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Development of an Adaptive DWT Model for Classifying Internal Faults in Extra High Voltage Power Transformer

[1]Vincent. A. Chukwu, [2]Innocent. I. Eneh

[1]Transmission Company of Nigeria, Project Implementation Unit, CHQ, Abuja

[2]Department of Electrical and Electronic Engineering, Enugu State University of Science and Technology, Enugu.

[1]engrvinchukwu@gmail.com, +2348036684300, [2]innocent.ifeanyichukwu@esut.edu.ng, +2348037131319

ABSTRACT

Differential protection relay failure results in damage to Power Transmission equipment and in many cases leading to fire outbreak, human injuries and loss of lives. Effective network protection requires intelligence and proactive measures. Internal faults are one of the most critical types of power transformer faults. This is because they occur in the windings of the transformer and can lead to serious damage in the windings if urgent steps are not taken. Fault severity varies from type to type. Understanding early enough the type of internal fault that is on the transformer will go a long way in taking quick and accurate decision to resolve the fault. This study therefore presents the development of an adaptive DWT model for classifying internal faults in Extra High Voltage Power Transformer. The approach adopted for this research was to first model the case study transmission network (Onitsha - New Haven 330kV) in Simulink. The DWT system was modeled in simulink to decompose the differential fault signals from the transformer. An ANN controller was then created and trained to help discriminate between the decomposed signals. The developed ANN-based DWT (ADWT) differential protection scheme is the connected to the simulink model of the case study network. The integrated system is then integrated to evaluate the performance of the proposed model. Simulation results showed that out of 15 fault event, the proposed adaptive DWT protection scheme correctly classified 14 internal fault events. This gives a performance of 93.33% accuracy in fault classification. This impressive classification performance can be attributed to the capacity of the DWT system to create major differences in the fault and normal signal pattern and the ability of the ANN to take advantage of this variation in signal pattern to learn and categorize fault signals with a very high accuracy.

Keywords: Discrete Wavelet Transform (DWT), Internal Fault, Artificial Neural Network (ANN), Differential protection Relay, Fault- Classification & Detection, Simulation & Modelling

I. BACKGROUND OF THE STUDY

Electric power system structure generally consists of generators, transformers, and transmission and distribution lines. Many fault conditions like short circuit and other abnormal conditions often occur on a power system creating instability, failure of equipment as well as death in some cases. When there is heavy current associated with short circuits, damage to equipment is likely to occur where a suitable and functional protective relay and circuit breakers are not provided for the protection of each section of the power system (Ram, 1996).

Differential protection relay failure results in damage to Power Transmission equipment and in many cases leading to fire outbreak in most cases. The multiplying effect ranges from loss of revenue, death/body injuries of personnel in most cases. The average life span of transformer is thirty to forty year and for this to be achieved a robust differential protection relay operation must be in place. This is to protect and prevent loss of transformer in the power system when fault associated with abnormal current occurs. Power delivery therefore should be continuous and should be maintained at all time in synchronize with the generating station and distribution network. For EHV power transformer to continue to deliver electricity there is need for the transformer protection differential relay to be working optimally. Non protected occurrence of fault result in system collapse making the transformer to be out of service hence sustainability cannot be guaranteed. Security challenges remain one of the major challenges anywhere in the world including Nigeria. This issue presents itself when power transformer is out of supply resulting in such area or region to experience darkness, fears, danger to life, unsafe environment and general increase in criminality. The economic impact of the malfunctioning of the differential protection relay is significant. The ripple effects include loss of jobs, increased youth restiveness, wastage of resources and increased cost of living. Manufacturers will have to find alternative means of production, leading to increased cost and overall production expenses. Consequently, there will be a drop in Gross Domestic Product (GDP).

Power transformers are frequently subject to a variety of electromagnetic transients during their operating lifespan. These impose stresses in windings and other components that may lead to immediate or long-term failure (Avendañ, 2011). Internal faults develop as a consequence of these overstresses and its negative impact on the equipment and power stability and security can be enormous. Transformer internal faults need not only be detected but also need to be classified to know the type of internal fault and its impact on the network. This will greatly help in quick resolution of the fault situation in a manner that minimizes the number of feeders to be lost during the course of restoring the system. Historical data obtained from this classification will help power system operators put up proactive measures that will help prevent internal faults in power transformers. Unfortunately, the existing differential relays on transformer differential protection schemes lack the needed intelligence to classify internal faults as it can only be set to give two outputs, 0 and 1, indicating absence or presence of fault respectively. Development and simulation of an adaptive model for accurate classification of transformer internal faults can become an important tool for the implementation of adequate protection schemes. This paper therefore proposes an ANN based-Discrete Wavelet Transform (ADWT) for classifying internal transformer faults in EHV networks.

