltage level 220 KV rms, horizontal configuration.

Spacing between conductors,	D = 5.79 m
Height of the conductor above earth	h = 11.16 m
Radius of conductor	r = 12.355 mm
Height of ground wire	= 14.82 m
Distance between ground wires	= 7.11 m

(ii) Bundle conductor

Voltage level 400 KV, twin bundle conductor horizontal configuration.

Distance between phase conductor	D= 10.67 m
Spacing between sub conductors	s= 52.2 0 m
Height of conductor above earth	h= 13.72 m
Radius of sub conductor,	r_s= 15.84 mm
Height of ground wire	= 19.47 m
Distance between ground wires	= 15.24 m

The calculations are done at a frequency of 100 KHz.

Fig.1: Fuzzylogic Modeling Scheme

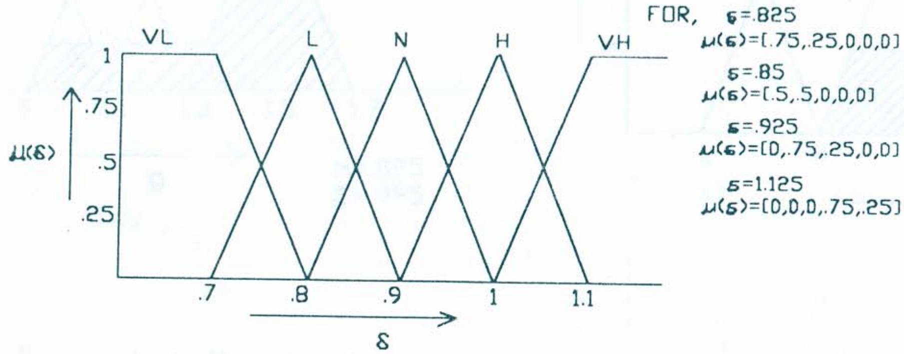

Fig.2: Membership function of δ

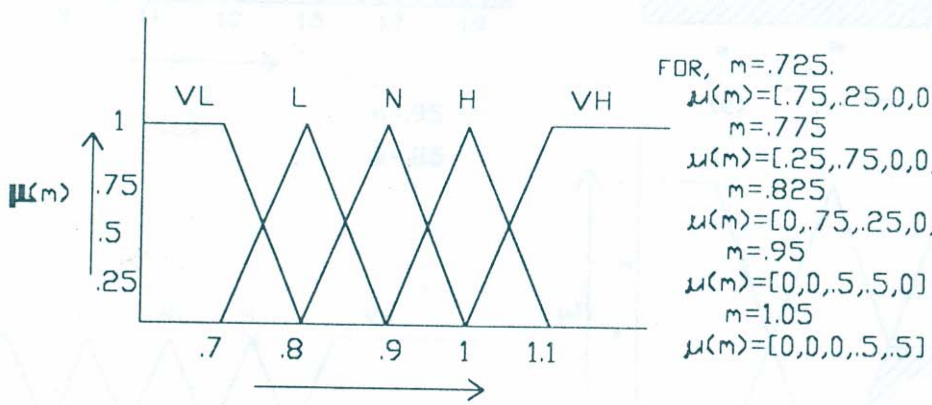

Fig.3: Membership function of m

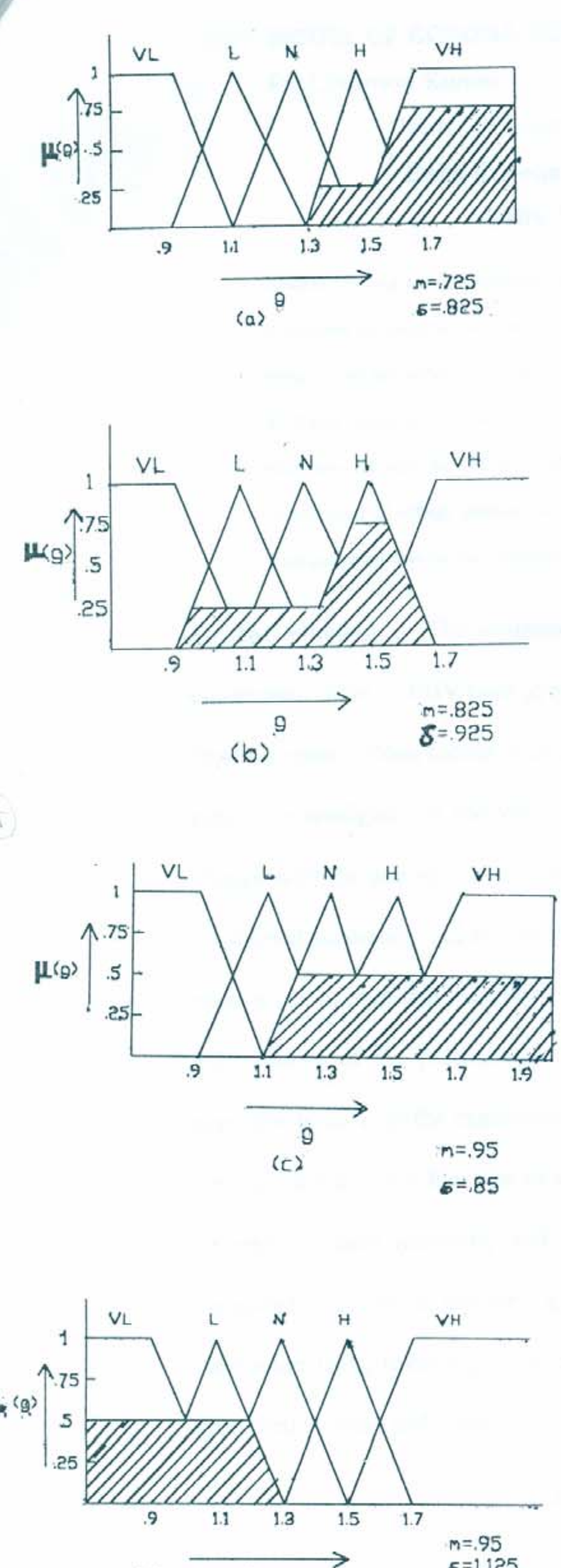

Fig.4 Defuzzification of g using COA method

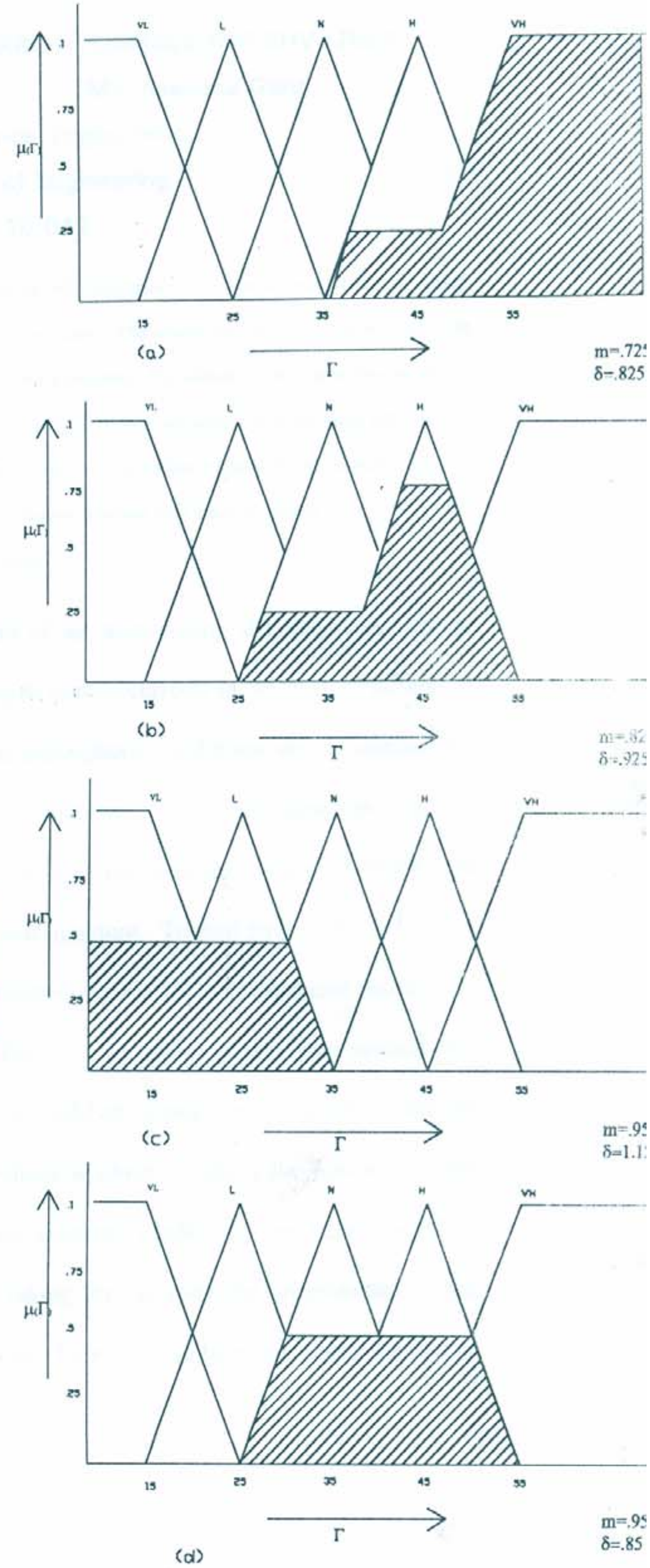

FIG:5 Defuzzification of 'Γ' using COA method