CALCULATION OF METALLIC CONDUCTOR VOLTAGE DUE TO ELECTROMAGNETIC COUPLING USING NEURAL FUZZY MODELING

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Abstract

Electromagnetic interference effects of transmission lines on nearby metallic structures such as pipelines, communication lines or railroads are a real problem, which can place both operator safety and structure integrity at risk. The level of these voltages can be reduced to a safe value in accordance with the IEEE standard 80 by designing a proper mitigation system. This paper presents a Neural Fuzzy model that can predict the level of the metallic conductor voltage before and after applying a mitigation system. The model outlined in this paper is both fast and accurate and can predict the voltage for any change in the system parameters (soil resistivity, fault current, lateral distance, mitigated or unmitigated system).

1. INTRODUCTION

Circuit conductors do not need to be electrically connected for interference to be transferred from one to the other. A significant contributing factor is when the conductors are installed in close proximity to overhead transmission lines without any additional mitigation measures to reduce the effect of the electromagnetic coupling.

AC interference can be divided into three main categories of coupling mechanisms based on the circuit type and they are namely, inductive, conductive and capacitive couplings [1-9]. The voltage difference existing between the two circuits, overhead line and any nearby metallic conductor such as pipeline, results in the establishment of an electric field between them. This effect is a demonstration of capacitive coupling. The inductive coupling is determined by magnetic field, unlike an electric field which has a source and end point, magnetic field lines have no beginning or end point. Conductive coupling results from the soil potential increase due to a large amount of currents discharged into the soil at transmission line structures, such as power line tower grounds, power plant grounding systems and electric substation. In this paper, interference levels due to inductive and conductive coupling are calculated under fault conditions. Capacitive coupling is neglected because the metallic conductor is buried in ground.

The high level of the pipeline voltage can be reduced to a safe value in accordance with the IEEE standard 80 by designing a proper mitigation system. The gradient control wires is one of the best mitigation system that is currently used [4].

Artificial neural networks (ANN) can be used to predict the induced voltage in the pipeline [10] because of their ability to handle noisy data, associate memory and parallel computational architecture. However, the robustness and accuracy of ANN based methods depend heavily on the choice of the network architecture, the convergence speed and the weight adaptation algorithm. Due to the implementation simplicity and the feasibility in hardware development, fuzzy logic technique has been employed in variety of domestic products, industrial processes and different power system areas [11-16]. There are several papers that talked about the calculation and prediction of the pipeline voltage at a specified system parameters, any change in the system parameters will required rerunning the software[1-7] , which is time consuming, while the proposal outlined in this paper are both fast and accurate.

In this paper the Adaptive Network-Fuzzy Inference System (ANFIS) is used to model, evaluate, analyze and predict the total pipeline voltages taking in consideration the different system parameters. The concept of ANFIS was proposed and extensively discussed in [17]. Matlab/Fuzzy toolbox environment has been employed to build the current ANFIS model for pipeline voltage evaluation and prediction [18].

2 . ADAPTIVE NETWORK-FUZZY INFERENCE SYSTEM

A fuzzy set is a collection of objects with membership values between 0 (complete exclusion) and 1 (complete membership). The membership values express the degrees to which each object is compatible with the properties or features distinctive to the collection. A membership function is a curve that defines how each point on the input space is mapped to a membership value (or degree of membership) between 0 and 1 [19-20]. There are many types of membership functions such as the triangular membership function, the trapezoidal membership function and the

Gaussian membership function. The fuzzy system without fuzzifier and defuzzifier is called pure fuzzy system. The main problem with the pure fuzzy system is that its inputs and outputs are fuzzy sets, whereas in engineering systems the inputs and outputs are real-valued variables. In order to use pure fuzzy system in engineering systems, a simple method is to add a fuzzifier, which transforms a real-valued variable into a fuzzy set, to the input and a defuzzifier, which transforms a fuzzy set into a real-valued variable, to the output. Fuzzy system with a fuzzifier and defuzzifier is shown in Fig.1

