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IMPROVING THE ACCURACY OF FAULT DETECTION IN A DISTRIBUTION TRANSFORMER USING AN INTELLIGENT TELEMETRIC SCHEME

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ABSTRACT

A power transformer is the major and essential component of power systems which are usually intended to contain about 30-years working life span. The idea of power system protection is to notice faults or irregular operating situations that might cause an unhealthy operation of the transformer, by which means the transformer's life span reduces. The problem of transformer like oil leakage, winding insulation failure, short circuits, and overvoltage is on increase with the conventional protection reviewed in this research owing to the long-term exposure of the transformer to these faults. This paper looks into a technique for improving the accuracy of fault detection in a distribution transformer using an intelligent telemetric scheme. To accomplish the research aim, characterization of various faults and causes on a 15MVA, 33/11KV distribution transformer was performed. A Transformer fault model was developed using MATLAB/SIMULINK for ANN training based on telemetric rules of fuzzy logic to detect faults in the distribution transformer. The simulated result illustrates that the system accurateness of fault detection is 92% efficient. A comparative analysis with other fault detection algorithms showed 1.6% improvement.

Keywords: Accuracy, Fault Detection, Distribution Transformer, Intelligent, Telemetric scheme

1. INTRODUCTION

The intermittent power supply in the country has become a chronic social malady that has to be decisively stemmed for the socio-economic growth of the country at large. One of the core things that cause inconsistency in the power supply is the fault from the transformer that has arisen as a result of the burning of transformer winding insulation, oil leakage in the transformer, short circuit, and over-voltage. The quality of the power system depends on the integrity of the protection scheme incorporated into the system.

The distribution transformer plays a very vital role and remains the most essential and expensive electrical power component. Therefore, the operation of transformers should be such to provide reliable and continuous service. The purpose of power system protection is to detect faults or abnormal operating conditions that might cause an unhealthy operation of the transformer. Faults such as transformer oil leakage, winding insulation fault, short circuits, and over-voltage faults need to be detected at the inception and isolated at the right time to reduce the damage to the system. However, the protection scheme must be able to evaluate the system parameter like the rated current, rated voltage, power rating, and impedance to be able to act. The local protective fuses and electromechanical relays present several drawbacks. And, some research was conducted on relays that can be interfaced with microprocessors in order to eliminate the drawbacks of the local protection scheme, which led to many improvements in transformer protection in terms of better reliability, improved protection, and control.

Transformers are openly subject to degradation or even damage because of disturbances and faults. For instance, when a fault or other disturbance events occur, the transformer winding will be imposed by magnetic forces. If such forces exceed the withstanding capability of the transformer, winding deformation will occur, and the damages accumulate. Such damages will decrease the operation life, reduce the likelihood of surviving future faults, and affect the transformer's normal operation (Abu-Siada and Islam, 2012). Meanwhile, a transformer may have a higher probability of experiencing partial discharge when the transformer ages, or after experiencing severe conditions such as lightning strikes, switching transients, and internal/external faults that impact the insulation of the transformer (Wang et al., 2002). Generally, it is axiomatic that Dissolved gas analysis (DGA) is a method to distinguish abnormal conditions such as partial discharge, over-heating, and arcing in an oil-immersed transformer, as a small amount of insulating oil under these abnormal conditions will be decomposed and generate different types of gas and other chemical compounds (Wang et al., 2002).

This research proposes a method for improving the accuracy of fault detection in a distribution transformer using an intelligent telemetric scheme, which provides more reliable, faster, and accurate fault detection. The cost of repairing a damaged transformer due to a fault not detected on time can be very high. The power transformers are connected in series with other system components and failure of such components results in power outages for industrial, commercial, and domestic consumers; imposing heavy losses on consumers and electricity companies.

2. Review of Literature

A number of articles involving several subjects about power transformer diagnostics, insulation characterization, and new materials for transformers have been published in this section. Sun et al, 2016 in their work "An Integrated Decision-Making Model for Transformer Condition Assessment Using Game Theory and Modified Evidence Combination Extended by D Numbers" proposed a new decision-making model for transformer condition assessment. The new model integrates the merits of fuzzy set theory, game theory, and modified evidence combinations extended by D numbers. It was shown that compared to the evidential reasoning-based method, the final evaluation result of the presented method could clearly show the health condition of the transformer.

Li et al, 2016 in their work "An Intelligent Sensor for the Ultra-High-Frequency Partial Discharge Online Monitoring of Power Transformers", introduced a new intelligent sensor for ultra-high-frequency (UHF) partial discharge (PD) online monitoring in power transformers. The statistical characteristic quantities of UHF PD signals were acquired by means of a new method, namely the level scanning method which is the base of the intelligent sensor. The experimental results of the proposed sensor under laboratory conditions showed that the intelligent sensor could accurately acquire statistical characteristic quantities of the UHF PD signal, which indicated that the proposed intelligent sensor was qualified for UHF PD online monitoring.

In recent years, a lot of research has been directed towards environmentally friendly insulating liquids, as an alternative to mineral oils. However, as the chemical compositions of these fluids are very different from those of mineral oils, new specification standards for non-mineral oils have been produced.

