LIGHTNING PERFORMANCE ASSESSMENT OF OVERHEAD HIGH VOLTAGE TRANSMISSION LINES USING AN ARTIFICIAL NEURAL NETWORK METHOD AND ITS APPLICATION TO THE HELLENIC LINES

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ABSTRACT

This paper presents a novel approach to the lightning performance assessment of overhead high voltage transmission lines based on artificial neural networks (ANN). A feed-forward (FF) ANN method was addressed which uses the Levenberg-Marquardt learning algorithm. Actual input and output data collected from operating Hellenic high voltage transmission lines such as: the tower footing resistance, the peak lightning current, the lightning current derivative, the lightning level and the number of line's lightning failures were used in the training process. The method has been applied, on several operating Hellenic transmission lines of 150 kV and 400 kV, carefully selected among others due to their high failure rates during lightning thunderstorms. The obtained results were almost identical to the field observation data collected from the Hellenic Public Power Corporation and these obtained using conventional techniques. The presented methodology can be proved valuable to the studies of electric power systems designers, intended in a more effective protection of high voltage transmission lines against lightning strokes.

Keywords: artificial neural networks, high voltage transmission lines, lightning performance.

INTRODUCTION

Lightning causes a significant part of disturbances, damages and unscheduled supply interruptions in the modern power systems. This is the reason why over the last fifty years, many lightning performance assessment methods have been presented in the technical literature. Analogue computers [1], Monte-Carlo simulation [2], geometrical models [3] and travelling waves [4] were some of the proposed methods. The current work demonstrates a novel approach for lightning performance assessment of high voltage transmission lines based on ANN, which have attracted much attention in the recent years. Many interesting ANN applications have been reported in power system areas [5-10], due to ANN's computational speed, their ability to handle complex non-linear functions, robustness and great efficiency, even in cases where full information for the studied problem was absent. In this paper a FF ANN model was developed which uses the Levenberg-Marquardt learning algorithm. Actual input and output data, collected from operating Hellenic high voltage transmission lines were used in the training, validation and testing process. The model is applied on operating Hellenic lines of 150 kV and 400 kV in order to validate its accuracy and the obtained results are compared with these produced using conventional methods as well as with real records of outage rate.

ASSOCIATED THEORY

Transmission Lines' Lightning Failure Rate

The total lightning failure rate N_T of a transmission line, or the outage rate, is the arithmetic sum of the shielding failure N_{SF} and the backflashover failure rate N_{BF}:

$$N_T = N_{SF} + N_{BF} \tag{1}$$

Shielding failure rate N_{SF} is associated to a required minimum current I_{min} to cause a line insulation flashover [10]. N_{SF} is defined as follows:

$$N_{SF} = N_L \cdot \int_{I_{min}}^{I_{max}} f(I)\, dI \tag{2}$$

where:

N_L is the number of lightning flashes that are intercepted by a transmission line given from the equation [11]:

$$N_L = 0.004 \cdot T^{1.35} \cdot \left(b + 4 \cdot h^{1.09}\right) \tag{3}$$

T is the lightning level in the vicinity of the line,
h is the average height of the shielding wires,
b is the horizontal spacing, of the shielding wires,
I_{max} is the maximum lightning current,
I_{min} is the minimum current equal to $2U_a \;/ Z_{surge}$ [10],
Z_{surge} is the conductor line surge impedance, equal to: $60\sqrt{\ln\frac{4h}{d} \cdot \ln\frac{4h}{D}}$ [11],

d is the equivalent conductor diameter without corona,
D is the equivalent conductor diameter with corona and
U_a is the insulation level of the transmission line.

Backflashover failure rate N_{BF} is estimated for transmission lines according to the method presented in [12, 13] and is given from the equation:

$$N_{BF} = N_L \cdot \int_0^{\infty} P(\delta)\ d\delta \tag{4}$$

where:
$P(\delta)$ is the probability distribution function of δ,
δ is an auxiliary variable given from the equation:

$$\delta = R \cdot I/2 - 0.85 \cdot U_a + L \cdot di/dt \tag{5}$$

R is the tower footing resistance,
I is the peak lightning current,
L is the total inductance of the system and
di/dt is the lightning current derivative.

Feed-forward (FF) neural networks

A typical three-layer FF ANN is presented in figure 1, having four inputs and three outputs with each node to represent a single neuron. The name feed-forward implies that the flow is one way and there are not feedback paths between neurons. The initial layer where the inputs come into the ANN is called the input layer and the last layer where the outputs come out of the ANN, is denoted as the output layer. All other layers between them are called hidden layers [14].

