Fuzzy Based Approach for the Safety Assessment of Human Body under ELF EM field Considering Power System States

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Abstract : This paper presents a study on the fuzzy based approach for the safety assessment of human body under ELF electric and magnetic(EM) field considering power system states. The analysis of ELF EM field based on quasi-static method is introduced. Up to the present, the analysis of ELF EM field has been conducted with the consideration of one transmission line, or a power line model only. In this paper, however, the power system is included to model the expected and/or unexpected uncertainty caused by the load fluctuation and parameter changes and the states are classified into two types, normal state resulting from normal operation and emergency state from outages. In order to analyze the uncertainty in the normal state, the Monte Carlo Simulation, a statistic approach was introduced and line current and bus voltage distribution are calculated by a contingency analysis method, in the emergency state. To access the safety of human body, the approach based on fuzzy linguistic variable is adopted to overcome the shortcomings of the assessment by a crisp set concept.

In order to validate the usefulness of the approach suggested herein, the case study using a sample system with 765[kV] was done. The results are presented and discussed.

1. INTRODUCTION

Since the modern industry depends largely on the electric energy, the consumption of the electric power is increasing steadily. To cope with the demand, the power system becomes larger in scale, higher in voltage. The advent and increasing use of higher voltage lines have increased the relative importance of field effects such as induced voltage and current in conducting bodies, which is recognized as a big social problem. The electromagnetic field environment associated with a power line is very complex and difficult to calculate exactly.

Several types of electric and magnetic field studies have been performed, searching for effects on body chemistry, disease, and behavior: 1) laboratory studies of humans; 2) animals; 3)laboratory studies of single cells, groups of cells, and, organs; 4) epidemiological studies of human populations looking for an association between 50-60Hz fields and various disease. [1,2,3,4]

These fields can be analyzed independent and associated respectively with the power line voltages and currents without considering power system itself. Many research results are obtained by the consideration of one transmission line, or a power line model only, which is simple-minded approach.[5,6]

However, the simple-minded approach excluding the power system fails in modeling the power system uncertainty such as the fluctuation of load and the changes of system parameter. The electromagnetic fields associated with power line depends on the variations of line voltages and currents resulting from the outages of the power system. Consequently, it is necessary to solve the field problem associated with power system in order to assess the safety of field effects and to calculate the fields. The power system states are classified into two types, normal state resulting from normal operation and emergency state from outages in this paper.

In order to analyze the uncertainty in the normal state, it was assumed that the load varies daily and annually. For the actual analysis of electric and magnetic field according to these changes, the irregularity of current was modeled by the Monte Carlo Simulation, a statistic approach. For evaluating the change of magnetic field, it is obtained that the probability density function(pdf), conditional probability and probability distribution of current. Also cumulative probability function is finally obtained by using the probability density function of magnetic field and probability density function of current.

Electric and magnetic field in the emergency state is analyzed using line current and bus voltage calculated by the contingency analysis method, based on the matrix inverse lemma, which get a system operator to take countermeasures to meet the previous accidents that can occur in the power system.

To access the safety of human body and to develop general safety standard for EM fields, the approach based on fuzzy linguistic variable using the concept of fuzzy predicate, fuzzy modifier, fuzzy qualifier is adopted to overcome the shortcomings of the assessment by a crisp set concept.

2. HUMAN SAFETY ASSESSMENT USING FUZZY LINGUISTIC VARIABLE

Up to date, the recommendation standards for safety criteria of electric and magnetic field say "hazardous" in case that the field value is above the specified value and "safe" in case that the field value under the specified value. But, since a human being does not feel the degree of safety for electric and magnetic field like that way, this kind of recommendation standards are very absurd.

2.1 Fuzzy linguistic variable

In general, most of variables can have numbers as their values but some variables have ,as their values, words or sentences in a natural or artificial language instead of numbers, which is called linguistic variables. And the linguistic variables which have values based on fuzzy set concept are named fuzzy linguistic variables.

To access the safety of human body of ELF EM field, the approach based on fuzzy linguistic variable using the term of "Field-intensity" as x, is shown in equation(1).

(Field-intensity, T(Field-intensity), U, G, M) (1)

where,

Field Intensity : name for X of the linguistic variable

T(Field Intensity) : {safe, very safe, hazardous, very hazardous, very very hazardous $\cdots$}

U : [0, ∞]

