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Forecasting the Dielectric Properties of the Insulation Material using an Embedded ANN Microcontroller

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Abstract – This paper describes a laboratory application for the forecasting the dielectric properties, using an artificial neural network embedded in a microprocessor. The dielectric permittivity and loss factor of the insulation material were determined as a function of temperature and frequency inputs by an implemented ANN model. For this purpose, a three-layer feed-forward back-propagation ANN model with two inputs and two outputs was created. The Levenberg-Marquardt back-propagation algorithm was selected as a training function, the gradient descent method with momentum weighting and bias learning function as an adaptive learning function, and mean squared normalized error as a performance function. The first layer of the network consists of three neurons, the second layer of six neurons with a tangent sigmoid activation function, and the output layer of two outputs with a linear transfer function. The initial values of weights and biases were selected randomly. Input and output data were rescaled to have the minimum possible determination errors. The microprocessor-based method is a low-cost determination system independent of computers and can be used in both laboratory and industrial applications.

Keywords: artificial neural network, dielectric constant, microcontroller

I. INTRODUCTION

Dielectrics are the most important topic in the single-semester high-voltage course for last-semester undergraduate engineering students. Applications involving dielectrics are very difficult in a laboratory environment because their properties vary over wide ranges with certain parameters such as frequency and temperature under realistic operating conditions [1].

Artificial neural networks (ANNs) are used in a wide research area covering the domain of many sciences, with emphasis on modeling and simulation. Besides, using specific ANN hardware instead of a PC is advantageous where real-time operation is required [2,3]. ANN hardware became available in the early 1990s, when neuro-chips and neuro-computers were implemented [2,3]. Asanović et al. designed a fully programmable single-chip microprocessor to execute artificial neural network algorithms [4]. Kumar et al. presented a review of design aspects of neuro-computers [5]. Aybay et al. proposed a classification of neural network hardware [3].

Nowadays, systems which execute ANN algorithms are generally modeled and simulated on PCs. Onduk designed and simulated an ANN-based real-time controller for power generators on a PC [6]. Bal modeled and simulated an ANN-based system that controls the speeds of DC motors [7]. Zhao et al. modeled and simulated an ANN to determine the dielectric loss angle for high-voltage electrical equipment [8]. İnal and Aras modeled and simulated an ANN to determine the dielectric properties of an insulation material [9]. However, it is possible to execute ANN algorithms in digital signal processors (DSPs), field-programmable gate arrays (FPGAs), and microcontrollers [10]. Khan and Rahman proposed an ANN-based online protection scheme for three-phase interior permanent-magnet motors [11]. Induction motor control has been implemented on a DSP using artificial neural networks [12,13]. Turkoglu has constructed a hardware implementation of an ANN model of a varicap diode using a PIC microcontroller [14].

Buldu and Korkmaz designed a USB kit using Microchip's PIC 16C765 microcontroller, which has a low-speed USB serial interface engine [15]. Khairurrijal et al. described an AT89S52 microcontroller-based single-board computer that is used for teaching the instrumentation systems course to second-year physics students [16]. Mohanna et al. used the dsPIC30F digital signal controller (DSC) as a target processor for general mathematics, general physics, basic electronics, and programming courses and their laboratories [17]. Hsu and Chao proposed an Intel 89S51-based teaching tool with the intent of providing an understanding of its basic operation and software simulation, enabling students to perform the experiments at home, and using a remote-controlled vehicle system to clarify the extensibility of microcontrollers [18].

In this study, the dielectric permittivity (ε) and loss factor (tan δ) of a polyester insulating material are determined using temperature and frequency inputs from an ANN model, and the ANN model as created, trained, and tested on a PC is then embedded into a microcontroller. This method also provides appropriate undergraduate students with an opportunity to understand ANN models independently of a PC.