Rogza, (2016) in his work “Streamer Propagation and Breakdown in a Very Small Point-Insulating Plate Gap in Mineral Oil and Ester Liquids at Positive Lightning Impulse Voltage”, carried out a comparison study of streamer propagation and breakdown between Ester liquids and mineral oil. The work was focused on the comparison of light waveforms registered using the photomultiplier technique. The results indicated that both esters demonstrated a lower resistance against the appearance of fast energetic streamers than mineral oil. Xiang et al, (2019) in their work “Comparison of Dissolved Gases in Mineral and Vegetable Insulating Oils under Typical Electrical and Thermal Faults”, also presented a comparative study of the formation of dissolved gases in mineral and vegetable-insulating oils. The authors used four interpretation dissolved gas analysis (DGA) methods and they confirmed that the diagnosis methods developed for mineral oil were not suitable for the diagnosis of electrical and thermal faults in vegetable-insulating oils and needed some modification. Thus, the proposed modified Duval Triangle method based on Duval Triangle 3 is used to diagnose the thermal and electrical fault of FR3 oil and camellia oil by redefining the zone boundaries of Duval Triangle 1 and obtaining more accurate diagnostic results. Furthermore, the generation mechanisms of gases in vegetable oils have been interpreted by means of unimolecular pyrolysis simulation and the reaction enthalpies calculation.

Bandara et al, (2014) in their work “Performance of Natural Ester as a Transformer Oil in Moisture-Rich Environments”, investigated the performance of natural ester (NE) in moisture-rich environments. They have compared the aging behavior of NE and mineral oil-impregnated pressboard (PB) insulation. While NE insulating oil possesses resistance to the aging of PB insulation, it was noted that the acidity and the color of NE oils could increase rapidly due to the pronounced hydrolytic degradation in a moisture-rich environment. On the other hand, dissipation factor (DDF), viscosity, and dielectric breakdown voltage were suitable for the assessment of the overall condition of NE insulation oils.

Wang et al, (2014) in their work “Reliability Analysis and Overload Capability Assessment of Oil-Immersed Power Transformers”, have introduced a new aspect of overload capability assessment of power transformers. In their article, they estimated the running time of a power transformer under overload conditions by means of the hot-spot temperature. The overloading probability was then fitted by the Weibull distribution, in which the desired parameters were computed according to a new proposed objective function.

Wang et al, (2017) in their work “Study of the Impact of Initial Moisture Content in Oil Impregnated Insulation Paper on Thermal Aging Rate of Condenser Bushing”, investigated the influence of initial moisture contents in the oil-impregnated paper of the condenser bushing. The results of their experience indicated that the initial moisture content has an appreciable impact on the degradation of the insulation paper during the initial aging period. They found that it was possible to evaluate the aging degree and moisture of solid insulation of bushing by doing some analysis of the DDF.

Forfana and Hadjadj, (2018), in their work "Electrical-Based Diagnostic Techniques for Assessing Insulation Condition in Aged Transformers", reported detailed descriptions and interpretations of traditional and advanced electrical diagnostic techniques. Online condition monitoring of power transformers was also discussed. Finally, the authors presented some suggestions/recommendations related to the nature of the defect or fault in the power transformer's main component.

Tang et al. (2016) in their work "Progress of Space Charge Research on Oil-Paper Insulation Using Pulsed Electro-Acoustic Techniques", reported on the space charge behavior in an oil-paper insulation system. Research progress during the last two decades was critically reviewed considering 62 references. The influences of applied voltage, temperature, moisture content, and aging on the space charge evolution in oil-paper insulation have been demonstrated. The review ends with future work on space charge measurement of oil-paper insulation materials. Sikorski et al, (2018) in their work "Moisture Migration in an Oil-Paper Insulation System in Relation to Online Partial Discharge Monitoring of Power Transformers", reported on important aspects regarding PDs monitoring on power transformers. They reported that PDs activity under thermal runaway should be associated with moisture changes in the insulating system.

Zou et al, (2019) in their work "Raman Spectral Characteristics of Oil-Paper Insulation and Its Application to Ageing Stage Assessment of Oil-Immersed Transformers", proposed a new way for assessing the aging condition of oil-paper insulation based on confocal laser Raman spectroscopy (CLRS) in conjunction with principal component analysis (PCA) and multi-classification support vector machine (SVM). The investigations were performed in laboratory conditions using 160 oil-paper insulation samples and the approach was validated with oil-paper insulation samples. The results reported demonstrated the feasibility of using CLRS in conjunction with the PCA-SVM technique for the aging stage assessment of oil-paper insulation.