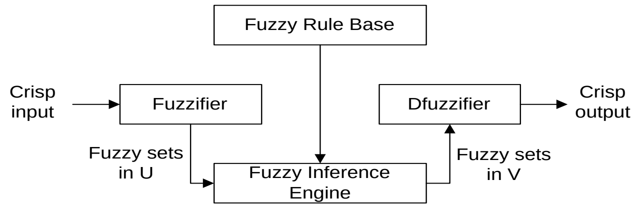

Fig.1: Basic configuration of fuzzy system with a fuzzifier and defuzzifier.

There are many methods of defuzzifiers to obtain the crisp output V from the fuzzy inference engines and the required crisp output denoted by (y*) such as the centroid method which is given by Equation 1 and the Weighted average method which is given by Equation 2.

$$y^* = \frac{\int y.Mf_B(y).dy}{\int Mf_B(y).dy} \tag{1}$$

$$y^* = \frac{\sum_{n=1}^{M} y_n z_n}{\sum_{n=1}^{M} z_n} \tag{2}$$

where:

Mf_B is the membership function for the set B

Z_n is the peak value

Y_n is value of the corresponding factor at the peak position

The Fuzzy Logic Toolbox allows us to create and edit fuzzy inference systems. We can create these systems using graphical tools or command-line functions, or we can generate them automatically using either clustering or adaptive network-fuzzy techniques. Matlab/(Simulink - Fuzzy toolbox) can easily build and test our fuzzy system in a block diagram simulation environment. This is made possible by a stand-alone Fuzzy Inference Engine that reads the fuzzy systems saved from a MATLAB session.

2.1 System Modeling

The system under study is presented in Fig. 2. It consists of 132kV transmission lines and a neighboring pipeline. The length of the parallelism (transmission lines and pipeline) is 10 km; the pipeline is placed at the central site with burial depth of 0.6m. The parallel scenario produces maximum coupling between power line and pipeline as a result higher induced voltage is expected to be produced. The following presents the system model parameters used in this study.

<u>*Pipeline*</u>

Coating Resistance: *20000* $\Omega.m^2$ *(*15665 $\Omega.m$)
Coating thickness: 0.0036m
Outer Diameter: *0.4064 m*
Inner Diameter: *0.39923 m*
Burial depth: *0.5 m*
Relative Resistivity: *17* (with respect to annealed copper).
Relative permeability: *250* (with respect to free space).
Grounding: *None*

<u>*Overhead Transmission line*</u>

AAAC (single-ELM) 132 kV

G.M.R: *0.7122 cm*
Conductor outer radius: *0.94 cm*
Outer strand radius: *0.188 cm*
Number of strands: *19*
Fault current (phase-to-ground fault): 5 KA

<u>*System*</u>

Length of parallel corridor: *10 km*
Soil Resistivity ρ: 100 *Ω .m*
Separation distance: 100 m

<u>*Mitigation System*</u>

Gradient control wire: Zinc ribbon with diamond-shaped 12.7x14.28 mm (1/2 x9/6 inch).
Mitigation wire resistivity: 3.47

Mitigation wire permeability: 1

The level of the pipeline voltage, owing to each type of coupling, depends on different factors (power lines voltage level, length of parallelism, separation distance, soil resistivity, load current magnitude, configuration of the power lines, pipeline coating and mitigation system used). The effects of these factors are discussed in [9]; some factors such as the fault current level, separation distance and soil resistivity are found to exhibit a large influence on the induced pipeline voltage. The Fuzzy model used in this work consists of 4 input nodes representing fault current (I_f), soil resistivity (ρ), separation distance (D) and mitigation system while the output node is one, representing the total pipeline voltage as shown in Fig.3. This Model of prediction is trained using the data obtained from CDGES [21] software for a practical system The membership functions (MFs) of each input and the rules set have been designed carefully for building the model parameters as shown in Fig. 4 and simply presented in Table 1.

