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A Novel Neural Network Approach for Harmonic Distortion Detection in Power Systems

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ABSTRACT: Harmonic distortion in power systems can lead to inefficiencies, equipment failures and operational risks. Generally, the high order harmonics are introduced in a system when the electricity is controlled by electronics. Traditional detection methods, such as Fourier and wavelet analysis, often face challenges with real-time detection due to high computational demands. The harmonic measurements are conducted on Power Quality Analysers, Harmonic Analysers and numeric meters. This paper proposes a novel neural network-based approach for harmonic distortion detection, utilizing the pattern recognition capabilities of Artificial Neural Networks (ANNs). The proposed method is simple, cost effective and feasible.

KEYWORDS: Artificial Neural Networks (ANN), Sigmoid function, Chaining, Total Harmonic Distortion (THD), Gradient Descent Method

I. INTRODUCTION

Harmonic distortion occurs when the normal sinusoidal waveform of electrical signals in a power system is altered by the presence of additional frequency components, called harmonics [1]. In an ideal power system, the current and voltage follow a clean sinusoidal wave at the fundamental frequency, typically 50 or 60 Hz. However, when nonlinear loads such as computers, LED lighting or variable frequency drives are connected to the system, these may introduce harmonics—frequencies that are integer multiples of the fundamental frequency (e.g., 150 Hz, 300 Hz) [2].These harmonic frequencies distort the original waveform, leading to power quality issues as stated below.

- Increased power losses in transmission lines
- Overheating of equipment like transformers and motors [3].
- Malfunctions or failures of sensitive electronic devices [4][5].
- Interference with communication systems.

Managing harmonic distortion is critical to ensuring the efficiency, reliability and safety of power systems [6][7]. Artificial Neural Networks (ANNs) are computational models inspired by the structure of human brain and function[8]. These are composed of interconnected layers of nodes, called neurons that work together to process information, learn patterns and make predictions. ANNs are a key technology in machine learning and are used to solve complex tasks like image recognition, speech processing and data classification[9].

The typical ANN consists of: the following main components.

- 1. Input Layer: Receives the raw data or input features.
- 2. Hidden Layers: These layers perform intermediate computations and extract features by adjusting weights and biases. The more hidden layers, the deeper the network.
- 3. Output Layer: Produces the final prediction or classification based on the learned data [10].

The ANNs learn through a process called training, which involves adjusting the weights of connections between neurons based on the error in predictions. This is done using optimization techniques like backpropagation and gradient descent. Over time, the network improves its ability to recognize patterns and make accurate predictions[11]. These are highly flexible and capable of modeling nonlinear relationships, making them powerful tools for applications such as





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image and speech recognition, natural language processing and infields like power system analysis, including harmonics detection [12].



Fig.1. Two Input, One Output ANN

Fig 1 illustrates Two Input, one output ANN applied through input layer, hidden layer and output layer forming feed forward path. As discussed above the main components are as follows.

- Input Layer: Raw or pre-processed current/voltage waveform data (from sensors or power meters).
- Hidden Layers: One or more layers of neurons with activation functions like ReLU, Sigmoid, or Tanh, to capture non-linearities in the data.
- Output Layer: Predicted harmonic orders or THD levels [13].

II. DETECTION OF HARMONICS

Harmonics are integer multiple of fundamental quantity of current and voltage. Harmonics in a non-linear load are detected by analyzing the distortion in the current or voltage waveform. The non-linear loads such as computers, fluorescent lights and power electronics draw current in a non-sinusoidal manner, which distorts the waveform and creates harmonics. Conventionally, the harmonics are detected generally using following techniques.

1. Fourier Transform (FT)

The most common method to detect harmonics is through the Fourier Transformer more specifically the Fast Fourier Transform (FFT). This method decomposes the waveform into its sinusoidal components, identifying the fundamental frequency and the harmonic frequencies.

Theresult of an FFT analysis show the magnitude and phase of the fundamental frequency (usually 50/60 Hz) and its harmonics (multiples of the fundamental frequency like 2nd, 3rd, etc.).

2. Total Harmonic Distortion (THD) Measurement

Total Harmonic Distortion is a metric used to quantify the harmonic content. It is calculated as the ratio of the root mean square (RMS) value of all harmonic components to the RMS value of the fundamental frequency.

A high THD indicates significant harmonic presence, which can be measured using harmonic analyzers or power quality analyzers or numeric meters.

3. Harmonic Analyzers

Specialized equipment such as harmonic analyzers or power quality meters can be used to measure and detect harmonic components in electrical systems. These devices are capable of real-time monitoring and analyzing waveform distortions caused by harmonics.





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4. Digital Signal Processing (DSP)

DSP techniques can be used to process the sampled signals from the power system. Algorithms such as Discrete Fourier Transform (DFT), wavelet transforms, or Kalman filtering are often employed for harmonic detection, especially in real-time applications.

5. Artificial Intelligence and Machine Learning Approaches

AI and ML-based methods, such as neural networks and fuzzy logic, can also be employed to detect harmonics. These methods are trained to recognize patterns of distortion that are indicative of harmonics and can be more adaptive to complex, dynamic environments.

