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Improving Accuracy of Fault Detection in Power Transformers using Artificial Neural Network Based Digital Relay

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Abstract— This paper presents a cost-effective technique for improvement of power transformer protection using Artificial Neural Network (ANN) digital relay. The model was developed using MATLAB/SIMULINK and designed to detect faults in power transformers. The simulated results show that the system is 97% efficient and thus can be used to detect fault and other abnormal conditions in power transformers. Hence, Transmission and Distribution Companies can deploy the system in power transformers for efficient and reliable working condition.

Index Terms— Artificial neural network, digital relay, fault detection, power transformer, transformer protection.

1. Introduction

PROTECTION against fault in power systems is very essential and vital for reliable performance. A power system is said to be faulty when an undesirable condition occurs in that power system, where the undesirable condition might be short circuits, over current, over voltage etc.

The purpose of power system protection is to detect faults or abnormal operating conditions such as; short circuits, over current, overvoltage and other related transformer faults, thereby initiating corrective action. Relays are mostly used in power system to detect the fault and take the necessary action to minimize damage to the equipment or to the system. However, it must be able to evaluate a wide variety of parameters to establish that corrective action is required, it cannot prevent the fault. The Protective relays require reasonably accurate reproduction of the abnormal and normal conditions in the power system for correct sensing and operation.

Furthermore, for the past several years, fuses, circuit breakers and electromechanical relays were used for the protection of power systems. The traditional protective fuses and electromechanical relays present several draw backs. Alternatively, some researches were conducted on relay which can be interfaced with microprocessors in order to eradicate the drawbacks of the traditional protective techniques, which led to many improvements in transformer protection in terms of better reliability, improved protection and control.

This paper examines a low cost technique using an artificial neural network-based digital relay which provides a more reliable, faster and accuracy in fault detection.

Large power transformers belong to a class of very expensive and vital components in electric power systems. A power transformer needs continuous monitoring and fast protection as it is a very expensive piece of equipment and an essential element in an electrical power system. If a power transformer experiences a fault, it is necessary to take the transformer out of service as soon as possible so that the damage is minimized [1].

The costs associated with repairing a damaged transformer may be very high. The unplanned outage of a power transformer can also cost electric utilities millions of naira. Consequently, it is of a great importance to minimize the frequency and duration of unwanted outages. These unwanted outages can be minimized by incorporating very reliable protective relays on power transformer which are capable of accurate fault detection. The commonest protection technique used is the percentage differential logic. This provides discrimination between an internal fault and different operating conditions which can mislead the conventional protection, thereby affecting the power system stability negatively [2].

The work solves the problem of incorrect tripping of the conventional relay by improving the performance of transformer protection using artificial neural networks-based digital relay and MatLab/Simulink. The task of protective relaying is to distinguish between internal faults and normal conditions and consequently, to initiate tripping decision making [3].

ANN based digital relay can provide excellent pattern recognition, the accuracy of the conventional relay that protects the transformer is low, compared to recent

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technological advancements; it lacks accuracy and promptness, sometimes it trips when there is no fault. If the transformer is not well protected with reliable and accurate protective device, the down time may be high and high chances of equipment breakdown. This will make the system unreliable, thereby causing frequent interruption of power for the users and high cost of replacement of equipment for the power company.

2. THEORY/REVIEW OF RELATED LITERATURE

This section presents the theory and review some related literature regarding this work.

2.1. Power Transformers Protection

Merz-Price circulating current principle is the basis for the differential protection used for power transformers. This provides protection against internal phase-to-phase and phase-to-earth faults and is generally used for transformers of rating exceeding 2 MVA as reported in [4]. This protection system as applied to power transformers is fundamentally the same as that for generators but with certain complicating features not encountered in the generator application. Fig. 1 shows the Merz-Price protection system as applied to a star/delta power transformer. The overload protection is provided by the use of overload fuses in the pilot wires between the three pairs of Current Transformers (CTs). When the overload blows a fuse, one of the pair of CTs is disconnected from the relay which receives the current from the remaining CTs. The balance is thus disturbed and the relay operates. Thus a backup protection is provided. .