2.0 LITERATURE REVIEW

2.1 POWER SYSTEM PROTECTION

The main focus of power system protection is to provide isolation of a problem area in the system quickly, so that the disturbance perceived in the rest of the system is minimized. Disturbance in the power system is a significant concern for many electric utilities due to its impact on the operation and damage to vital equipment in the power system**.** The power electric system has to assure a high level of reliability in the supply of electricity, although faults are most likely to occur from time to time due to internal or external factors that affect the system (Maria, 2020). Short circuit is a condition in which when an electrical current takes an unintended path with little or no electrical resistance. When a short circuit happens, a large amount of current can flow through the circuit. The large fault current generated could de-shape and damage power supply facilities (Şirketi, 2023).

The electric power system is protected from different types of faults by a relay initiation of signal to circuit breakers contacts so as to opens the affected circuit within the network and isolate the affected system area during the electrical fault condition. These relay senses the voltages and currents change due to the electrical fault on electric network. It is important that any system faults are detected and cleared, and other mitigating actions are taken as quickly as possible. These faults include but not limited to; short circuits between adjacent lines or between a transmission line and the ground, these kinds of faults are often associated with very high currents occurring in several orders larger than the steady-state operating currents and if allowed to persist, may cause thermal and/or mechanical damage to equipment.

Protection systems are included in power systems in a pessimistic and pragmatic approach to sense the fault and initiate a trip, or disconnection of the affected equipment or zone. Relays basically have two major operations; when the relay fails to operate during fault condition and operation when there is no fault condition.

2.2 TRANSFORMER PROTECTION ON POWER SYSTEMS

The transformer is protected from faults by a combination of protection schemes most notably the Over-current and Differential current system will use protective-relaying techniques to monitor Current magnitude, angle and compare to reference values to determine if a fault is present in the system. Other protection schemes like the Harmonic restraint relaying technique will analyze the waveform of the current and voltage signals and check them for abnormal harmonics which are present in the system during a fault. The relay has been an essential component in designing most protection systems, some other protection methods are focused on improving the relay, making it intelligent utilizing mathematical wave analysis tools like the Clark transform to analyze fault conditions correctly and make early responses if a fault within its protective zone (Padam, 2019). In this thesis therefore emphasis will be on the differential protection relays of EHV transformer.

2.3 DIFFERENTIAL PROTECTION ON EXTRA-HIGH VOLTAGE TRANSFORMERS

Figure 2.1 shows a typical differential relay connection diagram for the protection of power transformers. In this figure, the connections of current transformers (CTs) with the primary and secondary branches are shown, the ratio Np:Ns is the turn ratio between the primary and secondary windings of the transformer. In the case of internal faults, the

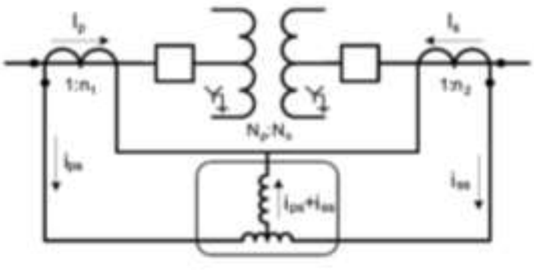

Figure 2.1: Schematic diagram of differential protection in Transformer

Difference between these currents becomes significant causing the differential relay to trip. The differential current (also called operating current) id can be obtained as the algebraic sum of currents entering and leaving the protected zone and it provides a sensitive measure of the fault current. In such event of a confirmed fault the relay sends a trip signal to the circuit breaker when the differential current is greater than a percentage of the preset restraint current.

2.4 THEORY OF TECHNIQUE

DISCRETE WAVELET TRANSFORM

Discrete wavelet transform (DWT) was defined by Hosseinzadeh (2020), as a system that decomposes a particular signal into a number of groups, where each set is a time series of coefficients describing the time progression of the signal in the matching frequency band. This approach in using this technique is to identify and classify these signal or fault in power system in both time and frequency domain. Temporary over-voltages (TOVs) are little damped or totally undamped power-frequency over-voltages of comparatively long interval (that is, seconds, even minutes). TOVs are typically triggered by faults to ground, resonance situations, load rejection, energization of unloaded transformers, or a combination of these (Martinez-Velasco, 2012). The wavelet transform approach can be used to identify and classify these transient faults in the power system. It should be noted that wavelet is a short duration oscillatory waveform with zero average value which decays very fast to zero amplitude as shown in figure 2.5. Fault in power system have similar slowly changing trend associated with transient and rapidly decaying wavelike oscillation that has zero mean.

Wavelet decomposition is a protective relaying which breaks up the signals into both time and frequency, allowing for a more complete and efficient description of each phase, current and accurate fault detection **Error! Reference source not found.**. Traditional digital protective relays present several drawbacks; for instance, they are usually based on algorithms that estimate the fundamental component of the current and voltage signals neglecting higher frequency transient components, for this reason wavelet decomposition is ideal for studying transient signals and obtaining a much better current characterization and a more reliable discrimination. Wavelets allow the decomposition of a signal into different levels of resolution; an advantage is that it enables one to study the local features of the signal with a detail matched to their characteristic scale. In the temporal domain such a property allows for an effective representation of transient signals. Wavelet technique has already been studied by a lot of authors and shows a great improvement in stability of the system where it is applied.

