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Predicting the Capacitance of Parallel Plate Capacitors Using Adaptive Neuro-Fuzzy Inference System (ANFIS)

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ABSTRACT

Parallel plate capacitors are indispensable passive devices with diverse applications in the field of electronics. The accurate prediction of capacitance value at full charge is of paramount importance during this valuable device's design stage. This work presents a parallel plate capacitance prediction using the Adaptive Neuro-Fuzzy Inference System (ANFIS). The design of the experiment has been achieved using the Taguchi experimental design method. This study's control variables are dielectric absolute permittivity, plate surface area, and plate separation, while capacitance is the single response variable considered. The ANFIS model has a 100% prediction accuracy on training datasets and 83.63% prediction accuracy on testing datasets. The results indicate the reliability of the ANFIS model in parallel plate capacitance prediction during the design stage.

Keywords — *ANFIS, Parallel Plate Capacitance, Absolute Permittivity, Plate Surface Area, and Plate Separation.*

I. INTRODUCTION

Accurate pre-determination of capacitance is vital in producing application-suitable devices. Various researchers have employed diverse analytical capacitance prediction methods. These analytical methods have the following drawbacks: time-consuming, laborious, and prone to human error. With the advancement of computational intelligence technology, artificial intelligence-based methods have been proved to be vital tools in that regard. Nishiyama and Nakamura [1] utilized the Boundary Element Method (BEM) to predict parallel plate capacitors' capacitance. In a separate study, Reitan [2] predicted the capacitance of rectangular parallel plate capacitors using sub-areas. The matrix inversion method has been used by Adams and Mautz [3].

According to Jang [4], Adaptive Neuro-Fuzzy Inference System (ANFIS) combines the attributes of the Artificial Neural Network (ANN) and Fuzzy Logic (FL), making it a powerful computational intelligence prediction tool. The incorporated ANN technique gives ANFIS the capability to learn using training datasets. Furthermore, the model's solutions can be expressed in the form of fuzzy sets. This investigative study has chosen ANFIS for the following reasons: no complex mathematical models are used, fast implementation, and adaptivity [5].

II. METHODS

This experiment has been designed using the Taguchi Design of Experiment (DOE). Three dielectric materials have been used in this study, viz. air, rubber, and paper. Dielectric absolute permittivity, plate surface area, and plate separation have been selected as the control parameters in this investigative research. Each of the parameters has been assigned three levels. These process variables and their associated levels are presented in Table 1.

TABLE I PROCESS PARAMETERS AND LEVELS

Parameters	Levels		
	1	2	3
Dielectric Absolute Permittivity (F/m)	8.85 E-12	17.7 E-12	30.97 E-12
Plate Surface Area (cm^2)	100	1200	2000
Plate Separation (mm)	2	8	16

The Taguchi L9 orthogonal array has been implemented in designing the experiment. This yielded 9 experimental runs. The experimentation order is presented in Table 2.

TABLE II TAGUCHI L9 ORTHOGONAL ARRAY DESIGN OF EXPERIMENT

Exp. Number	Dielectric Absolute Permittivity (F/m)	Plate Surface Area (cm^2)	Plate Separation (mm)
1	8.85E-12	100	2
2	8.85E-12	1200	8

3	8.85E-12	2000	16
4	17.7E-12	100	8
5	17.7E-12	1200	16
6	17.7E-12	2000	2
7	30.97E-12	100	16
8	30.97E-12	1200	2
9	30.97E-12	2000	8

TABLE III EXTRA EXPERIMENTAL DATA FOR MODEL VALIDATION

Exp. Number	Dielectric Absolute Permittivity (F/m)	Plate Surface Area (cm^2)	Plate Separation (mm)
10	8.85E-12	200	2
11	8.85E-12	200	10
12	17.7E-12	1000	8
13	17.7E-12	1500	2
14	30.97E-12	2000	16

III. RESULTS AND ANALYSIS

Capacitance has been the single response variable in this study. The experimentally obtained parallel plate capacitance values are tabulated in Table 4. The following experimental runs have been utilized for model training: 1, 2, 3, 5, 6, 8, 9, 11, and 14. The model prediction efficiency on training datasets is presented in Table 5.

TABLE IV CAPACITANCE EXPERIMENTAL RESULTS

Exp No.	Dielectric Absolute Permittivity (F/m)	Plate Surface Area (cm^2)	Plate Separation (mm)	Capacitance (nF)
1	8.85E-12	100	2	0.044
2	8.85E-12	1200	8	0.133
3	8.85E-12	2000	16	0.111
4	17.7E-12	100	8	0.022
5	17.7E-12	1200	16	0.133
6	17.7E-12	2000	2	1.000
7	30.97E-12	100	16	0.019
8	30.97E-12	1200	2	1.000
9	30.97E-12	2000	8	0.774
10	8.85e-12	200	2	0.089
11	8.85E-12	200	10	0.018
12	17.7E-12	1000	16	0.111
13	17.7E-12	1500	2	1.000
14	30.97E-12	2000	16	0.387

A screenshot of the ANFIS test plot against training data is presented in Fig. 1. In the screenshot, experimentally determined capacitance values are represented by the blue dots. The ANFIS predicted that the red stars represent capacitance values. The degree of overlapping of the blue dots and the red stars indicates the ANFIS model's prediction capability. The screenshot indicates a total overlap between the blue dots and the red stars. The prediction accuracy of ANFIS on training datasets based on MAPE is presented in Table 5. The prediction accuracy of ANFIS on training datasets is 100%.