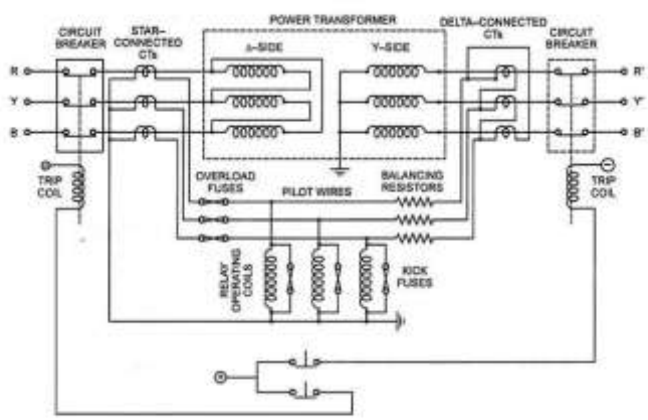

Fig. 1: Merz-Price protection system.

On energizing a transformer, the transient magnetizing current flowing into the transformer may be as large as 10 times the full-load current and it decays relatively slowly. Since the large magnetizing current flows only in primary windings, it causes difference in CTs output and makes the differential protection of transformer to operate falsely. In order to prevent operation of differential protection due to in-rush of magnetizing current, the “kick fuses” are provided across the relay coils, these fuses are of the “time-limit” type with an inverse characteristic and do not operate in short-time duration of the switching-in-surge

Under sustained fault conditions, the fuses operate (blow off) and the full current flows through the relay coils and operate the protection system. This scheme affects the relay setting. To avoid this, arrangements are sometimes made to have the “kick fuses” in circuit only during the period of switching-on. This problem can also be overcome by using a relay with an inverse and definite minimum time characteristic instead of an instantaneous type.

The circulating current protection system also provides protection against inter-turn faults. Short circuit between turns on the same phase alters the turn-ratio of the power transformer and so causes unbalance between CT pairs and make the protection system to operate. However, the change in the turn-ratio of the transformer must be considerable so as to cause flow of sufficient current into the relay to operate. Such short circuits are dealt with more efficiently by Buchholz protection. There are two basic requirements which are to be satisfied by differential relay connections. The differential relay should not operate on overload or external faults, and it must operate on severe internal faults

2.2. Protective Relay

A relay is automatic device which senses an abnormal condition of electrical circuit and closes its contacts. These contacts in turns close and complete the circuit breaker trip coil circuit hence make the circuit breaker tripped for disconnecting the faulty portion of the electrical circuit from rest of the healthy circuit. The protection system operates and isolates the faulty section. The operation of the protection system should be fast and selective i.e. it should isolate only the faulty section in the shortest possible time causing minimum disturbance to the system [5]. Also, if main protection fails to operate, there should be a backup protection for which proper relay co-ordination is necessary. Protective relay works in the way of sensing and control devices to accomplish its function. Under normal power system operation, a protective relay remains idle and serves no active function. But when fault or undesirable condition occurs, Protective Relay must be operated and function correctly. Failure of a protective relay can result in devastating equipment damage and prolonged downtime.

Differential protection relay operates when the phase difference of two or more similar electrical quantities exceeds a predetermined amount. It works on the principle of comparison between the phase angle and the magnitude of the same electrical quantities. For example: when comparing the current entering and current leaving the transmission line, the magnitude of the current entering the transmission line is more than the current leaving it, that means the additional current flows is because of fault. The difference in the current can operate the differential protection relay. The essential condition requires for the working of the differential protection relay is as follows:

1. The network should have two or more similar electrical quantities.
2. The quantities should have the phase displacement of approximately 180º.

What makes a relay to be a differential relay is when the relay is differentiating the current in which the phasor difference between the current entering the winding and the current leaving the winding is used for sensing and relay operation. The differential protection relay principle is used for the protection of the generator, transformer, generator-transformer, feeder (transmission line), large motor, bus-bars etc.

2.3. Artificial Neural Network Based Digital Relay

Around 1980s the digital relay entered the market, the digital protection relays is a revolution step in changing Relay technology [5]. Compared to the electromechanical Relay, the digital relay takes the advantages of the development of microprocessors and microcontrollers. Instead of using analog signals, the digital relay converts all measured analog quantities into digital signals.

In Digital Relay Microprocessors and micro controllers are used in replacement of analogue circuits used in electromechanical Relay to implement relay functions. In Digital relays, AC quantities are manipulated in analogue form and subsequently converted into square-wave (binary) voltages. Logic circuits or microprocessors compare the phase relationships of the square waves to make a trip decision. A microprocessor performs mathematical and/or logical operations on the data to make trip decisions.

