

# ARTIFICIAL NEURAL NETWORK-BASED APPROACH FOR TRANSFORMER FAULT DETECTION AND INRUSH CURRENT DISCRIMINATION USING WAVELET COEFFICIENTS

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## ABSTRACT

Transformer protection remains a critical concern in power systems, particularly due to the challenge of accurately and swiftly distinguishing magnetizing inrush currents from internal fault currents. To address this issue, artificial neural networks (ANNs) have been proposed and proven effective, offering a cost-efficient, reliable, and noninvasive solution for transformer monitoring and fault detection. This paper presents an innovative algorithm that utilizes statistical parameters derived from the detailed D1-level wavelet coefficients of the signal as inputs to the ANN. This method provides a novel, real-time approach for accurately differentiating between magnetizing inrush currents and inter-turn faults. Furthermore, the proposed ANN-based model extends its capability to identifying the fault location—determining whether the inter-turn fault resides in the primary or secondary winding of the transformer.

**Keywords:** Artificial Neural Network, Fault Detection, Inrush Current, Inter-turn Fault, Transformer Protection, Wavelet Coefficients, Wavelet Transform

## 1. INTRODUCTION

Power transformers are critical components in power systems, and their reliable protection is essential to prevent operational failures. Differential protection has long been the primary method employed for safeguarding power transformers. It relies on differential relays that detect internal faults by comparing current differences and are designed to block operations during magnetizing inrush conditions. However, a significant limitation of this method is its vulnerability to maloperation due to transient inrush currents, which commonly occur during transformer energization. These inrush currents often contain substantial second harmonic components.

Traditional digital differential protection techniques depend heavily on analyzing the harmonic content of the differential current. The common assumption is that the ratio of second harmonic to the fundamental component is higher during inrush conditions than during internal faults. Nonetheless, second harmonic components can also be present during internal faults, due to factors such as current transformer (CT) saturation, parallel capacitances, or isolated transformer sections. In some cases, the second harmonic magnitude during faults may exceed that observed during inrush, leading to misclassification by conventional harmonic restraint methods.

To address these limitations and improve reliability, various advanced techniques have been developed to distinguish inrush currents from internal fault currents. Given that both types of signals are non-stationary, wavelet transform-based signal processing has proven effective for analyzing and extracting distinguishing features. Although wavelet techniques offer superior time-frequency resolution, they typically require long data windows and are susceptible to noise interference.

For example, the method in [6] combines Wavelet Transform (WT) with Adaptive Neuro-Fuzzy Inference System (ANFIS) to discriminate between inrush and internal fault currents. However, because it relies on detail level 5 (D5) wavelet coefficients for pattern recognition, its performance degrades in noisy environments. Similarly, the technique in [5] differentiates inter-turn faults from magnetizing inrush conditions using peaks in the |D5| wavelet coefficients. Although this method eliminates the need for predefined threshold values, it still struggles in noisy conditions, especially when the precise switching instance is unclear.

Feedforward Neural Networks (FFNNs) [7–10] have also been applied to detect inrush conditions, but they face two primary challenges: the training process is time-consuming, and determining the optimal number of neurons to prevent overfitting or underfitting lacks a systematic approach. To mitigate these issues, Radial Basis Function Networks (RBFNs) [11] have been introduced. RBFNs offer a simpler structure and a more transparent learning process, making them suitable for this application.

Additionally, some approaches use harmonic content of differential current as input for fuzzy logic systems [6], [12], offering another path to improving transformer protection.

## 2. ARTIFICIAL NEURAL NETWORK

The use of Artificial Neural Networks (ANNs) for fault classification in power systems has garnered significant attention in recent years. Dr. Robert Hecht-Nielsen, a pioneer in the development of early neurocomputers, described an ANN as “a computing system made up of a number of simple, highly interconnected processing elements, which process information by their dynamic state response to external inputs.” Essentially, ANNs are designed to model complex patterns and relationships in data by simulating the way biological neural networks function. They are trained for specific tasks—such as pattern recognition or data classification—through a structured learning process that adjusts the internal parameters based on input-output mappings..

### 2.1 ARCHITECTURE OF NEURAL NETWORKS

Neural networks are typically structured in multiple layers, each comprising numerous interconnected processing units known as neurons or nodes. These layers include an input layer, one or more hidden layers, and an output layer. Each node within a layer applies an activation function to the weighted sum of its inputs, which determines the node's output. The input layer receives the raw data and passes it through to the hidden layers, where the core computations occur via a network of weighted connections. These hidden layers extract features and identify patterns in the data. Finally, the processed information reaches the output layer, which produces the final result of the network, such as a classification or decision, as illustrated in the corresponding figure..

