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Comparison of ANN, CF and LR Methods for Harmonic Estimation

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Abstract - Power quality is an important criterion in electrical power systems. Harmonics negatively affect the power quality. Harmonic analysis and estimation have been made with various methods in the literature. In this study Artificial Neural Network (ANN), Curve Fitting (CF) and linear regression (LR) models have been developed for the estimation of the THD_I values. Some of the measured data have been used to generate models, the remaining part have been used to test the model. Estimation results obtained from the ANN, CF, LR models are compared to each other. Estimated THD_I values obtained from ANN, CF, LR models were close to real THD_I values so that ANN, CF, LR models can be used for the THD_I estimations. With this way, planning of the power systems can be made to increase the power quality in electrical power systems.

Keywords *– Artificial Neural Network, Curve Fitting, Harmonic, Linear Regression, Power Quality, Power Distribution System, THD*

1. INTRODUCTION

The power quality term has become one of the most important term in the power systems. There are many types of equipment that causes power quality problems. Computer, television, air conditioning, UPS, speed control device, welding machine, can be given as example to this type of non-linear loads. These loads generate the harmonics and negatively affect the power quality. Harmonic distortion is the most significant power quality problem. Total Harmonic Distortion (THD) is used as an indication of current and voltage distortion values. Harmonic limitations are described in the IEEE 519 standard [1], [2]. ANN's are used for harmonic estimates and signal analysis in literature [3], [4], [5], [6]. ANN has been used to estimate the nonlinear harmonic loads [7]. ANN estimation method has been proposed for the current estimation of nonlinear loads which contains harmonic components in reference [8]. On the other hand, in some papers [9-15] curve fitting methods have been used. In reference [16], estimation of multivariate regression functions has been made with LR method. Modeling and estimation of the propagation loss in wireless systems with LR method proposed in reference [17]. For improving performance in heterogeneous Networks (hetnets), LR estimation method was proposed in reference [18]. In reference [19], linear regression-based estimation method was proposed to identifying sound. In reference [20], for defining the foreground of computer systems, LR based modeling method has been used. In reference [21], LR estimation method has been used for channel estimation in wireless networks. For estimating the growth trend of THD estimation, LR method has been used in reference [22]. In reference [23], LR method has been used for the frequency estimation. In reference [24], LR method has been used for the estimation. In this study, values were

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measured with devices connected to the grid. These values have been used in ANN, CF, LR models for training and testing purposes.

2.HARMONICS IN POWER SYSTEMS

Nonlinear devices cause harmonic distortion in the power system. The most commonly indices used for measuring the harmonic content of a waveform are the total harmonic distortion (THD).

Total current harmonic distortion can be expressed as,

$$THD_I = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^{\,2}}}{I_1} \quad (1)$$

Total volage harmonic distortion can be expressed as,

$$THD_V = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^{\,2}}}{V_1} \quad (2)$$

Studied energy distribution system is supplied from different transformer centers. The input voltage of distribution system is 154 kV. 154 / 34.5 kV transformer is used to turn voltage. values have been measured at the 34.5 kV side of the transformer. values measured from the system were used in the models for harmonic estimation. Single-line diagram of the distribution system is given in Figure 1.

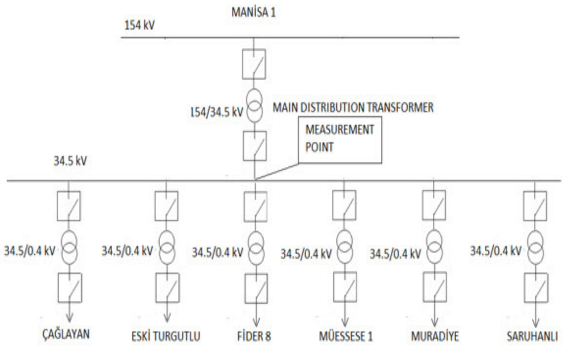

Figure1. Single-line diagram of the energy distribution system

Table1. Measured Load Current and values for modeling and testing.