Modern power systems are complex networks. The complexity of these networks demands the relays used for protection to be reliable, secure, accurate and short decision making time. With the development of very large scale integrated (VLSI) chips and microprocessors the demand of modern day complex power systems can be fulfilled. Digital relays are programmable information processors instead of torque balancing devices.

In order for a protection relay to operate effectively, it must have the following qualities

I. Reliability: power protection relays should remain inoperative always as long as a fault does not occur. But when a fault occurs, they should respond as quickly as possible.
II. Selectivity: it must only operate on the section that has experienced a fault to avoid unnecessary power outs due to wrong detections. It should also respond only when a fault occurs.
III. Sensitivity: The relaying equipment should be highly sensitive so that it can be relied on to provide the required detection.
IV. Speed: the relaying equipment must operate at the required speed. It should not delay so as to give time for system equipment to get destroyed. It should also not be too fast to cause undesired operation.

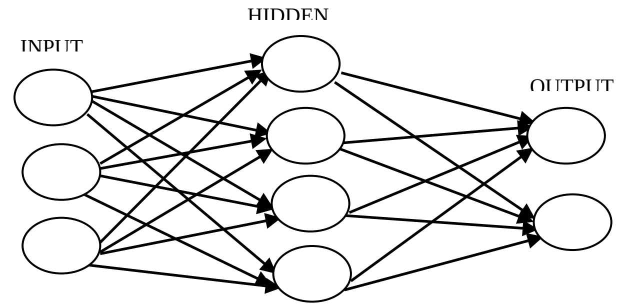

Fig. 2: Artificial neural networks.

Artificial Neural Networks are relatively crude electronic models based on the neural structure of the brain. The brain basically learns from experience. It is natural proof that some problems that are beyond the scope of current computers are indeed solvable by small energy efficient packages [6].

Once a network has been structured for a particular application, that network is ready to be trained. To start this process as shown in Fig. 2, the initial weights are chosen randomly. Then, the training or learning begins. There are two approaches to training; supervised and unsupervised. Supervised training involves a mechanism of providing the network with the desired output either by manually "grading" the network's performance or by providing the desired outputs with the inputs. Unsupervised training is where the network has to make sense of the inputs without outside help. The vast bulk of networks utilize supervised training. Unsupervised training is used to perform some initial characterization on inputs.

Neural Network Toolbox provides functions and apps for modeling complex nonlinear systems that are not easily modeled with a closed-form equation. Neural Network Toolbox supports supervised learning with feed forward networks. It also supports unsupervised learning with self-organizing maps and competitive layers. The toolbox can design, train, visualize, and simulate neural networks. It can also be used for data fitting, pattern recognition, clustering, time-series prediction, and dynamic system modeling and control. They are three algorithms used in neural network toolbox,

I. Levenberg-Marquardt back propagation
II. Mean squared normalized error performance function
III. Default derivative

Levenberg-Marquardt algorithm is specifically designed to minimize the sum-of-square error functions. Mean squared normalized error performance function of an estimator measures the average of the squares of the "errors", that is, the difference between the estimators. MSE is a risk function, corresponding to the expected value of the squared error loss or quadratic loss. This function chooses the recommended derivative algorithm for the type of network whose derivatives are being calculated.

In [7] Transformer Differential Protection with Neural Based In-rush Stabilization was studied and the application of artificial neural network to in-rush discrimination in power transformer was presented. Genetic Algorithm scheme was used in the ANN optimization for current transformer saturation detection module. The result shows that the developed optimized neural in-rush detection units have been tested with generated signals, proving better performance than traditionally used stabilization algorithms.

Artificial Neural Network Based Back up Differential Protection of Generator – Transformer Unit was studied in [8] and aim at improving the overall reliability of differential protection for generator and transformer unit. It uses a pattern classifier for the system. However the ANN-based pattern recognitions method is efficient in solving classification problems and a differential relay can be considered as a classifier which identifies the type of event that occurs on the power system network.

Similarly, in [9] power transformer protection using ANN, Fuzzy System and Clarke's Transform was examined and protection schemes are used to avoid interruptions of the power supply and catastrophic losses. They employ percentage differential logic, which provides discrimination between the internal fault and an external fault or a normal operating condition. The result shows that ANN is able to distinguish between current transformer saturation and operating conditions.