6. Wavelet Transform

The Wavelet Transform provides time-frequency analysis, which is useful for detecting harmonics that vary over time. This is especially useful in systems where the load conditions change frequently.

1. Problem Formulation: Harmonics Detection

In non-linear loads, the waveform of the current or voltage is distorted, resulting in harmonics that are multiples of the fundamental frequency. Detecting these harmonics is essential in maintaining power quality, avoiding overheating and reducing losses.

Neural networks can be used to classify and estimate the presence of harmonic components in real-time, based on patterns in the distorted waveforms.

2. Neural Network Architecture for Harmonics Detection

Feed forward Neural Networks (FNNs)or Convolutional Neural Networks (CNNs)can be employed to identify harmonic patterns in time-series data. This is discussed in his paper.

Recurrent Neural Networks (RNNs), specificallyLong Short-Term Memory (LSTM) networks, can be used for time-dependent harmonic analysis, as harmonics in a power system often exhibittemporaldependencies[14].

4. Preprocessing for Neural Networks

5. Combining Neural Networks with Traditional Techniques

- Neural networks can be integrated with traditional FFTorWavelet Transform methods. The transform can serve as a feature extraction technique, providing the frequency components to the neural network [15].
- Alternatively, neural networks can be used for post-processing, where traditional methods like FFT estimate the harmonics, and the neural network fine-tunes orclassifies the harmonics based on learned patterns [16].

6. Evaluation Metrics

- The neural network model should be evaluated based on its accuracy in detecting the correct harmonic order and magnitude. Typical metrics include:
- Mean Absolute Error (MAE) and Root Mean Square Error (RMSE): To measure the accuracy of harmonic magnitude predictions.
- Classification Accuracy: If the network classifies harmonic severity or order.
- Real-time performance: To assess how quickly the network can process and output results in a live environment

7. Challenges and Considerations

- Training Data: High-quality training data with a wide range of harmonics and load conditions is critical for accurate detection.
- Generalization: Neural networks need to generalize well to different loads and harmonic conditions to be effective in diverse settings.
- Hardware Limitations: Real-time detection requires optimized neural network architectures that can run efficiently on hardware with limited processing power (e.g., embedded systems in power quality meters) [17].





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By utilizing neural networks, more adaptive, real-time system for harmonic detection can be developed that improves upon traditional methods. Neural networks can capture complex relationships and adapt to varying load conditions, making them a powerful tool in the on-going effort to maintain power quality in systems with non-linear loads.

III. THE ANNBASED HARMONIC DEJECTION MODEL

The human brain is made up of billions of neurones, which are nerve cells. Dendroids and axons are the connectors that connect the neurones. The eyes, nose, touch, etc., all provide input to the neurones. Neurones process the inputs they receive before forwarding them for additional activation. The term "Biological Neural Network" (BNN) refers to this network made up of neurones and dendroids. Working with parallel processing, the BNN [7].

The development of artificial neural networks is based on this concept. Inspired by the BNN, ANNs are massively parallel computing systems made up of several processors connected to one another[8].



Fig.2. ANN Model for harmonic detection

An ANN model for harmonic detection is shown in Fig. 2. The input layer, hidden layer, and output layer are the three main layers that make up the ANN model. At the input layer, the ANN receives the input signals x1 and x2 as fundamental current or voltage and harmonic current or voltage, respectively.

Here the Current THD is calculated as root mean square of total harmonic current divided by fundamental current. Refer equation 1. On similar lines, the Voltage THD is calculated from total harmonic voltage and fundamental voltage.

The ANN is formed between two inputs –fundamental I1 and harmonic component Ih. These parameters may be current (I1, Ih)or voltage (V1 and Vh). The output of ANN will be current or voltage harmonic distortion.

The bias signal b is given additional to input signals. Bias can be introduced at the input layer. It is possible to take input x0 with weight w0 in the input layer so that w0=b, which is bias. Synoptic weights w0, w1, and w2 construct linkages that feed these inputs to a linear transfer function at the hidden layer. At the output layer, each input is altered by a weight (for example, multiplied by weights), and the result is y[9]. In the case of BNN, this so-called perceptron functions similarly to a neurone in a junction. Equation 2 mentions a linear equation that represents the expression for output y.

$$y = w_0 x_0 + w_1 x_1 + w_2 x_2 = \Sigma_0^2 w_i x_i \dots (2)$$

An activation function is used to further process the output y in order to provide a scalable output. Numerous activation functions exist, including hyperbolic tangent, sigmoid, and rectified linear unit (ReLU). An activation function that produces output Y between 0 and 1 is the sigmoid function. Equation 2 provides the expression for the sigmoid function. [10].