Discrete Wavelet Transform (DWT) is a mathematical technique for analyzing the transient signal (sudden or momentary variation in current, voltage or frequency which may result due to poor quality disturbance or fault in the system. As a mathematical tool, wavelet can be used to extract information from these transient signals by decomposing the signal into its components or scales or frequency band using low band and high band filters. Low pass filter will result in approximate coefficient of the original signal. High pass filter will provide the detail coefficient

The multi stage filter bank can be used to completely decompose the disturbance into different levels of low and high band for proper identification and classification.

2.5 REVIEW OF RELATED WORKS

Ram (2020) in his work “Digital Image Watermarking Technique Using Discrete Wavelet Transform and Discrete Cosine Transform,” demonstrated a novel approach to watermarking digital photos with hidden text. His proposal is a new technique for digital picture watermarking that does not rely on the original image for watermark identification, and it functions in the frequency domain by embedding a pseudo-random sequence of real numbers in a chosen set of DCT coefficient. To make sure the watermark can't be removed, it's embedded in strategically chosen coefficients that contain a lot of energy from the image in the transform domain. The advantages of his suggested method include increased resilience to attacks on the watermark, an improved specification for the threshold that verifies the watermark, and implicit visual masking using the time-frequency localization property of the wavelet transform. He found that the proposed method was resistant to a wide range of geometric distortions and signal processing methods.

Fu et al. (2021) in their work “DW-GAN: A Discrete Wavelet Transform GAN for Non-Homogeneous Dehazing,” pioneered the use of the 2D discrete wavelet transform to create a unique dehazing network (DW-GAN). The authors, in particular, proposed a two-branch network to address the aforementioned issues. Their proposed method is able to maintain more high-frequency information in feature maps because of the use of wavelet transform in the DWT sub-tree. In order to minimize artifacts in the recovered photos, the authors ultimately employed a patch-based discriminator. Extensive experimental results show that their proposed strategy qualitatively and quantitatively outperforms the state-of-the-arts.

Zhao and Zhang (2016) worked on Artificial Intelligence Application in Power System; the research on artificial intelligence in power system operation also focused on transient protection, through the use of discrete control and the continuous control. This work highlighted the basic AI concepts that were commonly applied in Power system operation for different reasons, most notably the artificial neural network (ANN) which arises from the perspective of simulated neurons that processed information using nonlinear mapping method (Zhao & Zhang, 2016).

3. METHODOLOGY

3.1 DESIGN METHOD

The approach adopted for this research was to first model the case study transmission network (Onitsha - New Haven 330kV) in Simulink. The DWT system was modeled in simulink to decompose the differential fault signals from the transformer. An ANN controller was then created and trained to help discriminate between the decomposed signals. The developed ANN-based DWT (ADWT) differential protection scheme is the connected to the simulink model of the case study network. The integrated system is then integrated to evaluate the performance of the proposed model.

3.2 DEVELOPMENT OF A SIMULINK MODEL OF THE CASE STUDY NETWORK

The line and bus parameters (line resistances and reactance, bus voltages and loads) of the Enugu-Onitsha transmission network are first obtained from TCN, Enugu. The parameters are shown in table 3.1. Simulink block of the various power system components that make up the protection scheme was first sourced from simscape library in simulink. The components were then copied into a fresh model work space. The components were linked together accordingly and then configured to reflect the parameter values obtained during characterization.

The developed simulink model of the case study network is shown in Figure 3.1.