A novel approach to power transformer fault protection using Artificial Network was investigated in [10] and found that artificial neural network has the capacity of resolving the transformer monitoring and fault detection problem which is cost-effective and reliable. The result shows that the ANN is successful in categorizing the type of event and extracted features as input.

ANN Based Distance Protection of Long Transmission Lines by Considering the Effect of Fault Resistance was studied in [11]. And used the ANN based distance method on the long transmission line and counted the effect of the fault resistance. However, they found that it takes more time for training and it can adjust the changing of the network conditions. They used a filter to remove the DC and the harmonics components.

3. Overview Research Methodology

The adopted method of this project (Artificial Neural Network based digital relay) was developed in this section. The simulink model of the test network with its transformer and the conventional relay was also developed in this section. To effectively deliver the objectives of this research, the network was first characterized. The input data for the neural network (three phase network voltage and current) were obtained by simulating the network under fault and normal operating conditions. The target to the neural network can either be zero or one (for fault detection). The creation and training of the ANN was done in simulink Matlab environment using the ANN toolbox. The trained ANN model was then connected to the test network. The performance of the ANN based digital relay was then compared with the performance of the conventional relay.
Different kinds of faults were then artificially introduced in the transformer and network so as to evaluate the performance of the ANN based digital relay. The performance of the ANN based relay was evaluated against the conventional relay based on its accuracy in fault detection.

3.1. Characterization of the Test Network Model

The test network shown in Fig. 3 and is made up of a 330 KV AC source, 150 MVA, 330/132KV three phase transformers, the transmission line of length 96KM medium line impedance and a RLC load rated at 100MW.

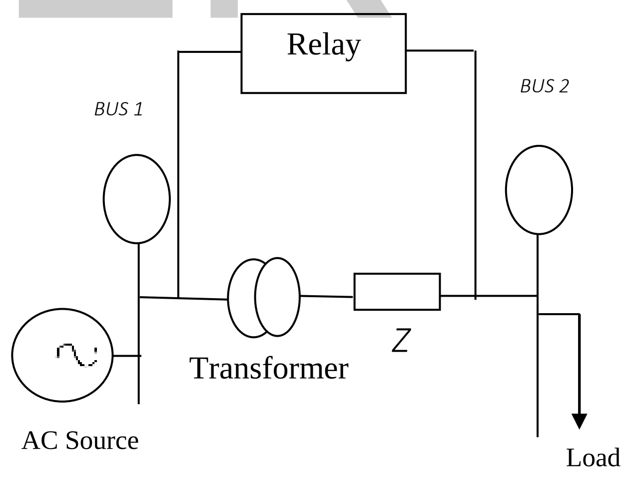

Fig. 3: Schematic diagram of a two bus bar test network.

The AC source, through the transformer is connected to bus 1 while the RLC load is connected at bus 2. The transmission links bus 1 and 2.

3.2. Development of Simulink Model for the Test Network

In developing the simulink model of the test network of Fig. 3 a programmable AC voltage source block was used for the AC voltage source. All components were obtained from the sim power system library. The blocks named above were first copied to a new MATLAB work space, configured to reflect their ratings and then linked up as shown in Fig. 3. The linked model is then saved as a simulink model file. A power system solver is imported into the model space and the entire network debugged to ensure that there are no errors.

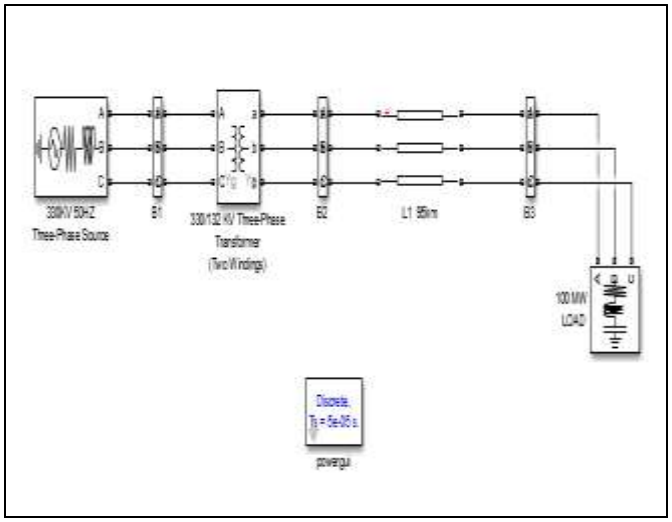

Fig. 4: Simulink model of the test network without relay.