The defuzzification method used was the weighted average while the aggregation method employed was the Maximum..

The Fuzzy model is trained in the training stage and then the Fuzzy is tested with the whole data to get a very precise output relative to the given data. The fault current is represented with four trapezoidal and triangle membership functions to cover the continuity of the current values over some studied cases while the others inputs are represented with triangle membership function only due to the frequent symmetry variation of the input. The number of rules developed as (IF then Else) were found to be 168(7x4x3x2) rules.

During the accuracy analysis of the model, if one of the factor are dropped the pipeline voltage will be affected depending on the weight of each factor contribution and it varies from 20% to 40% according the range of each input variation. The type, boundaries and the degree of overlap of the membership functions for the algorithm output are tuned carefully using the try and error method to smoothly obtain the minimum deviation between the fuzzy output and the given data. Definitely this method depends on the programmer experience.

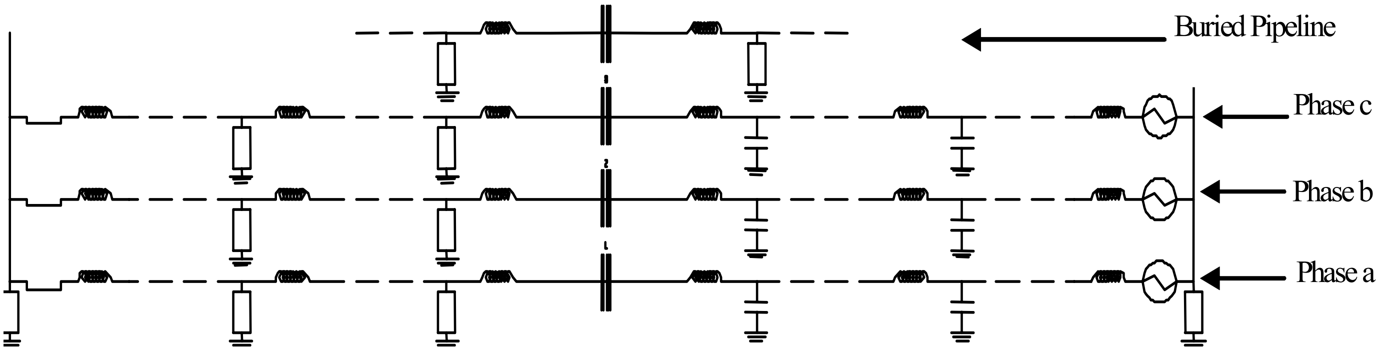

Fig.2: Circuit model

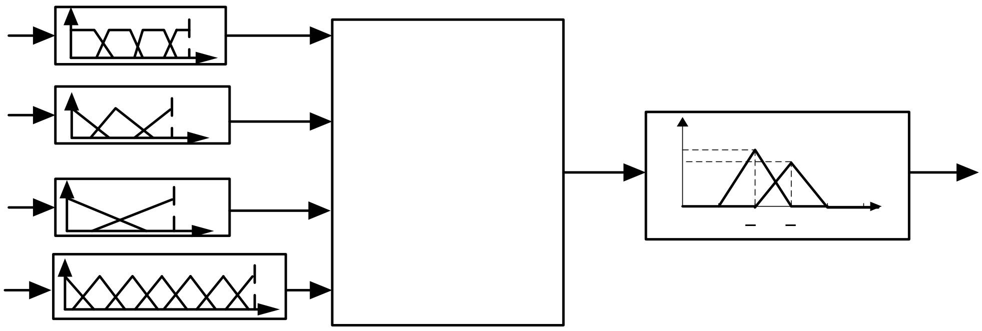

Fig.3: Simple layout of the prediction model for pipeline voltage based on fuzzy logic.