3. METHODOLOGY

The first method adopted in the implementation of this project was to characterize the transformer and determine possible faults that affect the power transformer. For that to be done, the following were considered.

i. Primary and secondary winding of the transformer
ii. Insulation
iii. Tank
iv. Transformer oil

3.1 To determine the possible faults that affect transformers

Table1 shows established transformer faults for the conventional protection scheme

Table 1: Transformer Faults

Causes of transformer faults	**Transformer Faults (%)**	**Time of identification (Sec)**
Transformer Oil leakage	36	4
Burning of transformer insulation	26	6
Short Circuit	23	7

Overvoltage	15	4

3.2 To develop a SIMULINK model for a telemetric scheme

The second thing that was done after the characterization was to develop the SIMULINK model of the telemetric scheme using MATLAB/ SIMULINK. In the Simulink environment, toolboxes that represent the parameters of the telemetric system were imported and the connection link was established. Figure 1 shows the SIMULINK model for telemetric that enhances the efficacy of detecting transformer faults early before it deteriorates

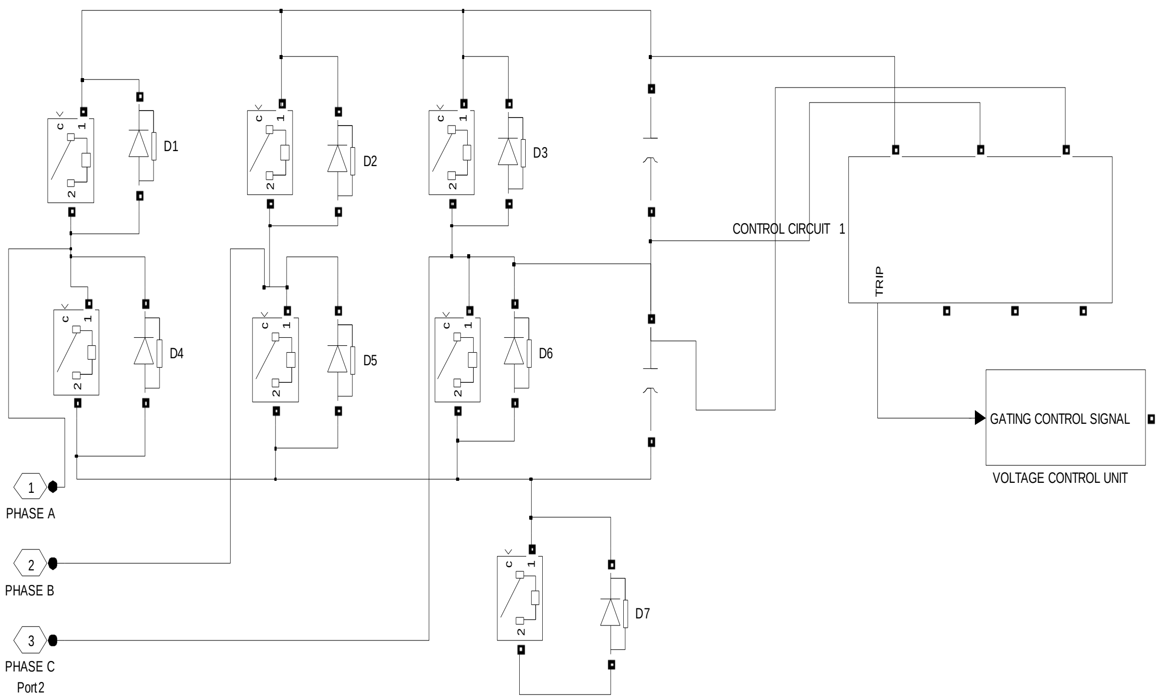

Figure 1 shows the developed SIMULINK model for telemetric that enhances the efficacy of detecting transformer faults early before it deteriorates

3.3 To develop a telemetric rule base that will detect the faults in the transformer

In this stage, a telemetric rule was developed for the detection of faults in the transformers. Figure 2 and 3 shows how to develop a telemetric rule base for the transformers.

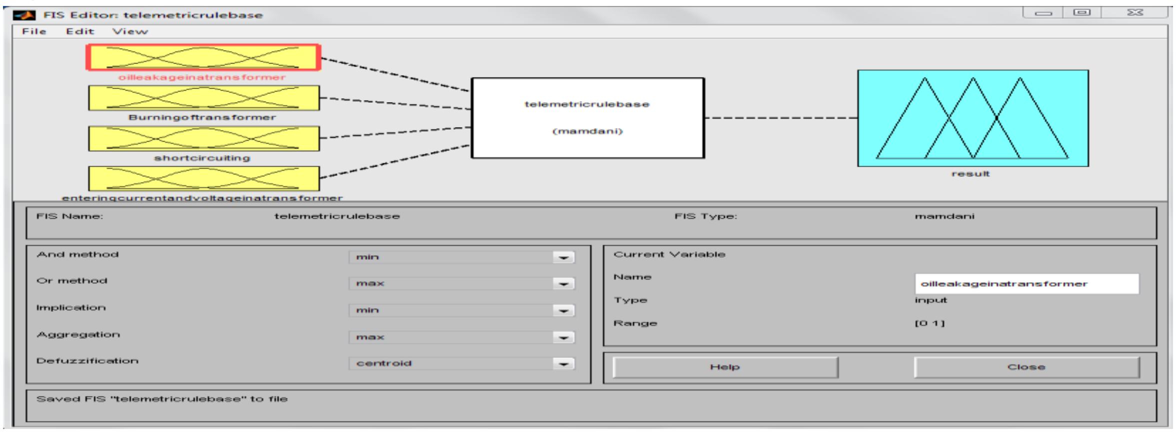

Figure 2 developed a telemetric fuzzy inference system that will detect the faults of a transformer

