A Case Study of Unbalance Power System with Fuzzy Fault Impedance

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ABSTRACT: The ideas presented in this paper are intended to be representative the more straightforward application of the fuzzy mathematics techniques in power systems. When the 3-phases system is not symmetrical due to line to line current fault as a result of unbalanced load and unbalanced faults, the analysis is down by Symmetrical Component method after transform the fuzzy magnitudes into crisps quantities using the defuzzification technique. A computational problem with fuzzy impedance fault is presented.

KEYWORDS: Disturbance power systems, Fuzzy power systems, Symmetrical components method, Systems faults.

I. INTRODUCTION

During the disturbances, particularly when the systemis heavily loaded, generator controls must act quickly tomaintain current and voltage. Powersystem stabilizers (PSS) are designed for thispurpose.The control problem is difficultas a fault presents a sudden unknown change in the dynamic systems. For more details, see [1-5].

Uncertainty arises in many ways within power system problems. Historically, uncertainty has been modelledbased on randomness, as in, stochastic models for random load variations, fluctuations in model parameters, and so on. In practice, uncertainty certainly arises from the knowledge of the system performance and goals of operation as well.
Fuzzy logic technology has achieved impressive success in diverse engineering applications ranging from mass market consumer products to sophisticated decision and control problems. Several of these applications have found their way into practice and fuzzy methods have become an important approach for practicing engineers to consider. Fuzzy sets were first proposed in the early 1960s as a general model of uncertainty encountered in engineering systems. Fuzzy sets began as a generalization of conventional set theory with the highly visible success of numerous control applications in the late 1980s. Uncertainty in fuzzy logic typically arises in the form of vagueness and/or conflicts, which are not represented naturally fuzzy within the probabilistic framework. Thus, the power of the approach stems from the ability to implement linguistic descriptions of control rules for difficult to modelsystems. One begins by establishing the approach for describing system state in terms of fuzzy sets, and transform the fuzzy quantities into non fuzzy quantities. For more details see [6-11].

II. FUZZY BASIC CONCEPTS

In this section, we are presented basic concepts of fuzzy set theory. Usually the structures embedded in fuzzy set theories are less rich than the Boolean lattice of classical set theory. Moreover, the defuzzification method is presented, see [6-11].
Definition (1) Fuzzy Sets: Let U be a universe set, a fuzzy set $\underline{A}$ of $\underline{U}$ is defined by a membership function$\mu_A(x) \to [0, 1],$ indicates the degree of x in A which defined as following:

$$\mu_A(x) = \begin{cases} 0, & (-\infty, a_1] \\ f_1(x), & [a_1, a_2] \\ 1, & [a_2, a_3] \\ f_2(x), & [a_3, a_4] \\ 0, & [a_4, +\infty) \end{cases} \tag{1}$$

Where a_1, a_2, a_3 and a_4 are real numbers, note that $f_1(x)$ and $f_2(x)$ are may be linear or convex nonlinear function.

Definition (2) Fuzzy Number: A fuzzy number $\tilde{A}$ is a convex normalized fuzzy set A of the real line R such that:

1. It exists exactly one $x_0 \in$ R with $\mu_{\tilde{A}}(x_0) = 1$ (x_0 is called the mean value of A).

2. $\mu_{\tilde{A}}(x)$ is piecewise continuous.

Definition (3) Triangular Fuzzy Number: A triangular fuzzy number $\tilde{A}$ is a fuzzy number with a piecewise linear membership function $\mu_{\tilde{A}}$ defined by:

$$\mu_{\tilde{A}} = \begin{cases} \frac{x-a_1}{a_2-a_1}, & a_1 \le x < a_2 \\ 1, & x = a_2 \\ \frac{a_3-x}{a_3-a_2}, & a_2 < x \le a_3 \\ 0, & otherwise. \end{cases} \tag{2}$$

which can be denoted by as triplet (a_1, a_2, a_3), in which its interval can be represented as μ-cut $A_\mu = [a_1 + a2-a1\mu, a3-a3-a2\mu$,

In the situations in which there are fuzzy variables, **defuzzification** can be considered as decision-making problem under fuzzy constraints.