From Figure 4, the features of the network are state below with the rated value of each unit in the network:

AC Voltage Source: 330KV/150MVA, 50HZ
Transformer Rating: 330KV/150MVA, 132KV, 50HZ
Impedance Rating: 96KM, 0.025ohms/KM,
0.93310^{-3}H/KM, 12.74 10^{-9} F/KM
Load Rating: 100MW
Relay Rating: 132KV

3.3. Simulink Model of the Conventional Relay System

The conventional relay system shown in Fig. 4 is set to trip for fault when the sum of the absolute values of the three phase input voltage to the transformer and three phase output voltage from the transformer is below 3.5 volt. The absolute value block in Fig. 4 converts all the phase voltage to positive value while the add block sum the voltage values. The simulink model of the conventional relay is shown in Fig. 5 and Fig. 6 is integrated to the test network. And the results are display on the workspace block.

To develop a simulink model of the conventional relay system of Fig. 5. A new model was created and various blocks were added. The blocks were then linked as shown in Fig. 6 and then simulated to check if they were errors. The “go to” tags referenced V_{abc}_B_1 and V_{abc}_B_2 inputs measured voltage level at bus B_1 and bus B_2 respectively.

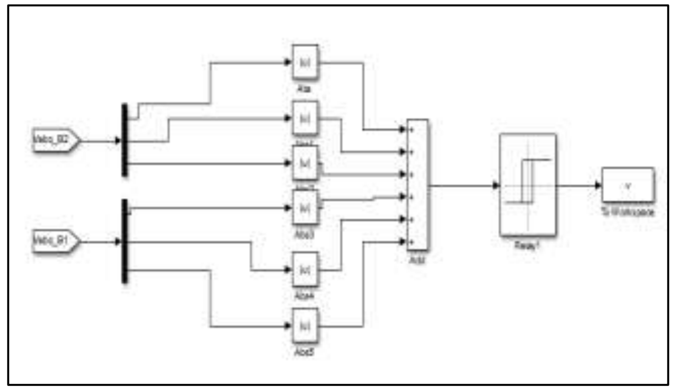

Fig. 5: Conventional differential relay model.

Figure 6 shows the simulink diagram of the Conventional Differential Relay connected to the simulink model of the test network, the reason for the connection is to see the performance of the conventional relay. The result of the simulation is shown in Table 1.

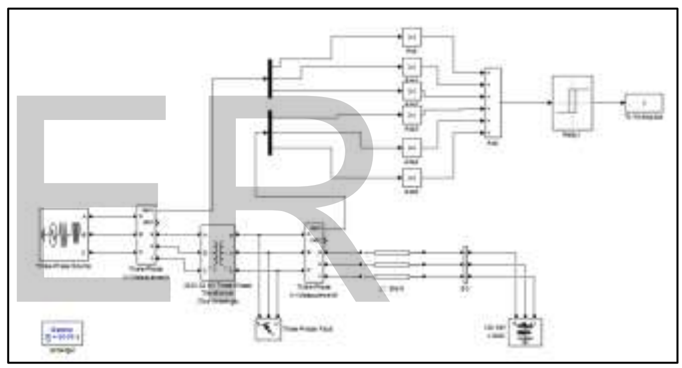

Fig. 6: Simulink model of conventional differential relay with test network.

3.4. Training the Neural Network Based Digital Relay

To obtain training data, the test network was simulated without any fault on the transformer. With the help of the Sim out block, the three phase voltage V_{abc} on the transformer bus was recorded. Various types of faults were then introduced in the test network with the help of the three phase fault block. The test network was again simulated and V_{abc} recorded. The V_{abc} obtained during the two scenarios formed the input to the ANN fault detector. In developing the ANN networks, the training data was first loaded on the ANN interface in MATLAB. After loading the data, the networks were then created and trained. After successful training, the developed networks were converted into Simulink models as shown in Fig.7.