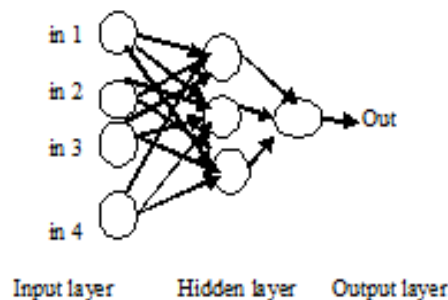


Figure 1: Architecture of ANN

## 3. PROPOSED ALGORITHM

In the proposed approach, a **Multilayer Perceptron (MLP)** neural network with two hidden neurons is employed to effectively distinguish between magnetizing inrush current and internal fault current in a power transformer. This neural model is trained to recognize patterns based on statistical features extracted from the current signals. The **trained weights**, representing long-term memory of the network, are utilized at the processor level to make real-time classification decisions regarding the nature of the disturbance.

The overall procedure for online detection and classification of transformer conditions using the proposed algorithm is illustrated in Figure [X]. The step-by-step implementation is described below:

- **Step 1:** One complete cycle of both primary and secondary current waveforms is captured using a real-time data acquisition system.
- **Step 2:** The **differential current** is computed using the relation:  

$$Id = Ip - Is$$

$$Id\_d = I\_p - I\_s$$
 where  $I_p$  is the primary current and  $I_s$  is the secondary current.
- **Step 3:** The **RMS value** of the differential current is calculated. If the RMS value is below a predefined threshold, the system concludes that no abnormal condition exists and returns to Step 1 for continued monitoring.
- **Step 4:** If the RMS value exceeds the threshold, the **Discrete Wavelet Transform (DWT)** of the differential current is computed to capture transient and non-stationary characteristics of the signal.
- **Step 5:** From the DWT, **statistical parameters** such as mean, standard deviation, skewness, and kurtosis are extracted from the first decomposition level (d1). These parameters provide a concise representation of the signal's behavior during the event.
- **Step 6:** The extracted parameters are then fed into the **Artificial Neural Network (ANN)** as input features. The ANN, trained on known cases of inrush and fault conditions, classifies the current disturbance accordingly.
- **Step 7:** If the ANN classifies the condition as an **internal fault**, a **trip signal** is issued to the circuit breaker to isolate the transformer. If the condition is identified as **inrush** or **healthy**, the system continues monitoring the differential current for any further disturbances.

This intelligent approach leverages the power of neural networks and wavelet-based signal analysis to ensure accurate and efficient discrimination between inrush and fault currents, thereby enhancing the reliability of transformer protection schemes.