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 $Y = \frac{1}{1 + e^{-y}}.....(3)$

The network forming a sequence of input layer, hidden layer and output layer is called feed forward network. The output so obtained through a feed forward network is called as predicted output. The predicted output (Y) is compared with the targeted output (T) in case of supervised learning algorithm. Error, represented by the letter e, is the difference between the intended and projected output [11]. The mistake should ideally be obliviously zero in order to produce the desired result. At its gradient with regard to weights, the error would be at its lowest. The gradient is the rate at which the error changes in relation to the weight (de/dw). It is necessary to return from mistake to weight in order to calculate gradient. We refer to this process as back propagation. Back propagation can be done in a variety of ways, including chaining, the gradient decent approach, and others. [12].



Fig.3. Flow chart for machine learning algorithm

Fig 3 shows a Flow chart used in this paper. The ML model is tested under training data and testing data. The model is deployed when the results are acceptable.

IV. OBSERVATIONS

Initially, status 0 indicates normal condition whereas status 1 indicates that the harmonic distortion has been detected. Based on previous results obtained from field, the datasets have been prepared comprising of three parameters fundamental current (I1) and harmonic current and status. The sample training data for current harmonics is furnished in Table I Status indicates targeted output. Both regular and warped situations can be seen in this historical data. Python initialises the weights w1, w2, and bias at random. Equation (1) is used to determine the output y. The output Y is calculated using the Sigmoid function, as illustrated in Fig. 2.It is specified that mode 1 is when the distortion event is noticed. Therefore, the system is normal if the output value is smaller than the neural network's threshold of 0.05; otherwise, the neural network generates the harmonic distortion event.





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Fundamental		Current	Status
Current	Harmonic	THD %	
Amp, 11	Current		
	Amp ,Ih		
0.99	0.001	0.101	Not
			distorted
0.98	0.004	0.408	Not
			distorted
0.90	0.044	4.888	Not
			distorted
0.07	0.0045	0.517	Not
0.87			distorted
0.8	0.046	5.75	Distorted
			wave
0.78	0.065	8.333	Distorted
			wave
0.75	0.045	6	Distorted
			wave
0.92	0.025	2.717	Not
			distorted
0.91	0.071	7.802	Distorted
			wave
0.94	0.045	4.787	Not
			distorted

TABLE 1.0BSERVATIONS - ITHD

The difference between the main meter and check meter units is used to calculate the theft units displayed in Table I. Zero is used to truncate a very small difference.

Fundamental Voltage Volts, V1	Harmonic Voltage Volts, Vh	Voltage THD %	Status	
63.5	0.012	0.018898	Not distorted	
62.12	0.045	0.07244	Not distorted	
63.99	0.047	0.073449	Not distorted	
63.12	0.0045	0.007129	Not distorted	
62.12	0.052	0.082869	Not distorted	
63.45	0.022	0.034673	Not distorted	
63.66	0.065	0.102105	Not distorted	
63.04	0.998	1.583122	Not distorted	
63.12	0.065	0.102978	Not distorted	

TABLE II	OBSERVATIONS	(VTHD)
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1		





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63.05 0.448 0.710547	Not distorted
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Targeted output T and output Y are compared. The difference between the intended output (T) and the expected output (Y) is then used to calculate error e. Equation 4 uses the chaining method to calculate the square of error and differentiate error e with regard to weights w1 and w2.

∂e	_	∂е∂Ү∂у	(1	`
∂w		дү ду дw	(4)

A number of consecutive repetitions are used to carry out the chaining. When the weight values remain constant over iterative cycles, convergence is considered to have been achieved. When convergence occurs, the error is at its lowest. The predicted output thus gets closer to the desired output.

On similar lines three parameters namely fundamental voltage (V1) and harmonic Voltage (Vh) and status are measured and furnished in Table II.

```
def which_data(fundamental,distortion):
y=point[0]*w1+point[1]*w2+b
Y=sigmoid(y)
print('Y=',Y)
print('error=',Y-T)
print('w1=',w1)
print('w2=',w2)
if Y<0.05:
    os.system('status normal')
    print('status normal')
else:
    os.system('Harmonic distortion detected')
print('Harmonic distortion detected')
which_data(0.09, 6.111)
```

Harmonic distortion detected

Fig.4. Sample PythonPsudo code for harmonic detection

The code is written in Python language. Fig.34 illustrates Sample Python Psudo code for harmonic detection Future research could explore the application of more advanced neural network architectures, such as convolutional or recurrent neural networks, to further enhance detection capabilities. Additionally, integrating this model with real-time monitoring tools could provide a comprehensive solution for proactive management of power system harmonics. Ultimately, the integration of AI-driven methods such as this can significantly contribute to the stability and reliability of the modern power grids, ensuring optimal performance and compliance with international power quality standards.

V. CONCLUSION

In conclusion, this paper presents a novel approach for detecting harmonic distortion in power systems using neural networks. The proposed method demonstrates the potential of machine learning to address challenges in power quality monitoring, offering higher accuracy and adaptability compared to traditional techniques. By leveraging neural networks, the system can effectively identify complex harmonic patterns, enhancing both real-time detection and mitigation of distortions in power distribution networks. This approach opens new avenues for automating power system diagnostics, minimizing manual intervention, and ensuring continuous power quality. The proposed method is novice, feasible and cost effective.

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