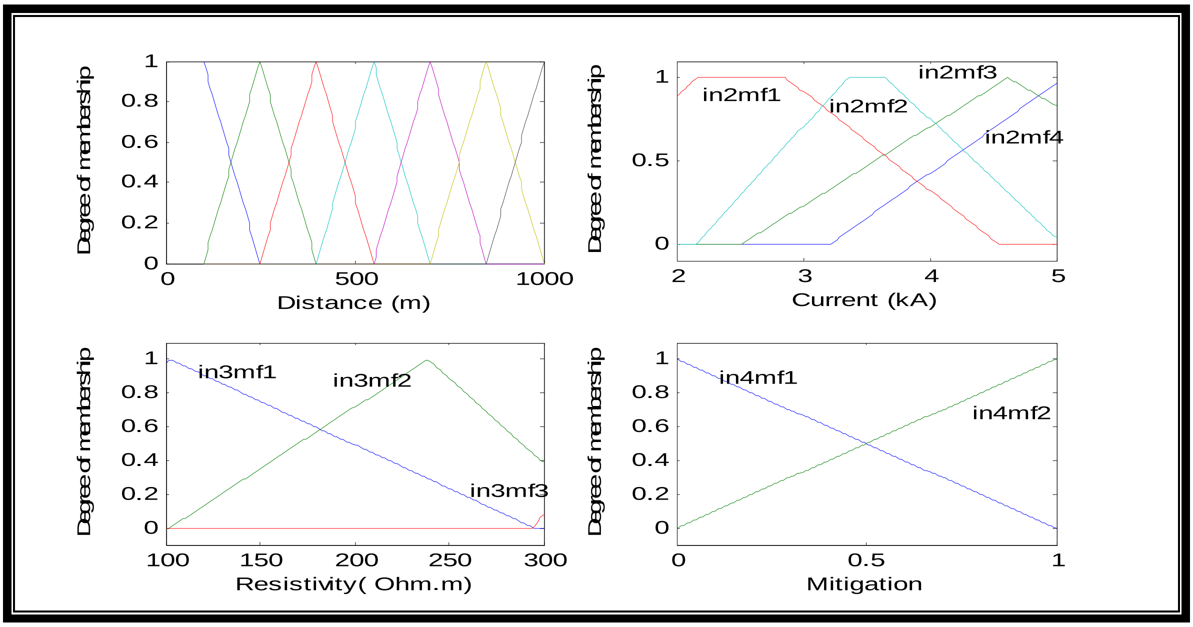

Fig.4: The different developed membership functions for the different inputs

. Table 1: Design parameters of the Developed Fuzzy model

Input	Range	No. of MFs	Type of MFs
I_f (kA)	[2 5]	4	Trapezoidal
ρ(Ω.m)	[100 300]	3	Triangle
Mitigation *	[0 1]	2	Triangle
D(m)	[100 1000]	7	Triangle

Mitigation*: 1 without mitigation, 0 with mitigation

3. RESULTS AND DISCUSSIONS

The validity of the fuzzy model was verified by comparing the simulation results with the corresponding given results obtained from the CDEGS software [21]. Figures 5 and 6 present a comparison between the given and predicted total pipeline voltages at different fault currents and different soil resistivities for a range of separation distances. It is clear that there is good agreement between the actual and predicted results. Moreover, it is clear from Fig. 6 that the voltage on the pipeline is reduced when a mitigation system (gradient control wire) is connected to the pipeline. Hence, the Fuzzy-based model developed in this work can predict the total voltage with high accuracy.

4. CONCLUSIONS

Adaptive network-fuzzy inference system model has been developed for predicting the total voltage on pipeline built in overhead power lines right-of-way. The actual system parameters (mitigation system, fault current, soil resistivity, and separation distance) were the Fuzzy input and conductor voltages was the output. Prior to the training process, a training data set consisting of a full range of typical system parameters and the pre-calculated voltage are first compiled. The network is then trained using these patterns until a good agreement between predicted voltage and given voltage is reached. Once the ANFIS is adequately trained, the network is then tested to insure that it can adequately predict the correct voltage, given system parameters that are not included in the training data set. The results demonstrate that the fuzzy-based model developed in this work can predict the total pipeline voltage with and without a mitigation system with high accuracy.