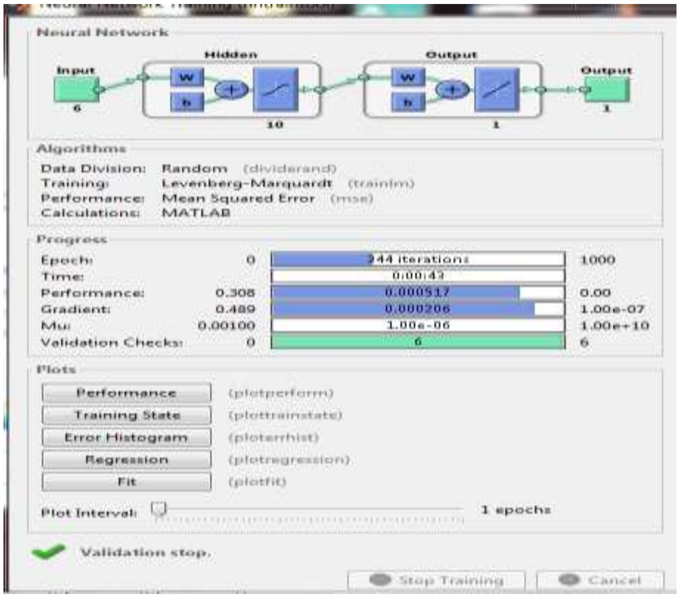

Fig. 7: ANN training environment.

3.5. Simulink Model of a Neural Network Based Digital Relay

The ANN fault detector is trained to detect any fault in the transformer with high sensitivity. The ANN fault detector is a feed forward neural network build using the neural network fitting built available in ANN tool box in MATLAB. The ANN fault detector architecture is shown in Fig.8.

it can be seen that the ANN fault detector has 3 inputs and one (1) output. Here the inputs are the three phase voltage at the transformer bus. There is just one output or target for the ANN fault detector.

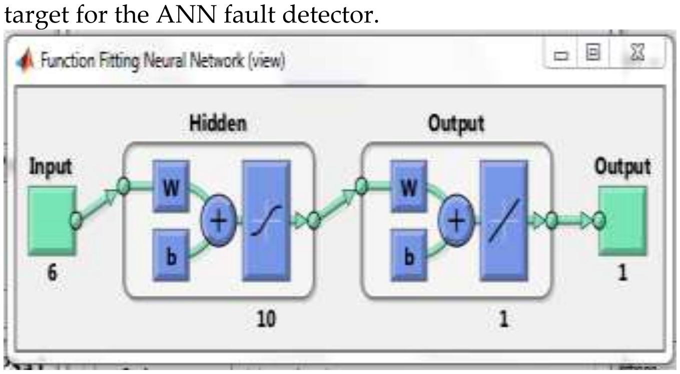

Fig. 8: ANN faults detector architecture.

This output is either zero (0) or one (1). Zero represents no fault and one represents presence of fault. The digital relay block is also sourced from sim power system library in MATLAB. The ANN fault detector Simulink model coupled to the digital relay is shown in Fig.9.

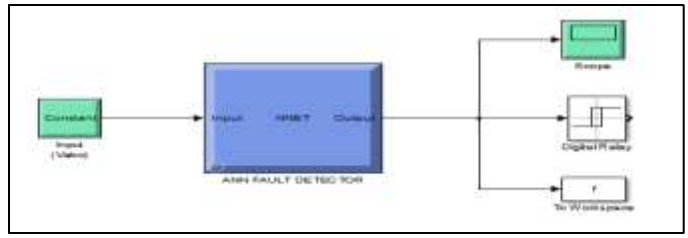

Fig. 9: ANN faults detector model with digital relay.

From Fig.9, the input to the ANN controller is the three phase voltage from the Network (combination of input and output of the transformer). The output of the ANN controller goes to the relay and is also sent to the “to work space” block for recording.

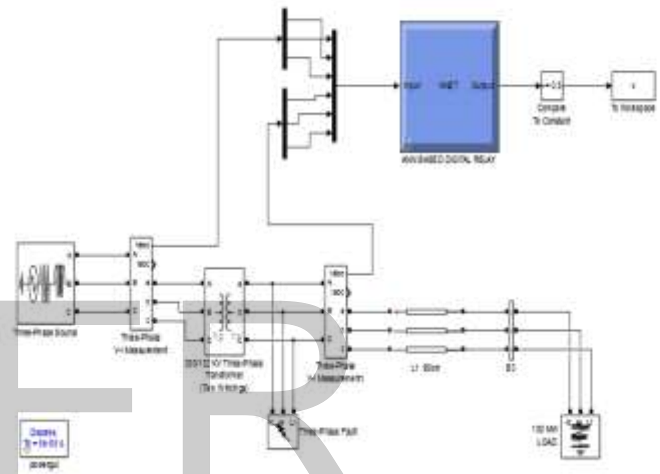

Fig. 10: Model of ANN digital relay with test network.