Figure 2 has four inputs of oil leakage in a transformer, burning of a transformer, short-circuiting in a transformer, and overvoltage in a transformer. It also has an output of the result

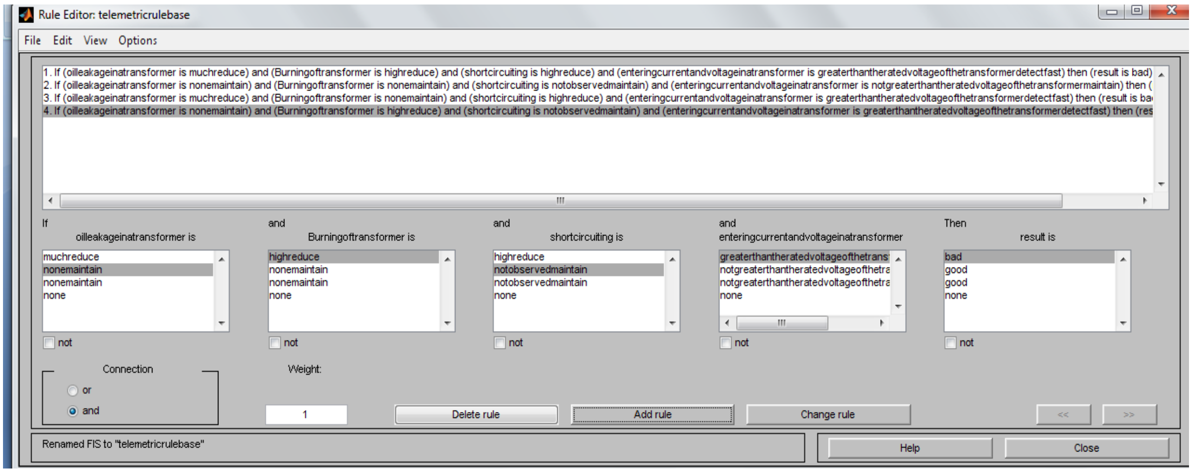

Figure 3: Shows developed a telemetric rule base that will detect the faults in the transformer fast before it deteriorates. The four rules are comprehensively detailed in table 2.

Table 2: Developed telemetric rules

1	If oil leakage in a transformer is much reduce	And burning of transformer is high reduce	And short circuiting in a transformer is high reduce	And there is over voltage in the transformer detect	Then result is bad
2	If oil leakage in a transformer is none maintain	And burning of transformer is none maintain	And short circuiting in a transformer is not observed maintain	And there is no over voltage in the transformer maintain	Then result is good
3	If oil leakage in a transformer is much reduce	And burning of transformer is none maintain	And short circuiting in a transformer is high reduce	And there is over voltage in the transformer detect	Then result is bad
4	If oil leakage in a transformer is none maintain	And burning of transformer is high reduce	And short circuiting in a transformer is not observed maintain	And there is over voltage in the transformer detect	Then result is bad

Table 2 shows the comprehensive detail of the developed telemetric rule base that will detect the faults in the transformer fast before it deteriorates. These rules were used for data collection guide at the Enugu Electricity Distribution Company (EEDC) of the various causes of transformer failure and time and then train with a neural network algorithm adopted from (Ogili, 2023) and presented as;

Pseudocode of the ANN

1. Initialize the neural network parameters such as input size, hidden size, and output size, weights (W1, W2) and biases (b1, b2) randomly.
2. Define a tangent hyperbolic activation function of the neurons
3. Implement the forward pass, which computes the weighted sum of inputs (X) and biases (b1), applies the sigmoid activation function, then computes the weighted sum of hidden layer activations (a1) and biases (b2), and applies the sigmoid activation function again to obtain the final output (a2).
4. Compute the prediction error (loss) using binary cross-entropy.
5. Implement the backward pass, which computes the gradients of the weights (W1, W2) and biases (b1, b2) using the chain rule of calculus and updates them using a specified learning rate.
6. Train the neural network by repeating the forward pass, backward pass, and weight/bias updates for a specified number of epochs as shown in figure 4;
7. Monitor the loss during training for evaluation.
8. Implement a prediction function that uses the trained weights and biases to make binary predictions (0 or 1) based on input data (X).