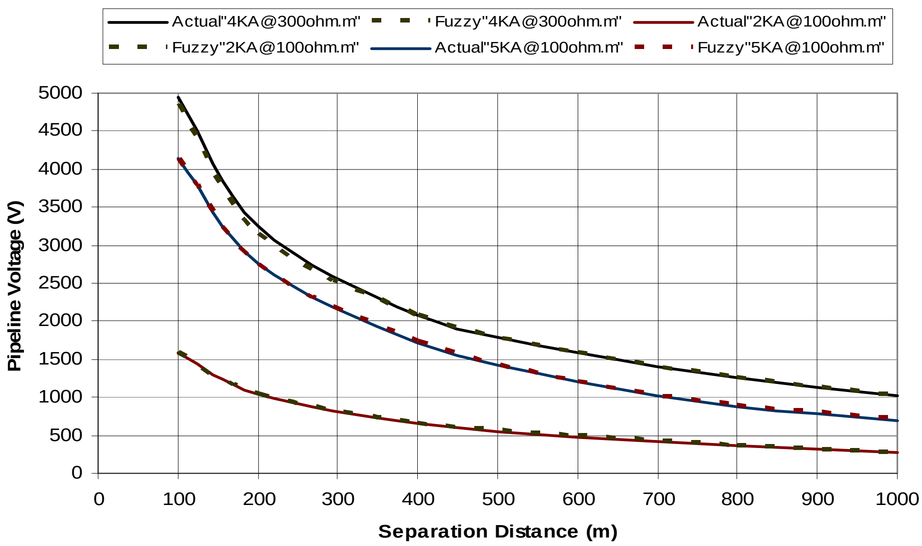

Fig. 5: Total pipeline voltages at different fault currents and soil resistivities, without mitigation.

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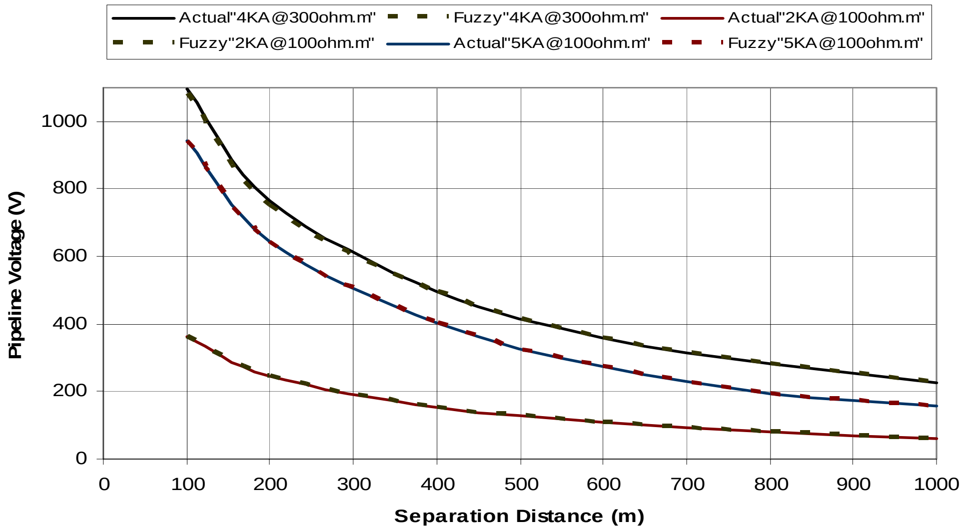

Fig.6: Total pipeline voltages at different fault currents and soil resistivities, with mitigation

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