Figure 10 shows the simulink diagram of the ANN Digital relay connected to the simulink model of the test network, the reason for the connection is to see the performance of the new developed ANN Digital relay and to compare the result of the new ANN digital relay with the conventional relay. The result of the simulation is shown in figure 4.1.

In the model of Fig.10, the three phase source feeds the network with a voltage of 330KV. The transformer receives this input from Bus B1, a three phase fault block is connected between the transformer and bus B2 to help in simulating different types of fault (Single phase, three phase fault, primary fault, secondary fault etc). The network also contains an impedance block and a100MW load. The load is connected to Bus 3. Bus 1 and Bus 2 are voltage measurement blocks. The ANN controller is fed with the combined values of the transformer input and output voltages (Vabc_B1 and Vabc_B2). The ANN controller based on its training identifies the fault associated with the transformer.

4. Results and Discussion

This section covers the simulation results together with discussion as shown in table 1.

A. *Performance Evaluation ANN Based Digital Relay*

Table 1: Simulation results of ANN based digital relay

S/N	Actual Reading	Conventional Relay	ANN Relay
1	1	1	1
2	1	1	0
3	1	1	0
4	1	1	1
5	1	1	1
6	1	1	1
7	1	1	1
8	1	1	1
9	1	1	1
10	1	1	1
11	1	1	1
12	1	1	1
13	1	1	1
14	1	1	1
15	1	1	1
16	1	1	1
17	1	1	1
18	1	1	1
19	1	0	0
20	1	0	1
21	1	0	1
22	1	0	1
23	1	1	1
24	1	1	1
25	1	1	1
26	1	1	1
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28	1	1	1
29	1	1	1
30	1	1	1
31	1	1	1
32	1	1	1
33	1	1	1
34	1	1	1
35	1	1	1
36	1	1	1
37	1	1	1
38	1	1	1
39	1	0	1
40	1	0	1
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92	1	1	1
93	1	1	1
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97	1	1	1
98	1	1	1
99	1	0	0
100	1	0	1