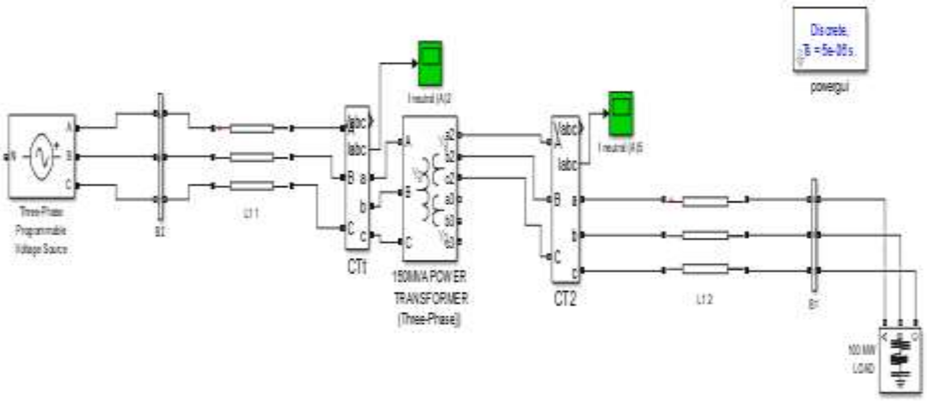

Figure 3.1: developed simulink model of the case study network

3.3 DEVELOPMENT OF A SIMULINK MODEL OF THE DISCRETE WAVELET TRANSFORM (DWT) FOR DECOMPOSING THE FAULT CURRENT SIGNALS.

The research project utilized the discrete wavelet transform system to distinguish between internal faults within the transformer and external faults. The discrete wavelet transform (DWT) is a sub-band coded system known for its ease of implementation and rapid calculation. It involves the use of analysis filters (specifically low-pass h(n) and high-pass g(n) filters) to decompose a digital signal. In the process, the original signal x[n], along with the low-pass filter h[n] and high-pass filter g[n], undergoes a first-stage decomposition, where the signal is split into two frequency bandwidth halves and passed through the respective filters. The output of the low-pass filter, known as coarse or approximation coefficients, is then subjected to a similar process, dividing the signal into two frequency bandwidth halves and filtering as in the initial stage. This iterative process continues until the signal has been decomposed to a predetermined level. The set of signals produced though still a representation of the same base signal belongs to different frequency bands. The output of the high-pass filter is called detail coefficient. Detail coefficients at level 1 and approximation coefficients at level 1 are presented in equations 3.1 and 3.2 respectively

$$d^1[n] = \sum_{k=0}^{n} x[k]h[n-k] \quad \text{.......................} (3.1)$$

$$a^1[n] = \sum_{k=0}^{n} x[k]g[n-k] \quad \text{.......................} (3.2)$$

3.4 IMPLEMENTATION OF THE DWT IN SIMULINK

The realized simulink model of the filter bank built discrete wavelet transform system is shown in figure 3.2. The elementary constituent blocks used in the development of the DWT simulink model include: high-pass filter, ‘‘from workspace’’ block, “to workspace’’ block, low-pass filter, down sample block.

The above specified blocks were obtained from simscape library in simulink. The blocks are the interconnected as shown in the DWT schematic diagram of figure 3.2. The blocks are then configured and the model workspace saved as an MDL file. The developed simulink model of the DWT system is shown in figure 3.3

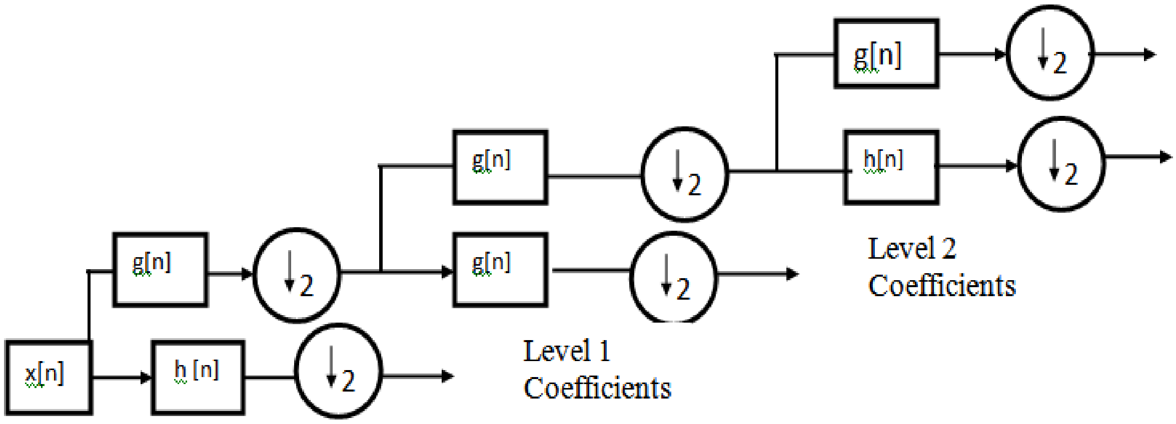

Figure 3.2: Schematic diagram of a DWT System.

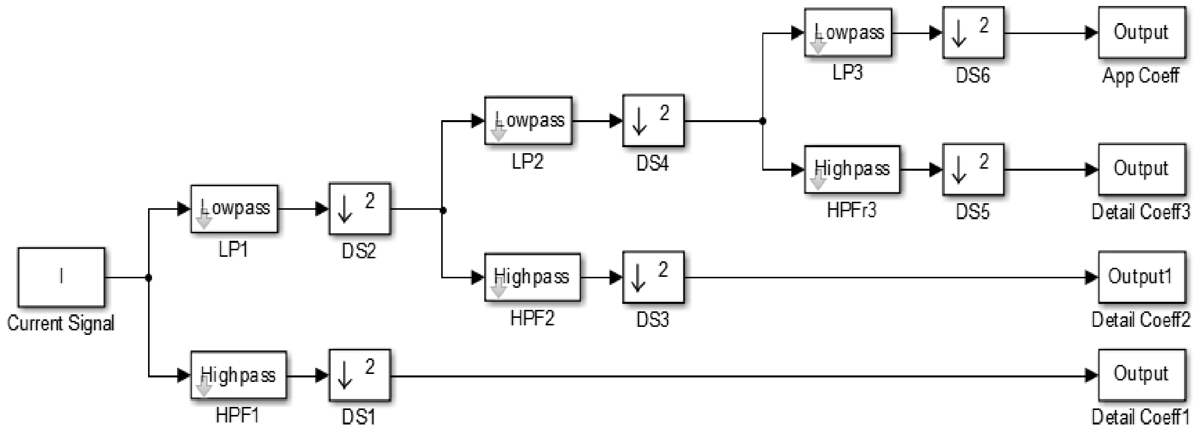

Figure 3.3: Simulink model of the DWT System.