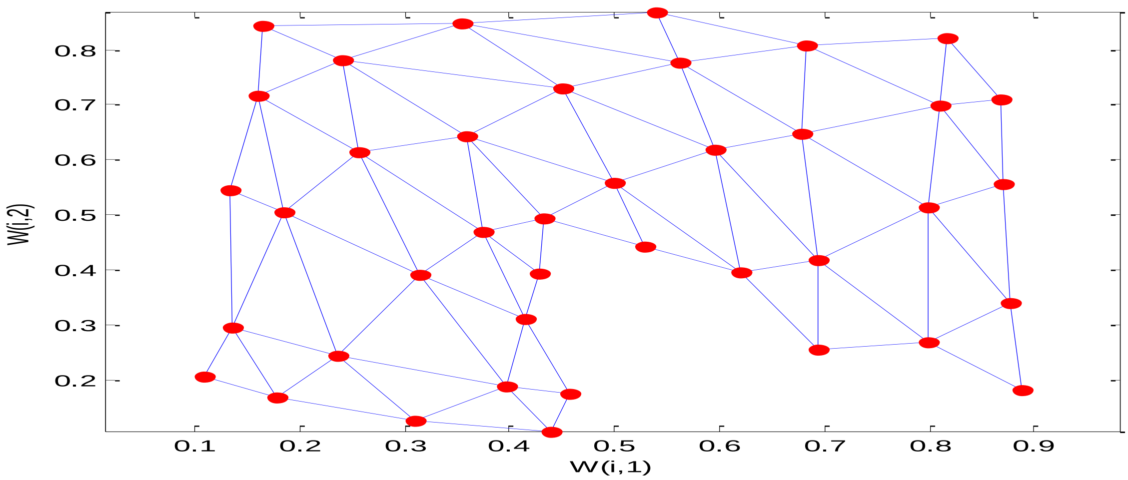

Figure 4: Shows trained ANN in a telemetric rule base to enhance the accuracy of its fault detection

In figure 4 It is shown that four rules were trained ten times to have forty neurons 4 x 10 = 40. These forty neurons look like human brains that mimic human intelligence. The training of ANN in a telemetric rule base enhances the detecting mechanism of faults in a transformer, the more you train the more intelligent system.

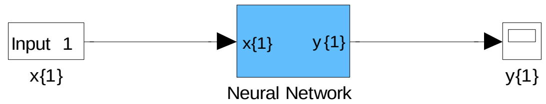

Fig 5 shows result of trained ANN in a telemetric rule base to enhance the efficiency of its fault detection. It will be integrated in the telemetric SIMLINK designed model to enhance its accuracy of fault detecting mechanism in a transformer. The system flow chart was presented as figure 6;