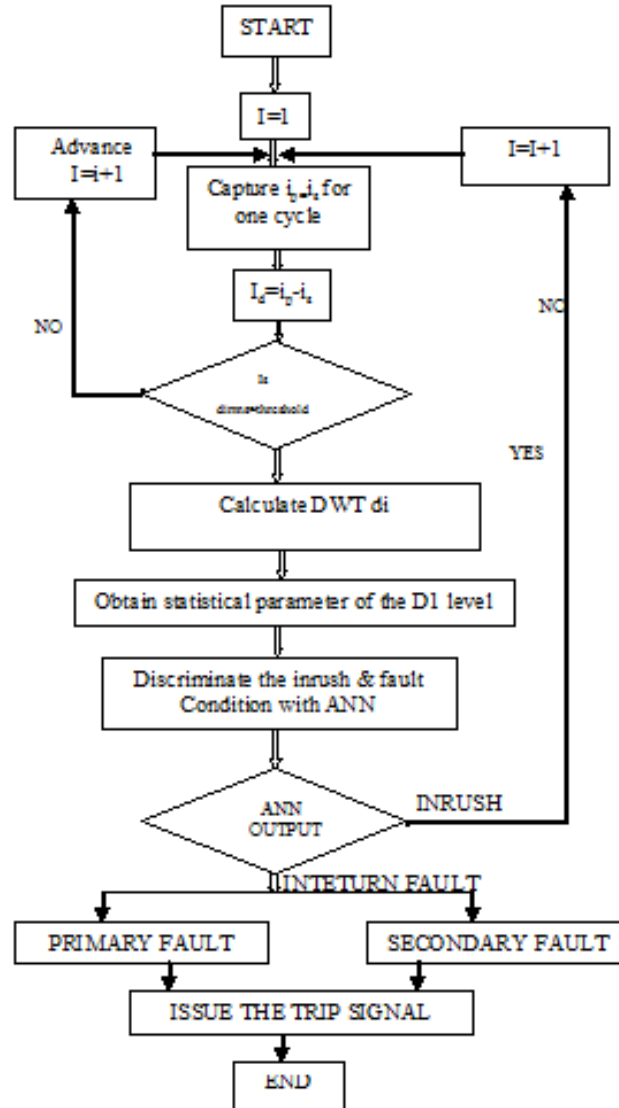


Figure 2: Flowchart for On-Line Detection Scheme

#### 4. SIMULATION RESULTS

Neural networks possess the capability to execute massively parallel computations, which significantly enhances their processing speed and efficiency. Additionally, they exhibit fault tolerance, as information is distributed across the network's interconnected structure. This characteristic allows the system to continue functioning even if some nodes or connections are compromised.

In the context of control systems, the implementation of a Neural PI (Proportional-Integral) controller offers notable advantages over conventional PI controllers. Specifically, it reduces peak overshoot and ensures a faster settling time, thereby improving the dynamic performance of the system.

The following MATLAB script outlines the procedure to create and train a feedforward neural network using provided input (i) and output (o1) datasets:

```

% Load input and output datasets
load n
% Normalize input and output data
k1 = max(i');
k2 = max(o1');
P = i' / k1; % Normalized input
  
```

```
T = o1' / k2; % Normalized target output
% Define neural network architecture
net = newff(minmax(P), [5 1], {'tansig', 'purelin'});
% Set training parameters
net.trainParam.epochs = 200;
% Train the network
net = train(net, P, T);
% Simulate the network output
Y = sim(net, P);
% Plot the target and simulated outputs
plot(P, T, P, Y, 'o');
% Generate a Simulink block from the trained network
gensim(net, -1);
```