3.5 DEVELOPMENT OF AN ADAPTIVE SYSTEM (ANN CONTROLLER) TO MAKE THE DIFFERENTIAL PROTECTIVE RELAY INTELLIGENT.

ANN Development Strategy

The application for fitting neural networks was utilized to generate, train, and implement the ANN model for detecting and categorizing various faults in transformers. This fitting application can accurately map numeric inputs to outputs, ensuring a high degree of accuracy. However, it is essential to thoroughly train the ANN model with an appropriate volume of data. This fitting application serves as a platform for training the neural network to recognize input-target patterns, utilizing a dataset that describes the state or states of a system and the corresponding target data. By doing so, when presented with additional input data for the same system, the network can predict the output with a high level of accuracy. The accuracy of the predictions is influenced by the volume and quality of the training data, as well as the level of training. A larger volume of data leads to higher accuracy

Generation of Training Data

. The training data is created by passing a differential current signal through the modeled DWT system and then computing the key variables of the approximation coefficients. These three variables are recorded for different scenarios of each type of fault, which include single phase to ground, double phase to ground, and three phase fault. Each type of internal fault has five fault levels, simulated by varying the fault resistance, resulting in five different fault signals for each type of fault. The aim is for the developed ADWT model to identify the specific type of internal fault encountered. The mean value, maximum value, and normalized value of each fault signal are then calculated to form the input of the ANN. Additionally, three different binary codes are used to represent the three different types of faults being considered: 001, 010 and 100 representing single line, double line and three phase faults respectively.

The architecture of the developed ANN model is presented in figure 3.4. The model has 3 inputs (mean, max and norm values of the decomposed fault signals) and 1 target (which is 001, 010 or 100 representing single line, double line and three phase faults respectively). The training data is presented in table 3.1.

The mean value, the maximum value and the normalized value of each of these fault signals are then calculated to form the 3 inputs of the ANN. The binary code (specified earlier) that correspond to each set of input data represents the single target in the training dataset.

Table 3.1: ANN training data

INPUT DATA			**TARGET DATA**
mean	**max**	**Norm**	
-0.0008221	2.348	614.5	P01
-0.0005531	2.152	560.6	P11
-0.00009698	1.5956	413.1	P22
0.00004458	1.201	313.9	P33
0.00008405	0.9598	253.1	P44
0.0004886	11.35	3564	R01
0.0003306	7.871	3082	R11
0.002342	3.404	1674	R22
0.001831	1.973	985.4	R33
0.001468	1.376	692.2	R44
0.0000008515	11.78	6041	Q01
0.0000007872	8.143	5288	Q11
0.0000005011	3.743	2825	Q22
0.0000005239	2.147	1666	Q33
0.0000005192	1.496	1154	Q44

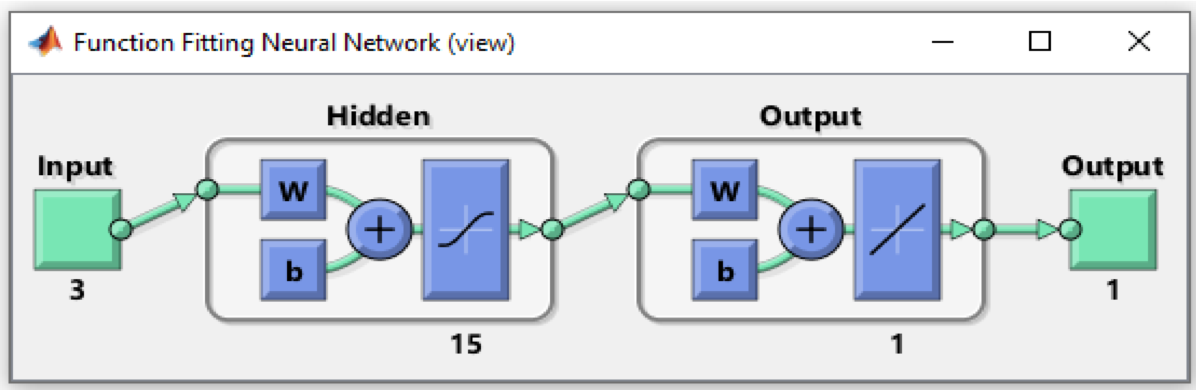

Figure 3.4: Architecture of the trained ANN model

The ANN architecture of figure 3.4 has 3 input layers, 15 hidden layer and 1 output layer. The regression plot of the trained ANN presented in figure 3.5 showed an overall accuracy of 95.1% in training, testing and validation.