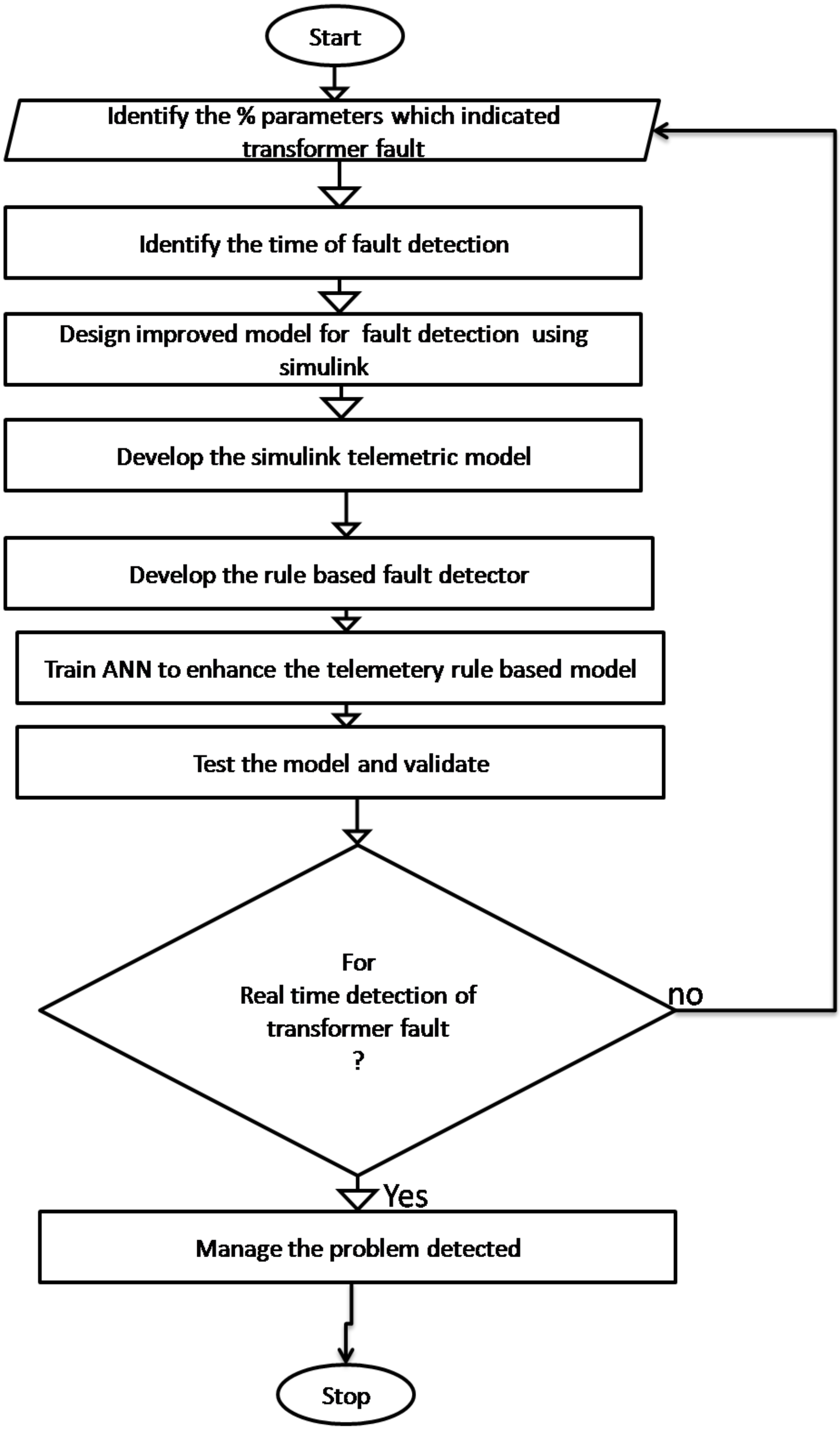

Figure 6: Shows Flow chart of an algorithm that will implement the process

3.6 To design a SIMULINK model for improving the accuracy of fault detection in a distribution transformer using an intelligent telemetric scheme

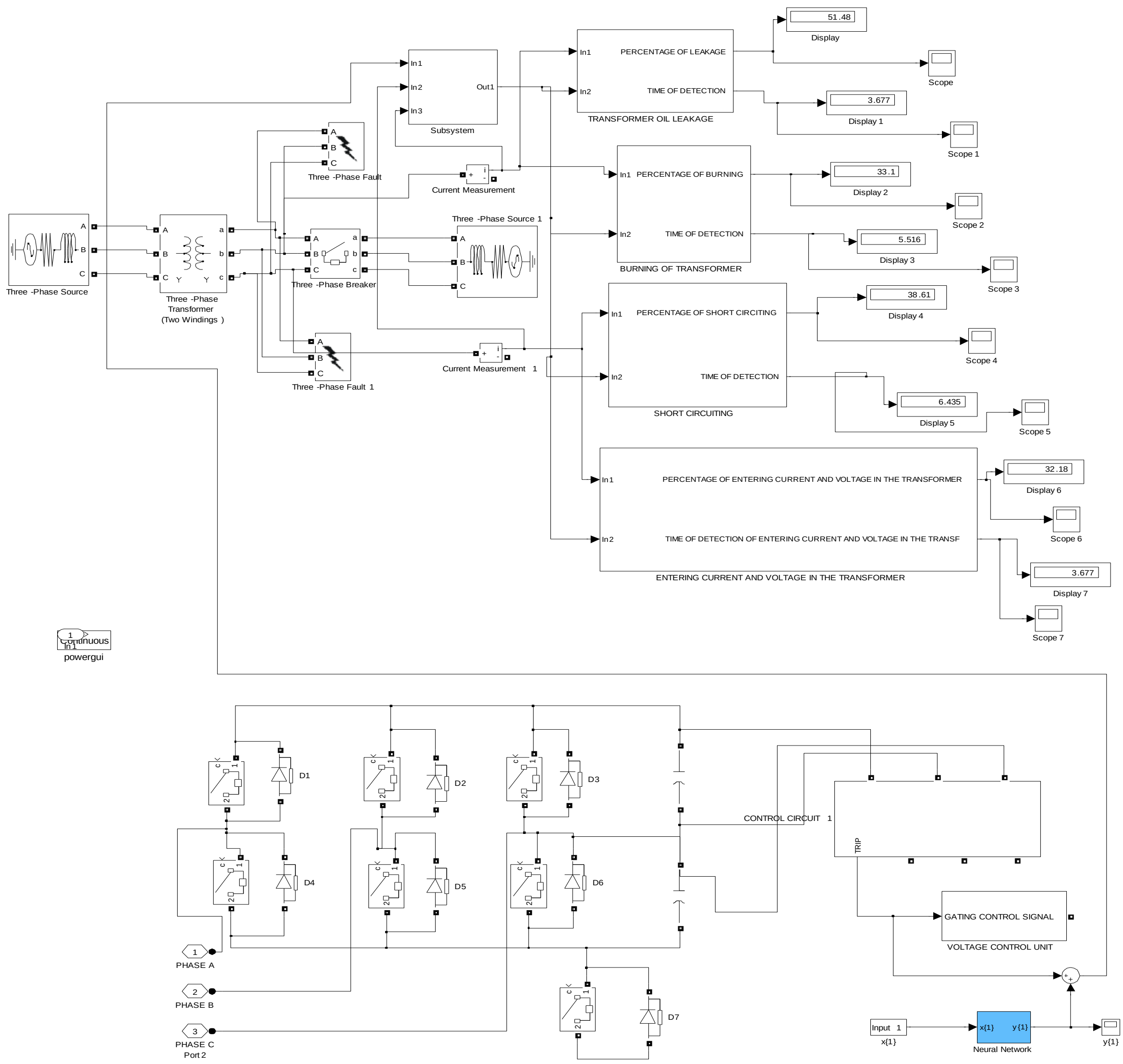

Figure 7 Designed a SIMULINK model for improving the accuracy of fault detection in a distribution transformer using an intelligent telemetric scheme.

4. RESULTS AND DISCUSSION

Table 3: shows the conventional and intelligent telemetric percentages of oil leakage in a transformer.