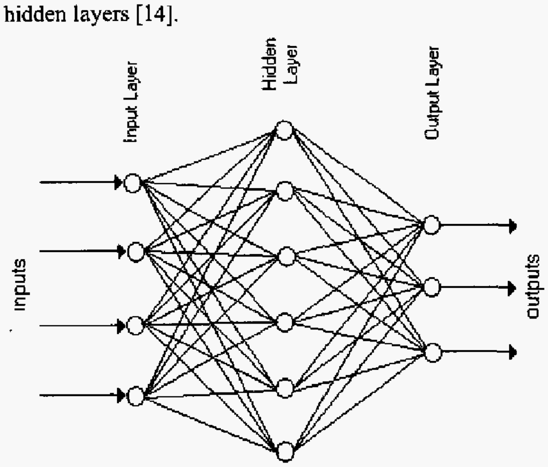

Figure 1: Structure of a three-layer feed-forward neural network

Each neuron can be modelled as shown in figure 2, with n being the number of inputs to the neuron.

Associated with each of the n inputs x_i are some adjustable scalar weights w_i (i=1,2,...,n), which multiply that inputs. In addition, an adjustable bias value, b, can be added to the summed scaled inputs. These combined inputs are then fed into an activation function, which produces the output y of the neuron, that is:

$$y = k\left(\sum_{i=1}^{n} w_i x_i + b\right) \tag{6}$$

where:
k is a logarithmic sigmoid function $k(u) = \left(1 + e^{-u}\right)^{-1}$ or a hyperbolic tangent sigmoid $k(u) = \left(e^{u} - e^{-u}\right)\left(e^{u} + e^{-u}\right)^{-1}$.

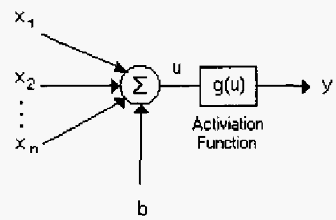

Figure 2: A Single Artificial Neuron

NEURAL NETWORK METHOD

A FF ANN model was developed in order to assess the lightning performance of overhead high voltage transmission lines. The model is consisting of four inputs and one output. The input values are: the tower footing resistance R, the peak lightning current I_{peak}, the lightning current derivative di/dt and the lightning level T. These four parameters were selected since they play important role to the lightning failure rate of a transmission line. The neural network's output value was considered to be the number of lightning failures of the line N_T.

All input and output data constitute either actual collected data or estimated data based on actual measurements. More specifically, the lightning level T has been supplied from National Meteorological Authority of Hellas [15], while the tower footing resistance R has been estimated using the geometric characteristics of the grounding grid and actual measurements of the resistivity of the soil [16, 17]. The peak lightning current I_{peak} and the lightning current derivative di/dt, were estimated using the statistical lightning parameters distributions presented by Berger, based on his measurements in Monte San Salvatore [18], in combination with the geographical and meteorological data of the examined area. Finally the output, i.e. the total lightning failure rate N_T, are actual collected data provided from the Hellenic Public Power Corporation [19].

Having decided the number of inputs and outputs, the next step is to determine the number of hidden layers, the number of neurons per layer, the learning algorithm and the transfer function of the developed neural network model. This is succeed by trying different combinations of them, selecting the structure with the best generalizing ability. For this case study, it was decided to be used one hidden layer consisting of eight neurons, the Levenberg-Marquardt learning algorithm [20, 21] and the hyperbolic sigmoid transfer function.

APPLICATION TO REAL CASES

Transmission lines characteristics

The proposed method has been applied and tested on 150 kV and 400 kV operating Hellenic transmission lines. These lines were carefully selected among others, due to: a) their high failure rates during lightning thunderstorms [19], b) their consistent construction for at least 90 present of their length and c) their sufficient length and their sufficient time in service in order to present a reasonable exposure to lightning.

The first line called Athina-Acheloos is a 400 kV line having a length of 250.557 km. It comprises a three phase double circuit, with two shielding wires (figure 3). The line has got 717 towers with an average span of 350 m. The line's insulation level is 1550 kV and the phase conductor dimensions are ACSR 954 MCM.

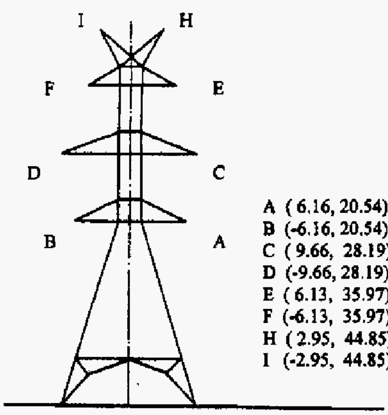

Figure 3: Typical tower of the analyzed 400kV Hellenic transmission line

The second line called Aktio-Argostoli is a 150 kV line having a length of 81.409 km. It comprises a three phase single circuit, with two shielding wires (figure 4). The line has got 224 towers with an average span of 363 m. The line's insulation level is 750 kV and the phase conductor dimensions are ACSR 336.4 MCM.