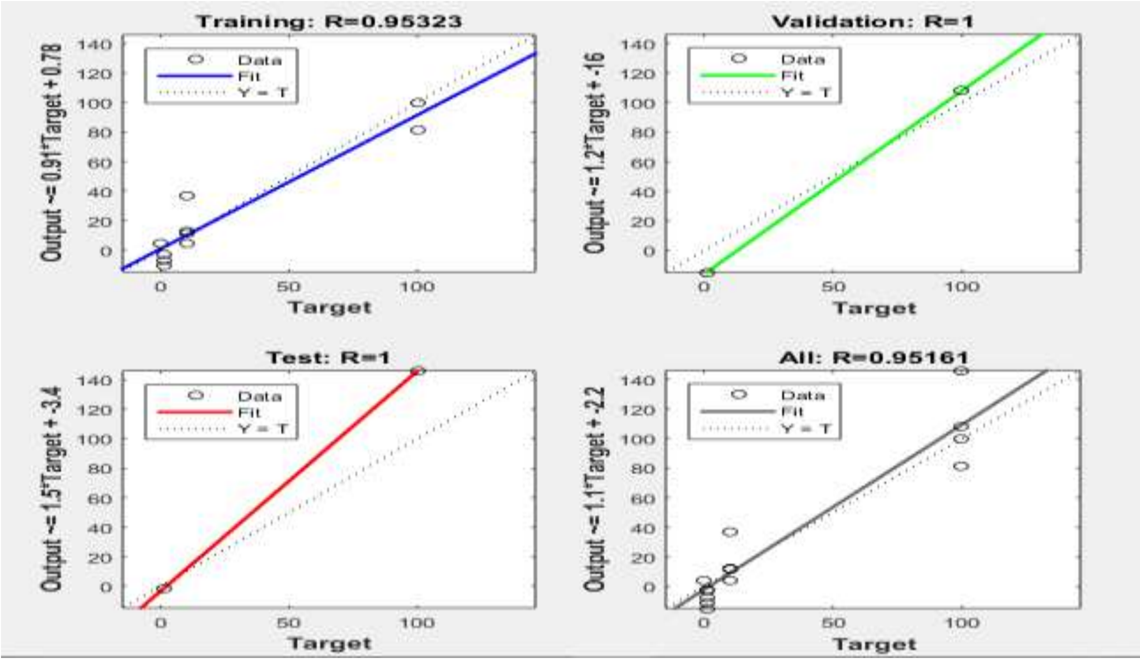

Figure 3.5: ANN training regression plot

3.6 SIMULATION AND RESULTS

The DWT decomposed signals for the three internal fault types and presented in figures 3.6 to 3.8.

After training and modeling of the ADWT system, it was integrated into the case study network and then simulated under conditions of the three internal faults under study to evaluate its accuracy. The result obtained from the simulation is presented in table 3.3 while the integrated model of the entire system is presented in figure 3.8.

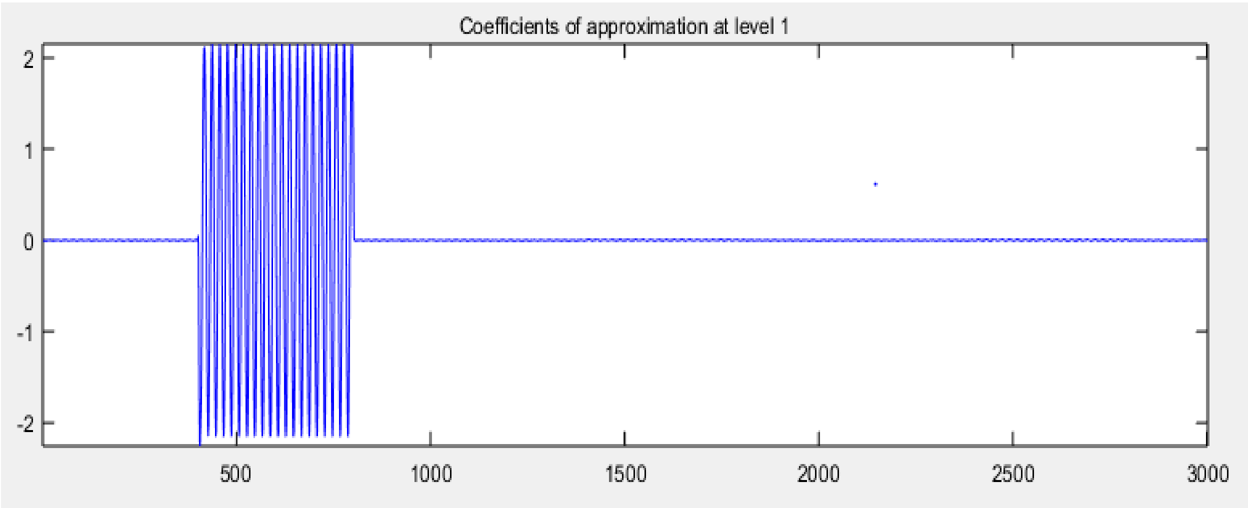

Figure 3.6: DWT decomposed signal (Coefficient of approximation) for Single phase to ground fault.