Definition (4) Defuzzification: It is a mapping from space of fuzzy action defined over an output universe into a space of nonfuzzy (crisp) actions.

Let a function f defined by $f(x) = c\mu_{\tilde{A}}(x)$ is a probability density function associated with $\tilde{A}$, by using the property that $\int_{-\infty}^{\infty} f(x)dx = 1$, we obtain $c = \frac{2}{a_3-a_1}$, then we have

$$f_{\tilde{A}}(x) = \begin{cases} \dfrac{2(x-a_1)}{(a_3-a_1)(a_2-a_1)}, & a_1 \le x < a_2 \\ \dfrac{2}{a_3-a_1}, & x = a_2 \\ \dfrac{2(a_3-x)}{(a_3-a_1)(a_3-a_2)}, & a_2 < x \le a_3 \\ 0, & otherwise. \end{cases}$$

Now, using the *Mellin Transform* to find the expected value from a probability density function, and constructing a procedure, using its μ-cut, to calculate the expected value of fuzzy stochastic variable $\tilde{\tilde{A}}$, which can be expressed as:

$$EV\left(\tilde{\tilde{A}}\right) = \frac{(2a_2-a_3-a_1)(a_3-a_1)}{8} + \frac{a_1+a_3}{2} \tag{3}$$

III. SYMMETRICAL COMPONENTS

Short circuits occur in power systems when equipment insulation fails due to system over voltages caused by lightning or switching surges, to insulation contamination (salt spray or pollution), or to other mechanical causes.

In fact, the ideas presented in this paper are intended to be more straightforward application of the fuzzy mathematics TECHNIQUES IN POWER SYSTEMS TO DATE. THE DISTURBANCES OF POWER SYSTEM DUE TO THE FAULT CURRENT "I" AND VOLTAGE "V", IN TERMS OF FUZZY MAGNITUDES OF VECTORS LENGTHS "$\tilde{L}_I$", "$\tilde{L}_V$" AND PHASE DISPLACEMENT "$\tilde{\theta}_I$" "$\tilde{\theta}_V$". WHEN THE 3-PHASES system is not symmetrical as a result of unbalanced load and unbalanced faults, the analysis is done by *Symmetrical Component method* after transform the fuzzy magnitudes of vectors lengths and phase displacement into crisps quantities using the defuzzification technique described before. The

method of symmetrical components, first developed in 1918, is a powerful technique for analyzing unbalanced three-phase systems. The symmetrical component method is basically a modeling technique that permits systematic analysis and design of three-phase systems.

In this paper, we shall focus our attention on the analysis of unsymmetrical fault, line to line type.
Consider a three-phase a, b and c unbalanced set of currents I_a , I_b and I_c with fuzzy magnitudes of vectors lengths L_i and phase displacement θ_i, $i = a, b, c$. The three basic components are: First the **positive sequence components** of currents and voltages (often denoted by the superscript "1") are the set of 3 phases with fuzzy numbers of magnitude and displacement from each other, having the same sequence of the original phases, formed a 3-phases unbalanced system. Second is the **negative sequence components** of currents and voltages (often denoted by the superscript "2") are the set of 3 phases with fuzzy numbers of magnitude and displacement from each other, having the opposite sequence of the original phases, formed a 3-phases unbalanced system. Third is the **zero sequence components** of currents and voltages (often denoted by the superscript "0".) are the set of 3 phases with fuzzy numbers of magnitude with zero displacement from each other.