Measurement Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Load current (I_L)	370	330	270	250	240	220	290	365	447	465	470	480	490	475
Measured THD_I	8,4	8,7	11,2	12	13	18	11,8	8,8	7	6,8	6,6	6,7	6	5,8

Measurement Number	1	2	3	4	5	6	7	8	9	10
Load current (I_L)	465	425	440	477	448	410	360	260	300	380
Measured THD_I	6,2	7	7,1	5,8	6,8	7,8	9	12,2	11,8	8,4

3. SIMULATION STUDIES
3.1. ANN METHOD

Artificial neural networks include three parts.
1. Input Layer
2. Hidden Layer
3. Output Layer

Input layer neurons receive the input data and send this data to the hidden layer neurons. ANN was used for estimation purposes, the most important performance is the accuracy of estimation. Estimation error values were determined by the following formulas [25]. Y describes the value of the real measuring data; F describes value generated by the model,

Estimation Error can be defined as below.

$$e = Y - F \quad (3)$$

The average error is calculated as following

$$\frac{1}{n}\sum_{i=1}^{n} e_i \quad (4)$$

The average absolute error can be written as below.

$$\frac{1}{n}\sum_{i=1}^{n} |e_i| \quad (5)$$

The percentage error can be written as below.

$$\frac{e_t}{Y_t} * 100 \quad (6)$$

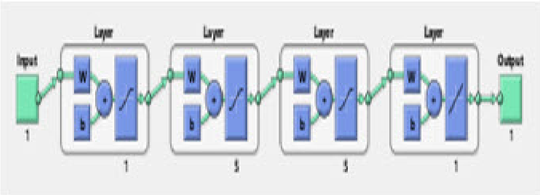

Figure 2. *ANN model with one input layer, two hidden layer, one output layer.*

ANN model has been shown in Figure 2. ANN model has 1-input, 2 hidden layers and one output layer. There is no connection between hidden layer. estimation has been done with the proposed ANN model.

3.2. CURVE FITTING

For determining a polynomial equation of the unknown intermediate values of data set curve fitting methods are used**.** Polynomial equation obtained from the curve fitting can't pass through the data points. Appropriate of polynomials are searched in different degrees [26].

Given the (n + 1) points: (x_0, y_0), (x_1, y_1), (x_2, y_2), … (x_n, y_n), There is more similar n'th degrees of polynomial passing through this point.

$$y = P_n(x) = b_0 + b_1x + b_2x^2 + \ldots + b_n x^n \quad (7)$$

This coefficients (b_0, b_1, b_2, … b_n) are achieved by solving linear equations.

$$\begin{aligned} b_0 + b_1x_0 + b_2x_0^2 + \ldots + b_nx_0^n &= y_0 \quad (8)\\ b_0 + b_1x_1 + b_2x_1^2 + \ldots + b_nx_1^n &= y_1\\ b_0 + b_1x_2 + b_2x_2^2 + \ldots + b_nx_2^n &= y_2\\ . \quad . \quad . \quad \ldots \quad . \quad &.\\ b_0 + b_1x_n + b_2x_n^2 + \ldots + b_nx_n^n &= y_n \end{aligned}$$

There is an error if the degree of the polynomial is chosen too small. If the degree of the polynomial is chosen too big unexpected fluctuations in the interpolation functions occur. Therefore choosing of the degree of polynomial is very important.

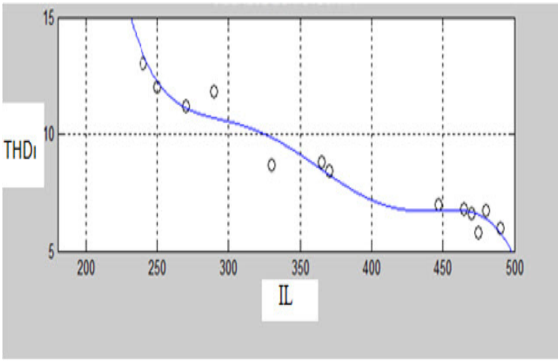

Figure 3. CF graph.

CF graph is shown in Figure 3. THD_I estimations were made by using this 5'th degree equation curve.

3.3.LINEAR REGRESSION METHOD

Linear regression attempts to model the relationship between two variables by fitting a linear equation to meassring data. One variable is considered to be an explanatory variable, and the other is considered to be a dependent variable.

Simple linear regression is a statistical method for obtaining a formula to predict values of one variable from another where there is a causal relationship between the two variables**.**

In simple linear regression, we predict scores on first variable from the scores on a second variable. The variable we are predicting is called the *criterion variable* and is referred to as Y. The variable we are basing our predictions on is called the *predictor variable* and is referred to as X.

The formula for a regression line is

$$Y=bX+A \quad (9)$$

where Y is the predicted score, b is the slope of the line, and A is the constant.

Linear regression consists of the best-fitting straight line through the points. The best-fitting line is called a *regression line.*

4. COMPARISON OF THE ESTIMATION RESULTS

Table 2 gives the information about percentage error, the measured and estimated THD_I via ANN, CF and LR methods The THD_I values in this table are used for testing the ANN, CF and LR methods. % error value is expressed as percentage of the difference between the measured THD_I and estimated THD_I.