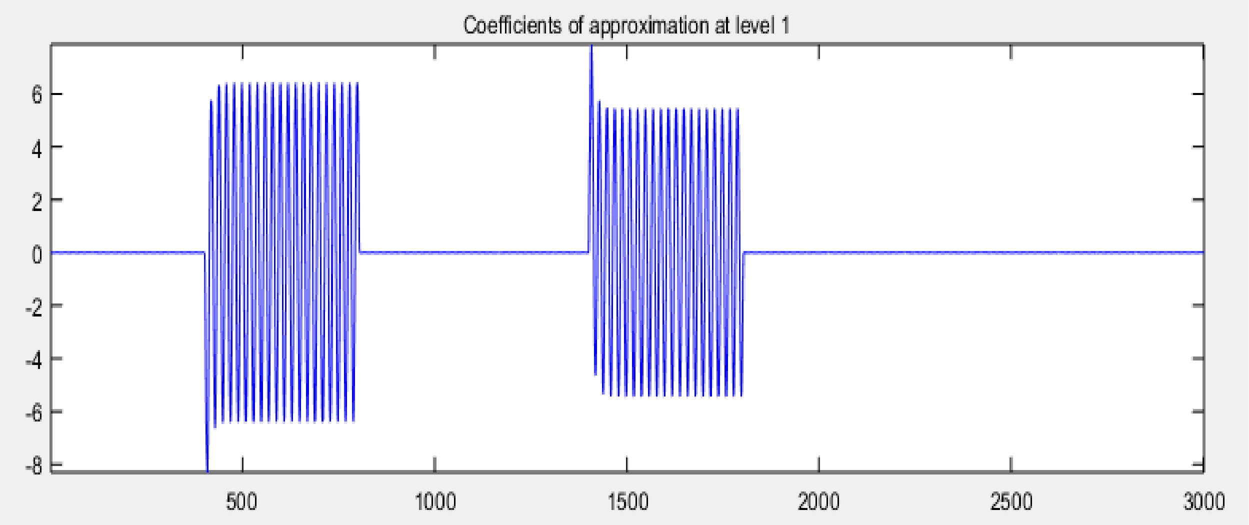

Figure 3.7: DWT decomposed signal (Coefficient of approximation) for double phase to ground fault.

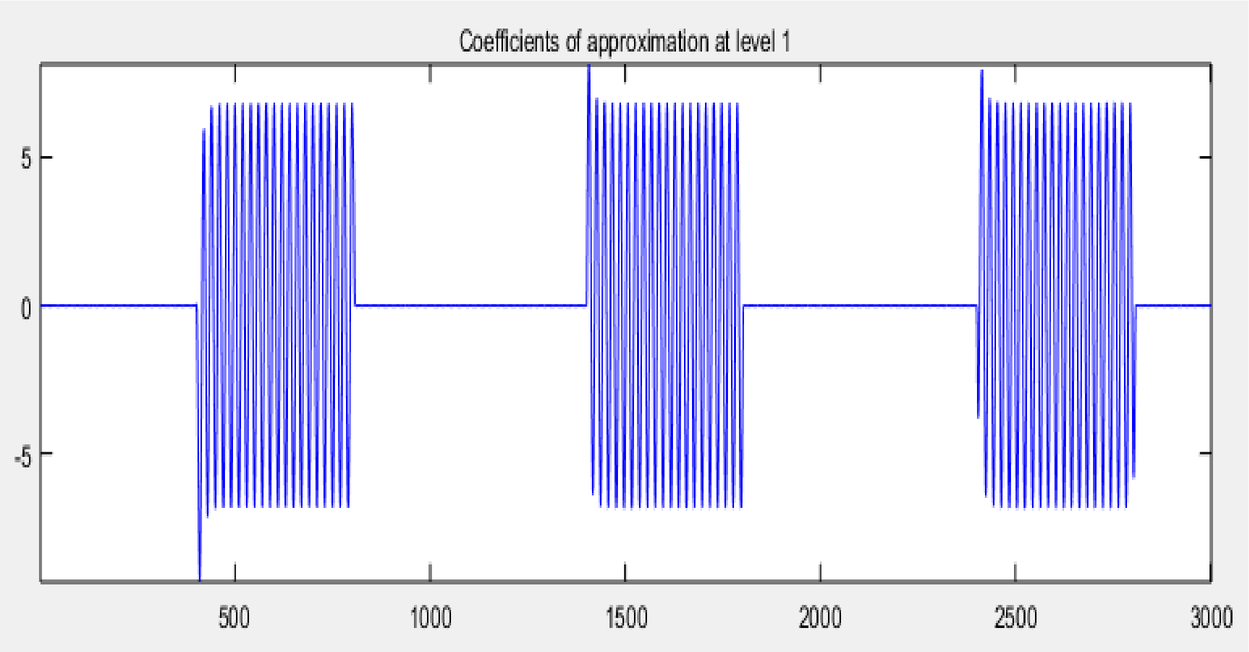

Figure 3.8: DWT decomposed signal (Coefficient of approximation) for three phase to ground fault.