The currents can be expressed in terms of the "symmetrical components" currents as follows:

$$I_a = I_a^0 + I_a^1 + I_a^2$$
$$I_b = I_b^0 + I_b^1 + I_b^2 \qquad (4)$$
$$I_c = I_c^0 + I_c^1 + I_c^2$$

Consider the operators "Q" and "Q^2" which are express as a unit vectors at angles of 120 and 240 degrees, respectively. Applying these operators on the symmetrical components:

Positive sequence equations: $I_a^1 = I_a^1$, $I_b^1 = Q^2 I_a^1$ and $I_c^1 = Q I_a^1$

Negative sequence equations: $I_a^2 = I_a^2$, $I_b^2 = Q I_a^2$ and $I_c^2 = Q^2 I_a^2$

Zero sequence equations: $I_a^0 = I_b^0 = I_c^0$. Therefore, the currents can be expressed in terms of operator (Q)

$$I_a = I_a^0 + I_a^1 + I_a^2$$
$$I_b = I_a^0 + Q^2 I_a^1 + Q I_a^2 \qquad (5)$$
$$I_c = I_a^0 + Q I_a^1 + Q^2 I_a^2$$

The above system can be expressed in the following

$$I_a^0 = \frac{1}{3}[I_a + I_b + I_c]$$
$$I_a^1 = \frac{1}{3}[I_a + Q I_b + Q^2 I_c] \qquad (6)$$
$$I_a^2 = \frac{1}{3}[I_a + Q^2 I_b + Q I_c]$$

Also similarly for voltages, can be expressed in the following

$$V_a = V_a^0 + V_a^1 + V_a^2$$
$$V_b = V_a^0 + Q^2 V_a^1 + Q V_a^2 \qquad (7)$$
$$V_c = V_a^0 + Q V_a^1 + Q^2 V_a^2$$

The above system can be expressed in the following

$$V_a^0 = \frac{1}{3}[V_a + V_b + V_c]$$
$$V_a^1 = \frac{1}{3}[V_a + Q V_b + Q^2 V_c] \qquad (8)$$
$$V_a^2 = \frac{1}{3}[V_a + Q^2 V_b + Q V_c]$$

IV. FAULTS ANALYSIS

Short circuits occur in three-phase power systems as follows, in order of frequency of occurrence: single line-to-ground, line-to-line, double line-to ground, and balanced three-phase faults. The path of the fault current may have either eitherzero impedance, which is called a bolted short circuit, or nonzero impedance. The resulting short circuit or ''fault'' current is determined by the internal voltages of the synchronous machines and by the system impedances between the machine voltages and the fault. Short-circuit currents may be several orders of magnitude larger than normal operating currents and, if allowed to persist, may cause thermal damage to equipment. Windings and bus bars may also suffer

mechanical damage due to high magnetic forces during faults. It is therefore necessary to remove faulted sections of a power system from service as soon as possible. There is no other subject of greater importance to an electrical engineer than the question of determination of short circuit currents under fault conditions.

In this paper we are considering the line to line fault, with the fuzzy fault impedance.

$$V_b = \tilde{Z}_f I_b + V_c \qquad (9)$$
$$I_b = -I_c \qquad (10)$$
$$I_a = 0 \qquad (11)$$
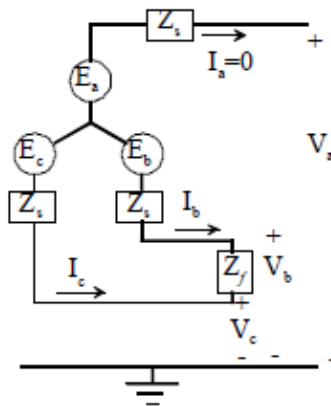
Using (3) to calculate $Z_f \cong EV(\tilde{Z}_f)$

Using 10&11 the symmetrical components of current become:

$$\begin{bmatrix} I_a^0 \\ I_a^1 \\ I_a^2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & Q & Q^2 \\ 1 & Q^2 & Q \end{bmatrix} \begin{bmatrix} 0 \\ I_b \\ -I_b \end{bmatrix}$$

Expanding the matrix equation we have:

$$I_a^0 = 0 \qquad (12)$$
$$I_a^1 = \frac{1}{3}(Q - Q^2)I_b \qquad (12)$$
$$I_a^2 = \frac{1}{3}(Q^2 - Q)I_b \qquad (13)$$