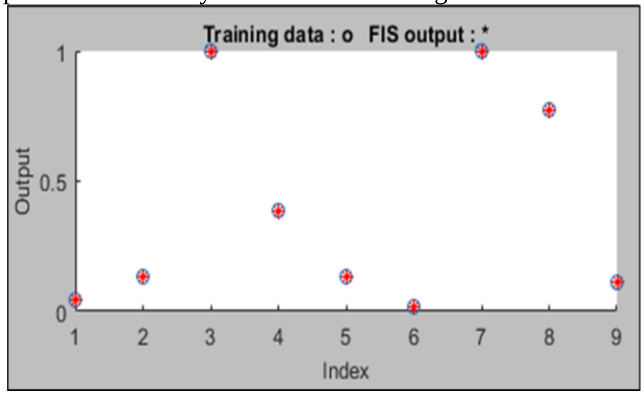

Fig. 1 MATLAB pictorial of ANFIS prediction accuracy on training datasets

TABLE V ANFIS PREDICTION ACCURACY ON TRAINING DATASETS

Analytically Calculated Capacitance (nF)	ANFIS Based Capacitance (nF)	% Absolute Error
0.044	0.044	0.00
0.133	0.133	0.00
1.000	1.000	0.00
0.387	0.387	0.00
0.133	0.133	0.00
0.018	0.018	0.00
1.000	1.000	0.00
0.774	0.774	0.00
0.111	0.111	0.00
MAPE (%)		**0.00**
Prediction Accuracy (%)		**100**

The following experimental runs have been utilized for model training: 4, 7, 10, 12, and 13. The model prediction efficiency on training datasets is presented in Table 6. The prediction accuracy value is an exhibition of ANFIS's high prediction power. A plot of ANFIS predicted the MATLAB pictorial snapshot presents parallel plate capacitance in Fig. 2. The ANFIS predicted that the red stars represent capacitance values. The degree of overlapping of the blue dots and the red stars indicates the ANFIS model's prediction capability. Table 6 represents an evaluation of ANFIS prediction accuracy based on MAPE on testing datasets. The prediction accuracy of ANFIS on testing datasets is 83.63%.

It has been discovered that the ANFIS model has a higher prediction accuracy on training datasets than on testing datasets. The ANFIS model has prediction accuracies on training datasets and testing datasets of 100% and 83.63%, respectively. Both values are high since they lie within the upper quartile region of prediction accuracy.

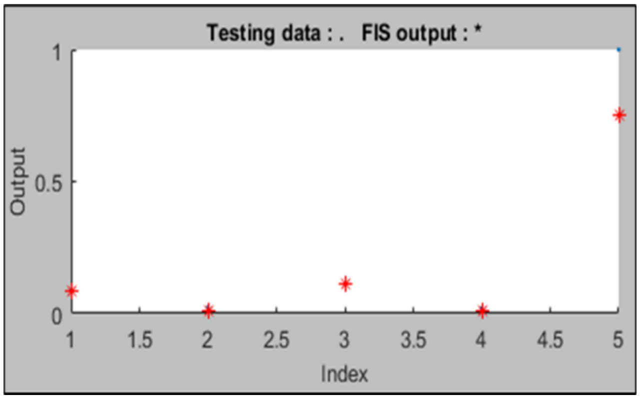

Fig. 2 MATLAB pictorial of ANFIS prediction accuracy on testing datasets

TABLE IV ANFIS PREDICTION ACCURACY ON TESTING DATASETS

Exp. Number	Analytically Calculated Capacitance (nF)	ANFIS Based Capacitance (nF)	% Absolute Error
1	0.089	0.088	1.12
2	0.022	0.019	13.63
3	0.111	0.111	0.00
4	0.019	0.011	42.10
5	1.000	0.750	25.00
MAPE (%)			**16.37**
Prediction Accuracy (%)			**83.63**

IV. CONCLUSION

The parallel plate capacitance prediction power of the ANFIS model has been evaluated in this study. It has been revealed that ANFIS has a higher prediction accuracy on training datasets in comparison to prediction accuracy on testing datasets. ANFIS yields a prediction accuracy of 100% on training datasets and 83.63% accuracy on testing datasets. Both values are high since they lie within the upper quartile region of prediction accuracy. Based on these results, ANFIS can be reliably used to predict parallel plate capacitance at the capacitor design stage. It is recommended that artificial intelligence tools such as Genetic Algorithms (GA) and Particle Swarm Optimization (PSO) optimize parallel plate capacitor design parameters to be evaluated.

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