Table 2 *% error, measured THD_I, estimated THD_I values.*

MEASUREMENT NUMBER	MEASURED THD_I	ESTIMATED ANN THD_I	ESTIMATED CF THD_I	ESTIMATED LR THD_I	PERCENTAGE ERROR ANN THD_I	PERCENTAGE ERROR CF THD_I	PERCENTAGE ERROR LR THD_I
1	6,2	6,8	6,72	6,51	8,82	7,73	5
2	7	7,01	6,75	7,53	0,14	3,7	7,5
3	7,1	6,99	6,72	7,14	1,57	5,65	0,56
4	5,8	5,53	6,5	6,2	4,88	10,76	6,8
5	6,8	6,99	6,74	6,94	2,71	0,89	2,05
6	7,8	8,08	6,94	7,91	3,46	12,39	1,4
7	9	8,2	8,7	9,1	9,75	3,44	1,11
8	12,2	11,44	11,5	11,7	6,64	6,08	4,09
9	11,8	11,42	10,5	10,7	3,32	12,38	9,1
10	8,4	7,7	7,86	8,68	9,09	6,87	3,33

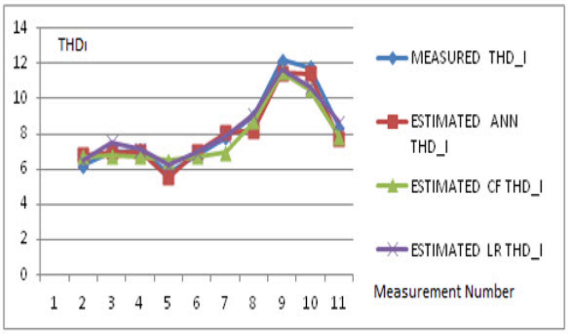

Figure 4 The measured THD_I and estimated THD_I values.

Figure 4 illustrates the measured THD_I and estimated THD_I values. As seen from the figure, estimated THD_I values are close to measured THD_I values.

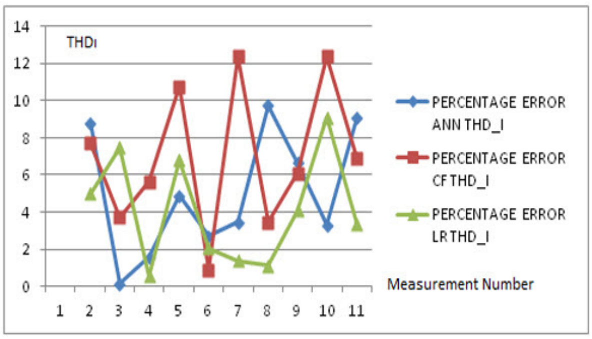

Figure 5. The percentage error between measured THD_I and estimated THD_I values

Figure 5 shows the % error between measured and obtained from ANN, CF and LR THD_I values. First estimation error values for ANN, CF and LR are 8,82 %, 7,73 %, 5 %, respectively . In second estimation error values are 0,14 %, 3,7%, 7,5 %, respectively. In third estimation error values are 1,57 %, 5,65%, 0,56 %, respectively. Estimated error values in the 4th estimation are 4,88 %, 10,76%, 6,8 %, respectively. Estimated error values in the fifth estimation are 2,71%, 0,89%, 2,05%, respectively. In sixth estimation error values are 3,46 %, 12,39%, 1,4 %, respectively. Estimated error values in the seventh estimation are 9,75 %, 3,44%, 1,11 %, respectively. In eighth estimation error values are 6,64 %, 6,08%, 4,09 %, respectively. Estimated error values in the 9th estimation are 3,32 %, 12,38%, 9,1 %, respectively. Estimated error values in the tenth estimation are 9,09 %, 6,87%, 3,33 %, respectively.

Test phase; the average errors are 5,03% for ANN, 6,98% for CF and 3,99 % for LR .

5. CONCLUSION

In this study, THD_I values in the electrical power systems were estimated by using ANN, CF and LR methods. With this proposed method, harmonics which is one of the power quality problems can be estimated previously to improve power quality. Especially harmonic analysis and the estimation are very important in the distribution system. Because of the harmonic distortion the losses and the various defects occur. Harmonics adversely affects power quality. Harmonic values are estimated approximately 95% accuracy by ANN algorithm, 93% by CF and 96% by LR algorithm. This accuracy values indicate that proposed ANN, CF and LR models can be used to estimate THD_I values. According to this estimated THD_I values, the required filter parameters can be determined and applied to the power distribution system. In this way, by reducing the harmonic values, a considerable increase in power quality can be provided. ANN, CF and LR THD_I estimation models, can be used in other power distribution systems for the THD_I estimation.

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