G (Field Intensity): $T^{i+1} = \{\text{hazardous}\} \cup \{\text{very } T^i\}$

M (hazardous) : $\{ (u, \mu_{hazardous}(u)) \mid u \in [0, \infty] \}$

2.2 Safety Assessment of Human Body

ELF electric field

Let X be a linguistic variable with the label of 'field-intensity' with u=[0, ∞]. Term of this linguistic variable, which is again fuzzy sets, could be called "safe," "very safe," "hazardous," and so on. The base-variable u is electric field value. In general, in considering the standards suggested by several countries,[14] electric field value of 20[kV/m] is adopted as a critical value for assessing the safety of the human body under the electric filed. The membership of a fuzzy set of "hazardous" is evaluated using equation (2);

$$\mu_{hazardous}(u) = \begin{cases} 1 & u \in [20, \infty] \\ \alpha_1\left[1 + \tanh\left(\dfrac{\alpha_2 \cdot \mu - \alpha_3}{\alpha_4}\right)\right] & u \in [0, 20] \end{cases} \qquad (2)$$

where, $\alpha_1 \cdots\cdots \alpha_4$ is weighting factors for determining the membership of the fuzzy set. Membership function is 1 over the 20[kV/m] of electric field considering of human risk due to human safety criteria presented by several countries, and become higher value in opposition to close vicinity to 20[kV/m], as show in Fig.1. Also, electric field in opposition to low value establish the factors of low value of membership function.(In this paper, $\alpha_1 = 0.5$, $\alpha_2 = 1.5$, $\alpha_3 = 15.0$, $\alpha_4 = 5.0$)

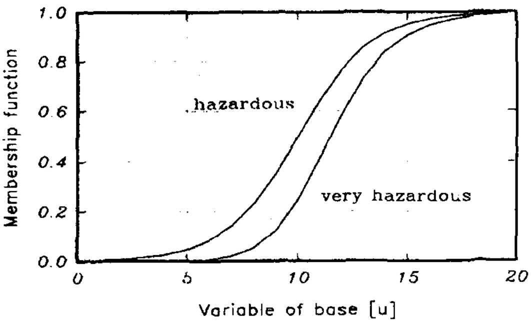

Fig.1 Membership function for fuzzy variable; hazardous

Membership function of a new fuzzy set F′, having "very false" as truth value, is presented in equation(3) when equation (2) is defined as the fuzzy set of "hazardous" in linguistic variable.

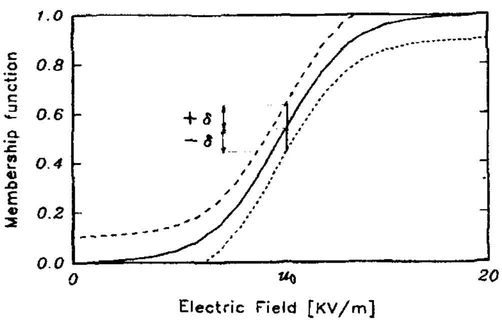

Fig. 2 New membership function with fuzziness, $\pm\delta$

$$\mu_F(u) = (1-\mu_{\text{true}}(u))^2$$
$$= (1-\mu_{\text{hazardous}}(u))^2$$
$$= \begin{cases} 0 & u \in [20,\infty] \\ \left[1-\alpha_1\left(1+\tanh\left(\dfrac{\alpha_2\cdot\mu-\alpha_3}{\alpha_4}\right)\right)\right]^2 & u \in [0,20] \end{cases} \quad (3)$$

However, the membership function decided by the equation (2) and (3) is dependent on the values of weighting factors. In order to eliminate the shortcomings, type-2 fuzzy function value is introduced. That is, to represent the membership of ambiguity, $\pm\delta$ is added to the membership function obtained from equation (2), and then another fuzzy set having new membership function with fuzziness of $\pm\delta$ in Fig.2 is generated.

As shown in Fig.2, the membership in case that electric field is μ_o, $\mu_{hazardous}(\mu_o)$becomes $\mu_{hazardous}(\mu_o)-\delta \le \mu_{hazardous}(\mu_o) \le \mu_{hazardous}(\mu_o)+\delta$ where, the value of membership function for $\mu_{hazardous}(\mu_o)$ is 1, the other μ_δ is given in equation (4)

$$\mu_\delta = 1-\frac{1}{\delta}D \quad (0 \le D \le \delta) \qquad (4)$$

ELF magnetic field

The same approach as in assessing the safety of human body under ELF electric field is introduced for the magnetic field. When representing the magnetic field as variable u, the membership function of $\mu_{hazardous}(\mu)$ is calculated by equation (5). Over the magnetic field value of 10[G], it is considered that the human body is hazardous in this paper.

$$\mu_{\text{hazardous}}(\text{u}) = \begin{cases} 1 & \text{u} \in [10, \infty] \\ \beta_1\left[1+\tanh\left(\frac{\beta_2 \cdot \mu - \beta_3}{\beta_4}\right)\right] & \text{u} \in [0, 10] \end{cases} \qquad (5)$$

3. CONCLUSIONS

1) To evaluate the effects of load fluctuation on the EM fields, a new method including power system states is suggested, which can give more reasonable results than a simple-minded approach based on a single power line model excluding the irregularity of power system.

2) To access the safety of human body, the approach based on fuzzy linguistic variable is adopted to overcome the shortcomings of the assessment by the crisp set concept of "safe" and "hazardous".