The third line called Megalopoli-Sparti is a 150 kV line having a length of 64.472 km. It comprises a three phase double circuit, with two shielding wires (figure 4). The line has got 173 towers with an average span of 372 m. The line's insulation level is 750 kV and the phase conductor dimensions are ACSR 336.4 MCM.

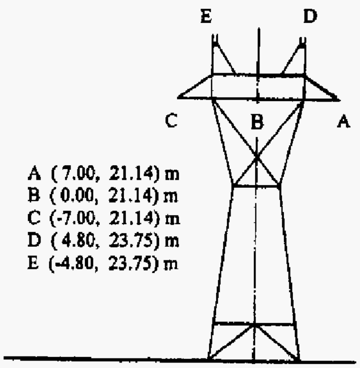

Figure 4: Typical tower of the analyzed 150kV Hellenic transmission line

In order greater accuracy to be achieved, it was avoided to be used in this case study mean transmission lines' parameters. Each of the above three transmission lines are divided into regions, making clear the different meteorological conditions and the different average values of tower footing resistance, which exist in each one of them. These regions and the different parameters that exist in each one of the three lines are presented in table 1.

Neural network training and validation

The Matlab neural network toolbox [22] was used for training the network. Seven hundred twenty values of each input and output data, referring to every one region of the examined transmission lines for every individual month of a six-year period, were used to train and validate the neural network model. In each training iteration, 20% of random samples were removed from the training set and validation error was calculated for these data. The training process was repeated until an error goal of 1% was achieved. Finally, the number of the estimated lightning failures of the examined transmission lines was checked with the number obtained from situations encountered in the training, i.e. the six-year period, and others which have not been encountered.

Results

In table 2 are presented the recorded average annual lightning failures [19] of the three examined transmission lines for the years 2000 and 2001, collected from the Hellenic Public Power Corporation, as well as the results obtained using conventional analytical methods (simulation methods) [13, 14] and these obtained according to the proposed artificial neural network method.

Table 1: Line Parameters of the Examined Transmission Lines [15, 19]

Line	Region	Towers	R (Ω) (Average regional value)	N_T (Average lightning failures 1994-1999)	T (Average lightning level 1994-1999)
Athina-Acheloos	I	1 - 130	28.92	1.33	12.17
	II	131 - 318	6.51	0.50	21.83
	III	319 - 578	26.77	2.67	33.50
	IV	579 - 717	5.42	0.67	37.83
Aktio-Argostoli	I	1-55	4.75	0.00	37.50
	II	56-137	64.93	0.83	34.17
	III	138-224	126.25	2.00	35.33
Megalopoli-Sparti	I	1 - 45	5.10	0.17	28.00
	II	46 - 75	39.65	0.67	31.67
	III	76 - 173	11.18	1.50	30.17

Table 2: Test Results of the Designed ANN Model

	Line I Athina-Acheloos			Line II Aktio-Argostoli			Line III Megalopoli-Sparti		
Year	Recorded Lightning Failures	Lightning Failures using Simulation Method	Lightning Failures using ANN Model	Recorded Lightning Failures	Lightning Failures using Simulation Methods	Lightning Failures using ANN Model	Recorded Lightning Failures	Lightning Failures using Simulation Methods	Lightning Failures using ANN Model
2000	6.00	5.46	5.77	3.00	2.89	2.69	2.00	2.14	1.83
2001	5.00	4.76	5.18	4.00	4.37	3.95	2.00	2.22	2.28

It is clear that the results obtained according to the proposed ANN method are very close to the actual ones and these results obtained according to the conventional analytical methods, something which implies that the proposed ANN method is well working and has an acceptable accuracy.

CONCLUSIONS

The paper describes an artificial neural network method for the lightning performance assessment of overhead high voltage transmission lines. Although several conventional analytical methods are published in the technical literature, which describe satisfactory the lightning performance of high voltage transmission lines, most of them are based on empirical and approximating equations.

In contrast to these methods, the proposed ANN method is using only actual line data in its calculations, something that clearly presents its main advantage. Moreover the efficient and economic implementation of ANN methods with today's computer technology and their easy application to almost every problem, constitute them as alternative attractive tools.

The presented method has been applied, on operating Hellenic transmission lines of 150 kV and 400 kV. The obtained results were almost identical to the field observation data collected from the Hellenic Public Power Corporation and these obtained using conventional analytical methods (simulation methods). The presented methodology can be used by electric power utilities as a useful tool for the design of electric power systems.

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