Observe the difference in figures 3.6 to 3.8 as regards the number of wave spikes contained in each signal. This clear difference helped in separating and classifying the three types of internal fault under consideration.

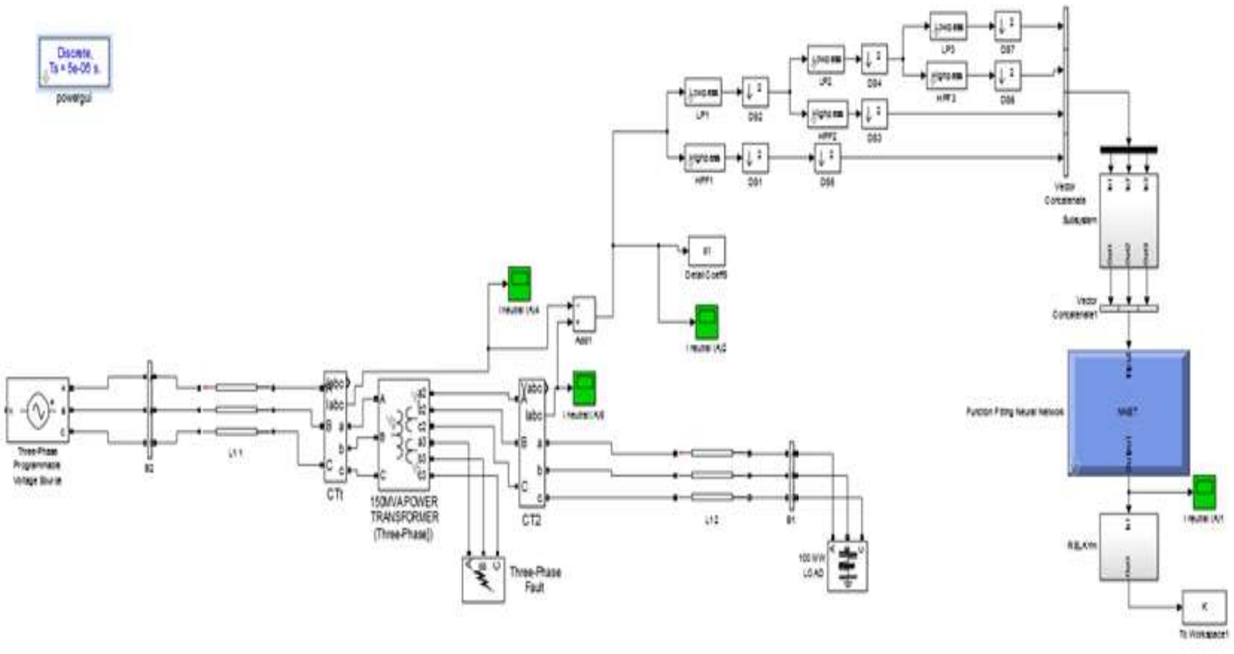

Figure 3.9: Model of the system integrating the ADWT model to the case study network

Table 3.2: Internal fault classification result Obtained from Proposed system

FAULT EVENTS	**FAULT STATUS**		
	ADAPTIVE DWT SCHEME OUTPUT	**ACTUAL STATUS**	**REMARK**
1	001	001	Correct
2	001	001	Correct
3	001	001	Correct
4	001	001	Correct
5	001	001	Correct
6	010	010	Correct
7	010	010	Correct
8	010	010	Correct
9	010	010	Correct
10	**000**	**010**	**Wrong**
11	100	100	Correct
12	100	100	Correct
13	100	100	Correct
14	100	100	Correct
15	100	100	Correct

From table 3.2, it can be seen that out of 15 fault event, the proposed adaptive DWT protection scheme correctly classified 14 internal fault events. This gives a performance of 93.33% accuracy in fault classification. This impressive classification performance can be attributed to the capacity of the DWT system to create major differences in the fault and normal signal pattern and the ability of the ANN to take advantage of this variation in signal pattern to learn and categorize fault signals with a very high accuracy.

4. CONCLUSION AND RECOMMENDATION

It can be concluded that ANN based adaptive Discrete Wavelet Transform differential protection scheme is effective in fault classification of 330kV/132kV Transformer internal fault at New Haven-Onitsha transmission network. It is recommended that ANN based adaptive Discrete Wavelet Transform differential protection scheme be installed at all buses in 330kV grid network to offer improved transformer protection. It is also recommended that other intelligent agents be used to see if they can offer better improvement in fault location of transmission line faults.

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