Time (Sec)	Oil leakage in a conventional transformer (%)	Oil leakage in an Intelligent telemetric transformer (%)
1	36	33.1
2	36	33.1
3	36	33.1
4	36	33.1
5	36	33.1
6	36	33.1

7	36	33.1

Table 3 compares fault level for conventional transformer and when an intelligent telemetric scheme is incorporated. From the above table 3, It's evident that the accuracy of fault detection is improved by 2.9%, the percentage of transformer oil leakage fault in a conventional distribution transformer is 36% and after integrating the telemetric scheme the accuracy was improved to 33.1%. The improvement achieve is 2.9% which is translated to 92%, while the graphical analysis was presented in figure 8;

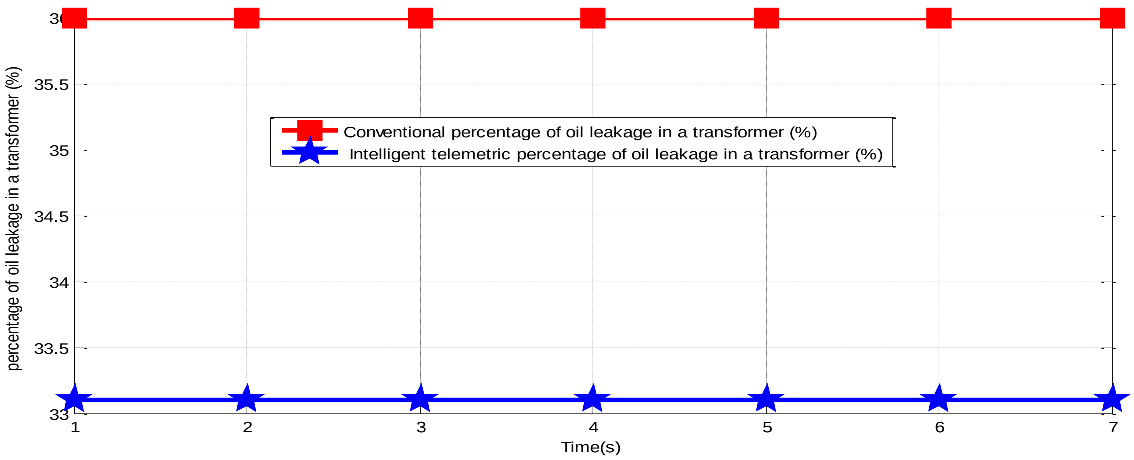

Figure 8: Comparing the conventional and intelligent telemetric percentage of oil leakage in a transformer

Table 4 comparing Conventional and intelligent telemetric transformer oil leakage time of detection.

Number of days (days)	Conventional transformer oil leakage time of detection(sec)	Intelligent telemetric transformer oil leakage time of detection (sec)
1	4	3.68
2	4	3.68
3	4	3.68
4	4	3.68
5	4	3.68
6	4	3.68
7	4	3.68

In Table 4 the conventional time for detecting oil leakage in a transformer is 4s. On the other hand, when an intelligent telemetric is imbibed in the system its time of detecting of oil leakage in a transformer is 3.68s. With these results achieved, it shows that the percentage improvement in detecting oil leakage in a transformer when an intelligent telemetric is incorporated into the system is 8.1%, while the graphical analysis was presented in figure 9;

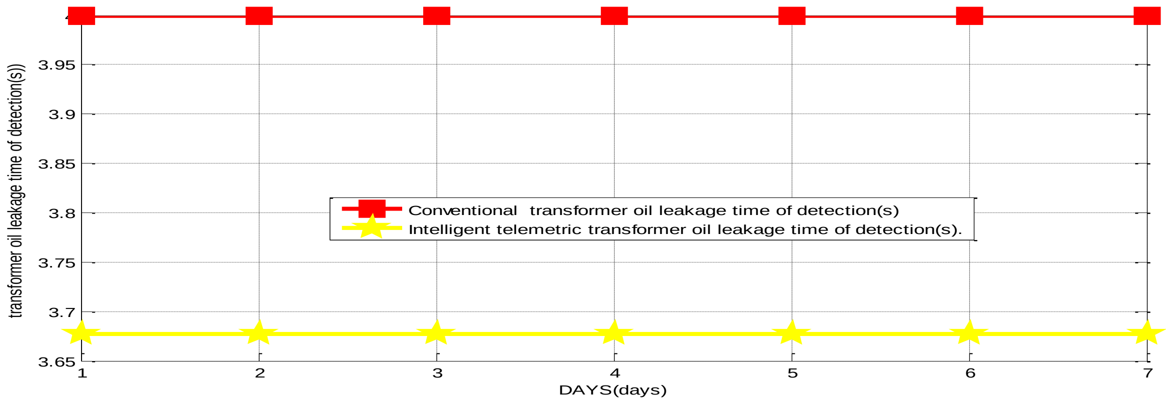

Figure 9: Compares conventional and intelligent telemetric transformer oil leakage time of detection.

Table 5: Compares Conventional and intelligent telemetric burning of transformer fault detection.