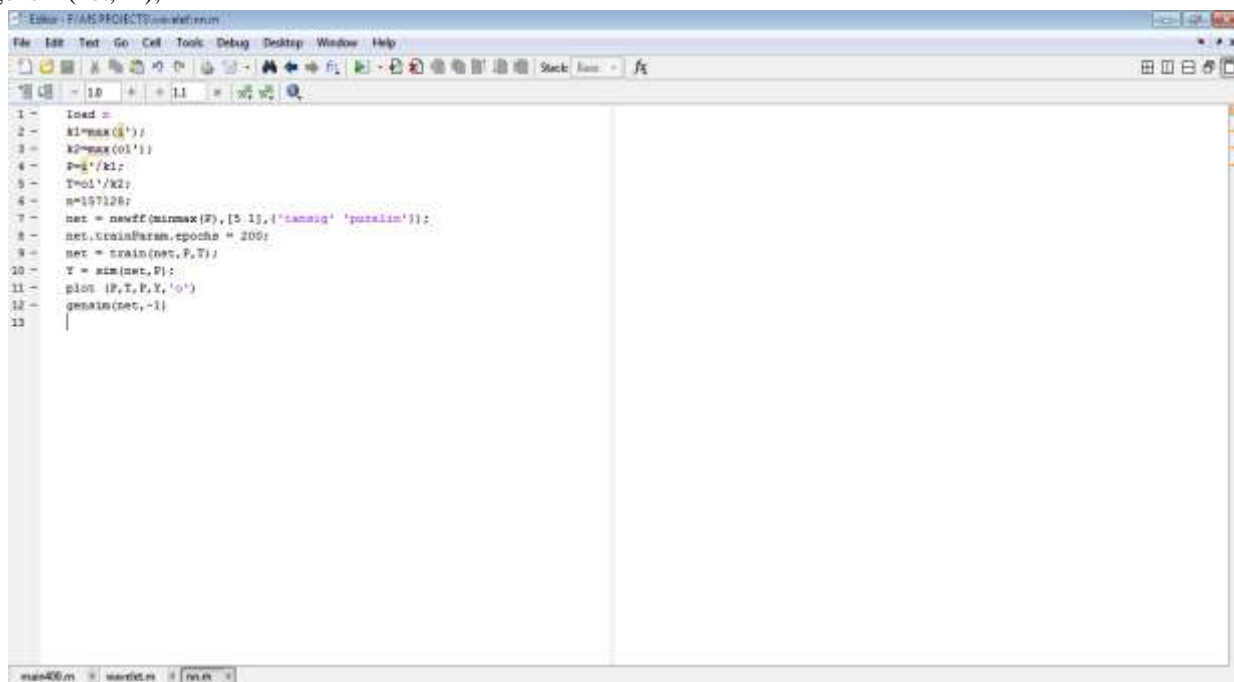


Figure 3: ANN M-File Program

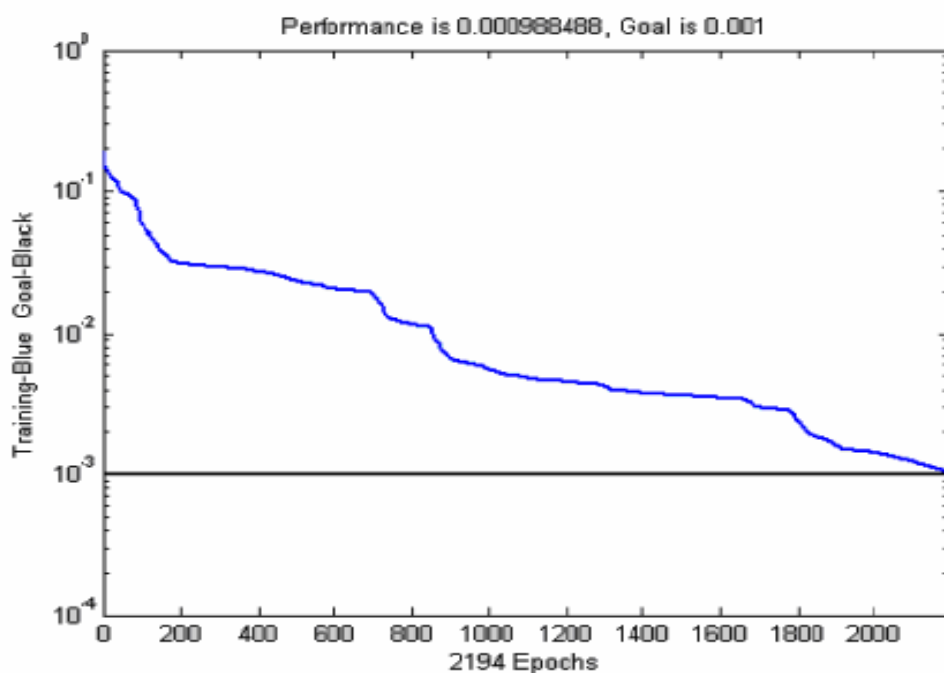
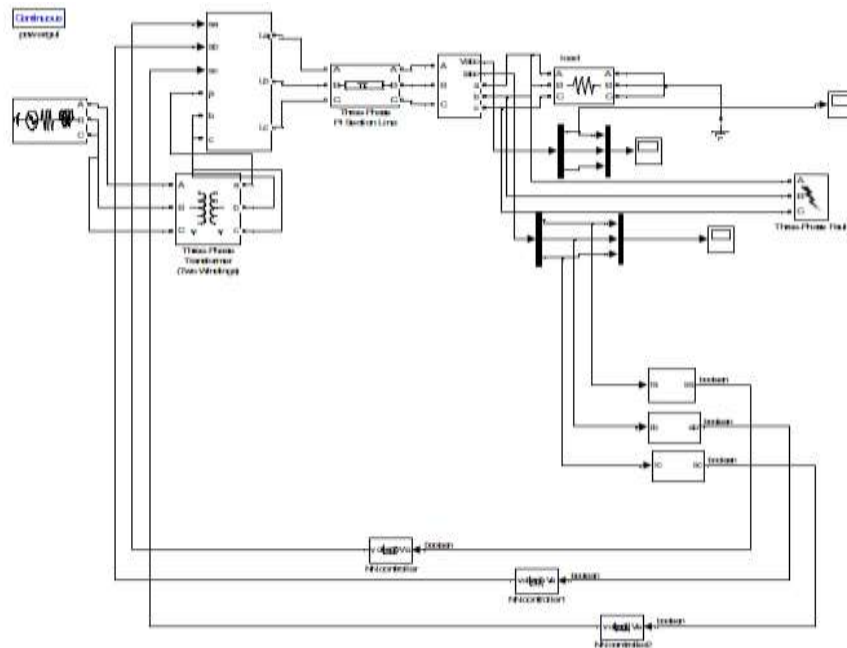
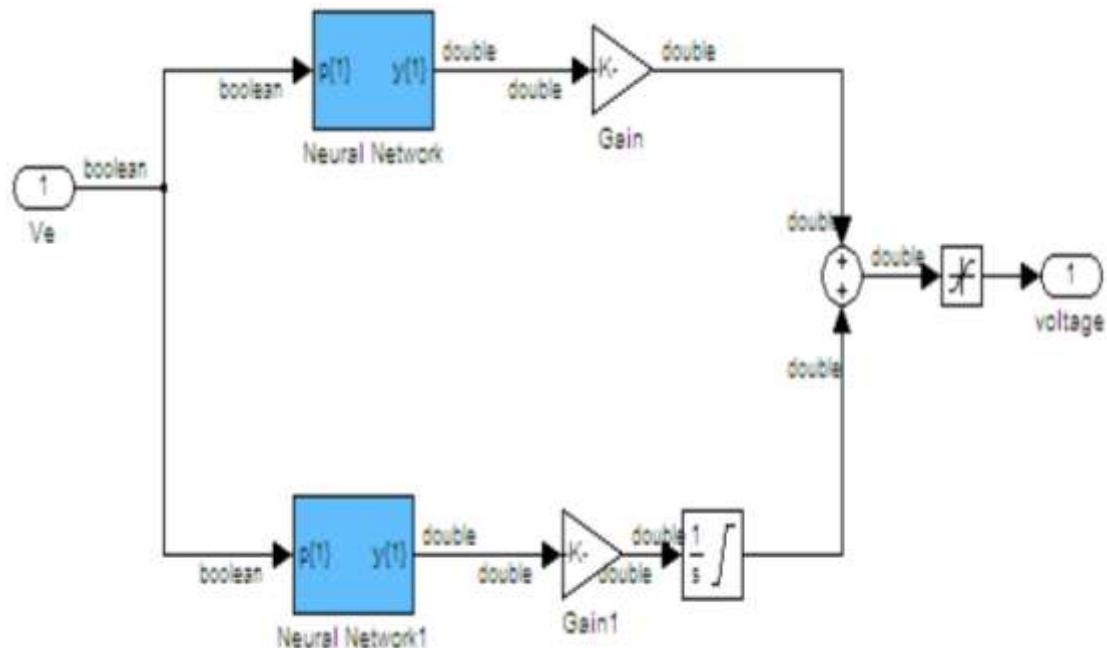