II. MATERIALS AND METHOD

Dielectric permittivity (ε), which varies with temperature and frequency, determines the insulation level and affects the dielectric breakdown voltage of insulation materials. This property is defined as a function of temperature and frequency by the following equation [9]:

$$\varepsilon = f(F,T) \quad (1)$$

Dielectric loss is also an important property of insulation materials. It is caused by the leakage current (Ir) and behaves as heat flow in insulation materials [9]. Dielectric loss (Wd) is defined as:

$$W_d = 2\pi FCU^2 \tan\delta \quad (2)$$

where F, C, U, and Ic are the frequency, capacity, applied voltage, and capacitive current respectively [9]. Tan δ is the dielectric loss factor and is defined as [9]:

$$\tan\delta = \frac{I_r}{I_c} \quad (3)$$

Artificial neural network (ANN) is a parallel distributed model which consists of simple processing units defined as neurons and their weighted connections with each other and the model includes neurons, an activation unit (Yk) for each neuron, connections between units (Wjk), an activation function (Fk) for each neuron, which determines the activation level between the effective input Sk(t) and the current activation Yk(t), an external input (θk) providing a bias to each neuron, a learning rule, and an operating environment [19]. The subscripts k and j refer to the k-th and j-th units respectively. A neuron is illustrated in Fig. 1.

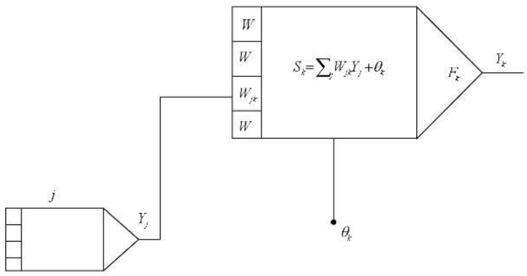

Fig. 1 A simple processing unit of ANNs [19]

The total input to unit k is defined as follows [19]:

$$S_k(t) = \sum_j W_{jk}(t)Y_j(t) + \theta_k(t) \quad (4)$$

The new value of the activation unit of the k-th neuron is defined as [19]:

$$Y_k(t+1) = F_k(S_k(t)) \quad (5)$$

Using Equations (4) and (5), Yk(t+1) can be expressed as [19]:

$$Y_k(t+1) = F_k\left[\sum_j W_{jk}(t)Y_j(t) + \theta_k(t)\right] \quad (6)$$

Certain threshold functions such as sign, linear, and semi-linear functions are used to restrict activation functions [19]. In the case that the activation function Fk is selected to be a sign function, Yk is defined as [19]:

$$Y_k = F(S_k) = \frac{1}{1+e^{-S_k}} \quad (7)$$

In multi-layered ANNs, neurons receive their inputs from the outputs of the neurons below them and send their outputs to the inputs of the neurons above them. The learning phase of an ANN is implemented by applying a learning rule [19].

III. Results

The dielectric permittivity and loss factor of the insulation material were determined as a function of temperature and frequency inputs by an implemented ANN model. For this purpose, a three-layer feed-forward back-propagation ANN model with two inputs and two outputs was created. The Levenberg-Marquardt back-propagation algorithm was selected as a training function, the gradient descent method with momentum weighting and bias learning function as an adaptive learning function, and mean squared normalized error as a performance function. The first layer of the network consists of three neurons, the second layer of six neurons with a tangent sigmoid activation function, and the output layer of two outputs with a linear transfer function. The initial values of weights and biases were selected randomly. Input and output data were rescaled to have the minimum possible determination errors. The topology of the ANN model as created is illustrated in Fig. 2. In this figure, the circles represent the neurons with their biases and activation functions.

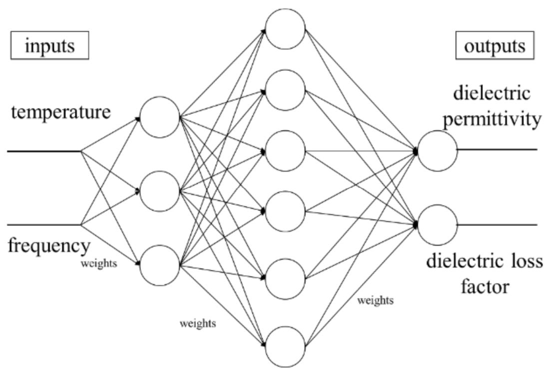

Fig. 2 The created ANN model

In the training phase of the ANN model, the experimental results obtained for the temperature and frequency values (as inputs) and the dielectric permittivity and loss factor values (as outputs) were provided to this model as a training set. This training set is shown in Table 1 from the previous work [9].

In the test phase of the ANN model, the test set of experimental results for the temperature and frequency values was input to the ANN model and the results of the model saved. Then these results were compared with the test set of experimental results for dielectric permittivity and loss factor. The test set is shown in Table 2 from the previous work [9].