From 12 &13 we have

$$I_a^1 = -I_a^2 \qquad (14)$$

Transform equation 9 in terms of symmetrical components we have

$$V_a^1 = Z_f I_a^1 + V_a^2$$

From the equations for phase voltages 7. Hence

$$V_b - V_c = (Q^2 - Q)(V_a^1 - V_a^2) \qquad (15)$$

Using the values of V_a^1 and V_a^2 from 14 and 15 we have

$$(Q^2 - Q)[E_a - (Z^1 + Z^2)I_a^1] = Z_f I_b$$

Then we have

$$E_a - (Z^1 + Z^2)I_a^1 = Z_f \frac{3I_a^1}{(Q - Q^2)}$$

$$(Q^2 - Q)(Q - Q^2) = 3$$

solving for I_a^1 we have

$$I_a^1 = \frac{E_a}{Z^1 + Z^2 + Z_f}$$

The phase currents are:

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & Q^2 & Q \\ 1 & Q & Q^2 \end{bmatrix} \begin{bmatrix} 0 \\ I_a^1 \\ -I_a^1 \end{bmatrix}$$

The fault current is

$$I_b = -I_c = (Q^2 - Q)I_a^1 = -j\sqrt{3}I_a^1$$

Using the symmetrical components of currents, the symmetrical components of voltage, hence phase voltages by transformation at the fault point are obtained. The terminal conditions for L-L faultand according to them the sequence networks may beconnected as shown below to satisfies the terminal conditions.
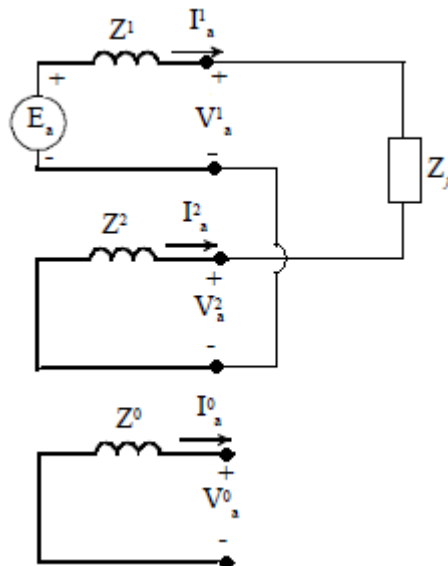
V. COMPUTATIONAL PROBLEM

The positive, negative and zero sequence networks are shown below with all quantities marked in per unit. Determine the fault current for a line-to-line fault through triangular fuzzy fault impedance number $\tilde{Z}_f$ = (j0.05, j0.1, j0.15).

Positive-sequence   Negative-sequence   Zero-sequence
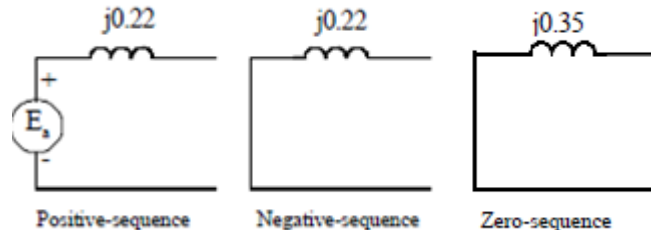
Solution:

Using (3) to calculate Z_f

The zero-sequence component of current is zero, i.e. I_a^0.

$$I_a^1 = -I_a^2 = \frac{V_a(0)}{Z^1 + Z^2 + Z_f}$$

$$= \frac{1}{j0.22 + j0.22 + j0.1}$$

$$= -j1.8519 \, p.u$$

The fault current is:

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} I_{3a}^0 \\ I_{3a}^1 \\ I_{3a}^2 \end{bmatrix}$$

$$= \begin{bmatrix} 0 \\ -3.2075 \\ 3.2075 \end{bmatrix} p.u$$

VI. CONCLUSION

Mathematical approach is presented to manipulate the fault impedance which is uncertain in order to build a suitable circuit to overcome such problem which will open the way for further research and study in this field.

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