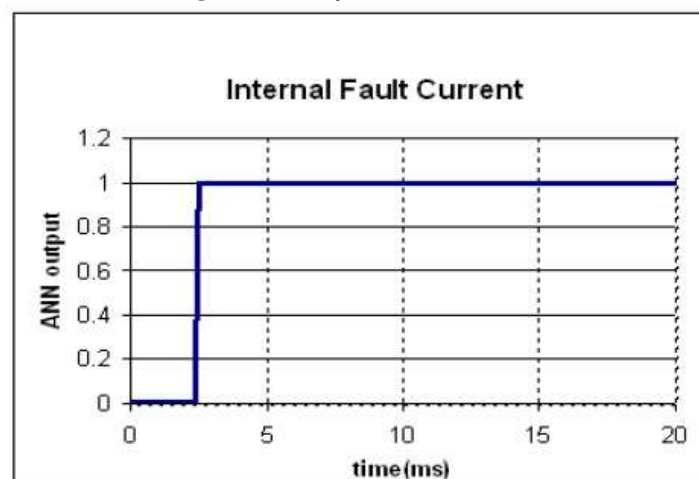
Figure 4: Training Epochs of ANN



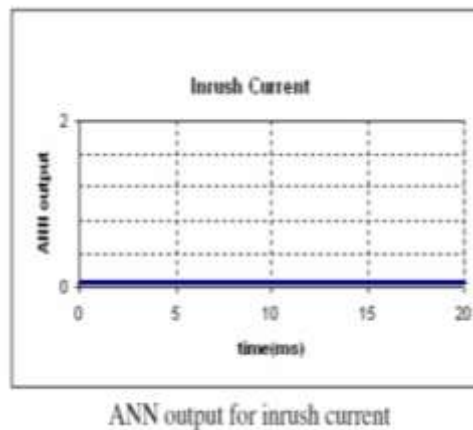
**Figure 5: Simulation Model with ANN**



**Figure 6: Subsystem Model of ANN**



**Figure 7: ANN output for internal fault current**



**Figure 8:** ANN output for inrush current

## 5. CONCLUSIONS

A new method is proposed to distinguish magnetizing inrush current from inter-turn faults in transformers using Wavelet Transform to extract time-frequency features from differential current signals. These features serve as inputs to an Artificial Neural Network (ANN), which accurately classifies the events in less than one cycle after initiation. The method performs reliably under varying conditions such as fault angle, resistance, and system parameters. In case of misclassification, the new event data can be added to the training set, and the ANN retrained to improve accuracy and adaptability.

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