The experimental results and the ANN results for dielectric permittivity (ε) and loss factor (tan δ) are shown in Fig. 3 and 4.

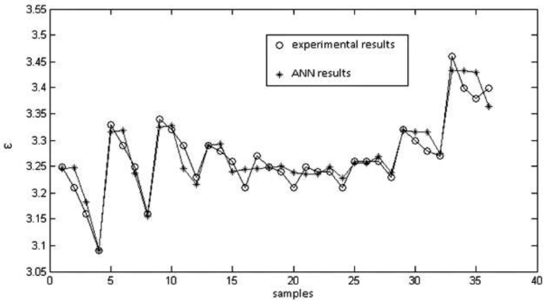

Fig. 3 Comparing experimental and ANN results of the ε

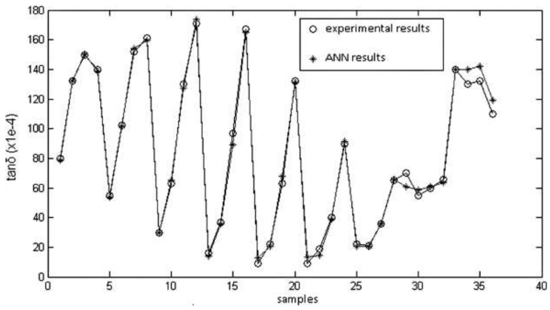

Fig. 4 Comparing experimental and ANN results of the tan δ

In this study, the parameters of the trained ANN model were embedded into the PIC18F452 microcontroller. Some of the properties of this microcontroller are: DC 40 MHz clock frequency, 32 KB flash memory, 1536 bytes RAM memory, 256 bytes EEPROM memory, 8 channels, 10-bit analog-digital (A/D) converter with linearity ≤ 1 LSb, addressable USART module, two capture/compare and PWM modules, and an 8×8 single-cycle hardware multiplier [20].

The minimum data acquisition time of the A/D module under the conditions reported in [20] is 12.86 µs, and in 10 MIPS operation, the eight-bit accumulation, abstraction, and multiply operations are executed in 100 ns [20]. This microcontroller was chosen because of its high-speed operation, low cost, and inclusion of free programming software tools.

The parameters of the trained ANN model, including the weights, biases, and activation functions, were transferred into a C file which was created using MPLAB and C18 software provided by Microchip. In addition to the transferred parameters, A/D converter, LCD, and main program code was added to the C file. After compilation, the code of the created HEX file was downloaded into the PIC18F452 microcontroller using a programmer card.

The entire system can be examined on three levels. On the first level, the ANN model was created, trained, and tested and its parameters saved. On the second level, the HEX file was created using the ANN parameters. On the third level, the HEX file was downloaded into the microcontroller, and the ANN results were observed by changing the temperature and frequency inputs. A flowchart of this system is shown in Fig. 5.

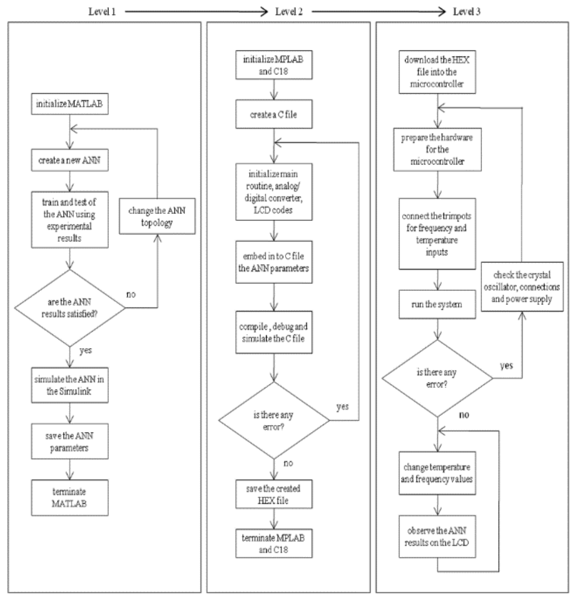

Fig. 5 Flowchart of the system

IV. CONCLUSION

The method proposed here easily forecasts the dielectric properties of an insulation material without the need for measurements at various temperatures and frequencies. In this study, an ANN model, which was created, trained, and tested using the MATLAB software, was embedded into a microcontroller. Thus, industrial applications, analyses, and tests which require an ANN model can be implemented without a PC.

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