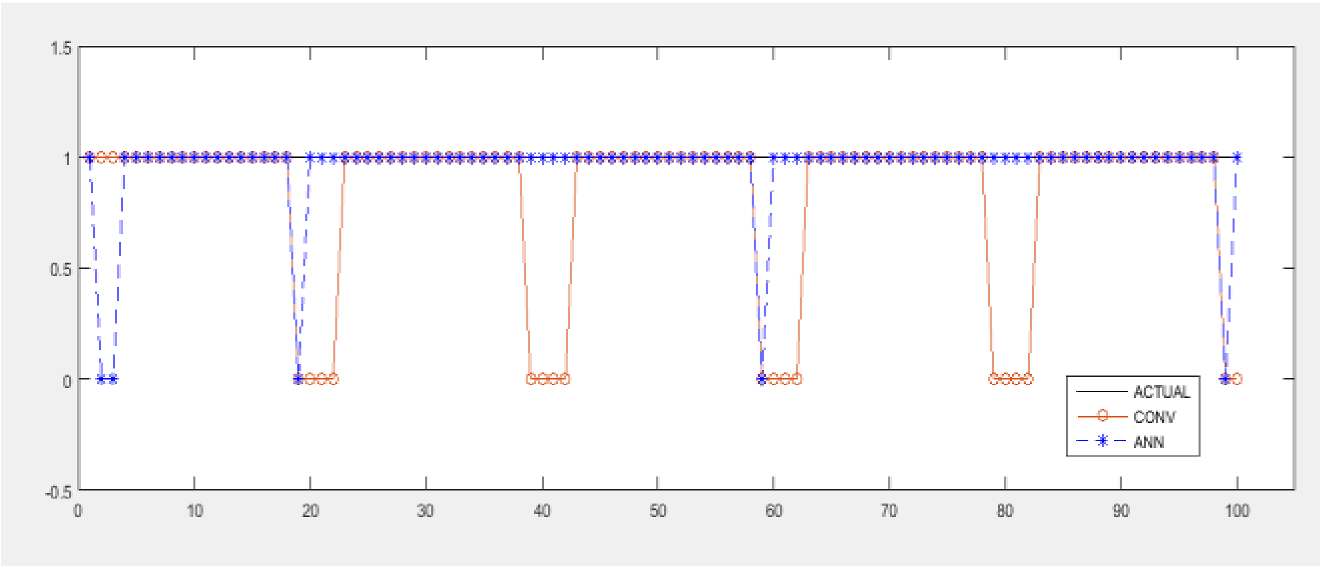

Fig. 11: Plot Of Relay Type Against Number Of Tripping

The plot in figure 11, shows the relationship between three relay performance in tripping the network. Comparing the ANN relay (ANN) and the conventional relay (CONV) with the actual relay tripping, the result shows that the ANN relay is able to trip correctly compare to the conventional relay. The ANN Relay trip more correctly because the gap between the line of the ANN Relay is very close to the actual tripping.

B. *Fault Detection*

This sub-section covers the summary of the evaluation of performance of fault detection by conventional and ANN based relay as presented in table 2.

Table 2: Performance comparison of fault detection

ANN Relay Tripping		**Conventional Tripping**		**Actual Tripping**
Correct Tripping	Wrong Tripping	Correct Tripping	Wrong Tripping	Correct Tripping
1950	51	1604	397	2001

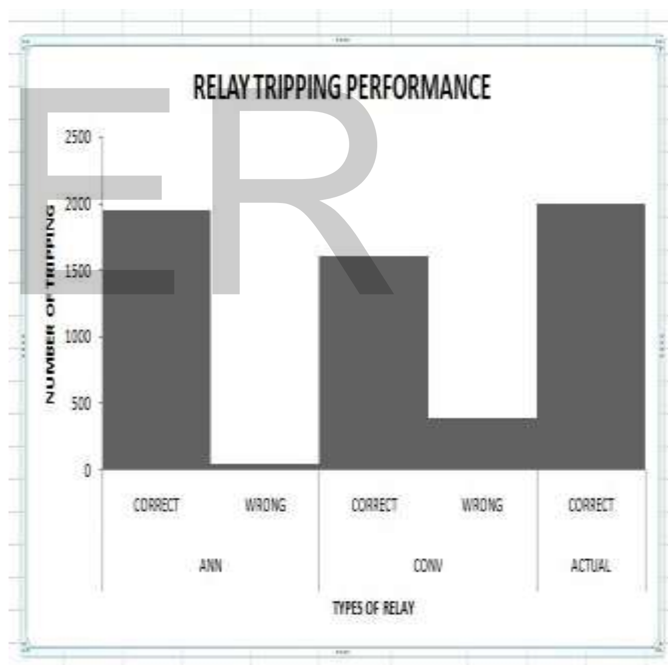

Fig. 12: Relay tripping performance.

C. *Equation for Calculating the Percentage of Tripping*

ANN Relay Tripping (%) = 2.55%

Therefore the correct tripping for the ANN relay will be 97.45%

Conventional Relay Tripping (%) = 19.84%

Therefore the correct tripping for the conventional relay will be 80.16%.

Table 3: Tripping perfcentage.

Percentage of Tripping		
Types of Tripping	**ANN Relay Tripping (%)**	**Conventional Tripping (%)**
Wrong	2.55	19.84
Correct	97.45	80.16

Table 3 shows the percentage of tripping. Comparing the ANN relay and the conventional relay the result shows that the ANN relay is able to trip correctly compare to the conventional relay.

5. Conclusion and Recommendation

In conclusion this paper presents a new approach for an artificial neural networks based digital relay of power transformers, in the cause of the work:

I. The input of the dataset is given to the Neural Network tool box for fault detection for tripping the fault current.
II. The Network was trained with the features extracted for the different fault conditions. The proposed Artificial Neural Network-Based Digital Relay techniques are showed their fast response for tripping the fault and it trip the fault with in 0.006 to 0.007s. The proposed algorithm provides more accurate results.
III. Simulation results show that, with the application of Artificial Neural Network and the unique way of choosing Artificial Neural Network inputs, the proposed Artificial Neural Network-Based Digital Relay operates properly under different conditions and the diagnosis is both accurate and fast in fault detection than the conventional relay as shown in the result.

However, the authors recommended that Artificial Neural Network-Based Digital Relay used in this work should be incorporated in Nigeria Network and other power system to enhance it protection. Moreover, for future work, other intelligent technique like Fuzzy Logic and Genetic Algorithms should be used for more comparison to see the best of result. The power company can implement this system on their transformer for reliable and efficient result.

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