Time (Sec)	Conventional burning of transformer fault detection (%)	Intelligent telemetric burning of transformer fault detection (%)
1	26	23.9
2	26	23.9
3	26	23.9
4	26	23.9
5	26	23.9
6	26	23.9
7	26	23.9

Table 5 shows that the conventional percentage of the burning of transformer is 26%while that when an intelligent telemetric is incorporated is 23.9%. These obtained results show that the percentage improvement in the reduction of the burning of transformers when an intelligent telemetric scheme is incorporated is 2.1%, while the graphical analysis was presented in figure 10;

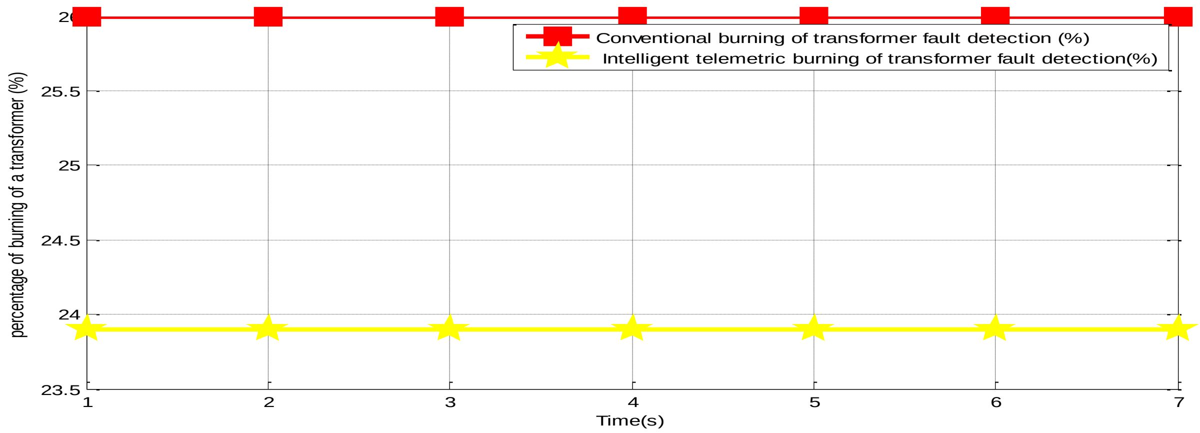

Figure 10: Comparing conventional and intelligent telemetric burning of transformer fault detection.

Table 6 compares the Conventional scheme and intelligent telemetric scheme for burning transformer fault detection time.

Number of days (days)	Conventional burning of transformer winding insulation detection time (Sec)	Intelligent telemetric burning of transformer fault detection time (Sec)
1	6s	5.52
2	6s	5.52
3	6s	5.52
4	6s	5.52
5	6s	5.52
6	6s	5.52
7	6s	5.52

Table 6 the conventional time the transformer burn is 6s while that when an intelligent telemetric technique is inculcated in the system is 5.52s. With these results obtained, it signifies that the percentage time improvement in the detecting burning of a transformer when an intelligent telemetric scheme is imbibed in the system is 0.48s, while the graphical analysis was presented in figure 11;

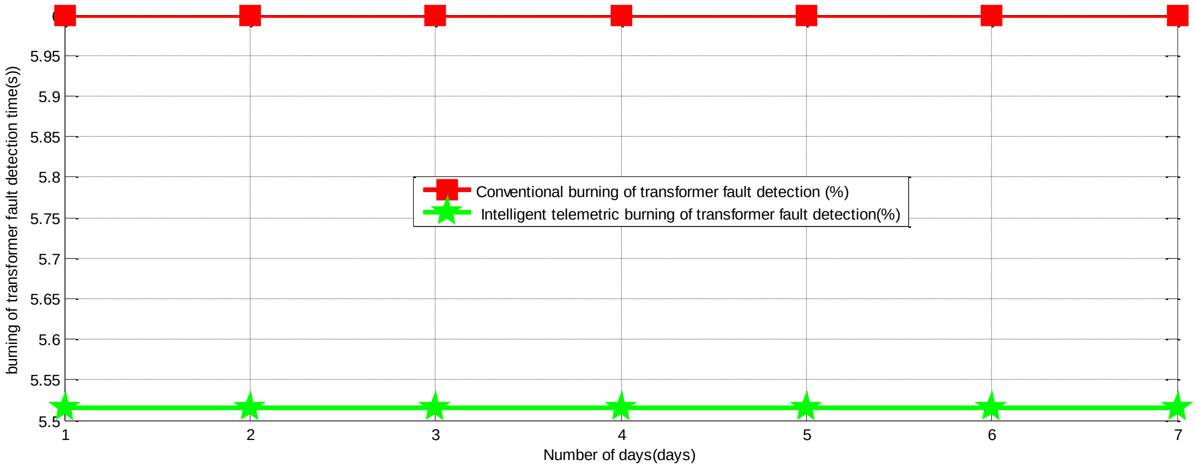

Figure 11: Comparing conventional and intelligent telemetric burning of transformer fault detection time.

Table 7: Comparing conventional and intelligent telemetric short circuits of transformer fault detection.

Time (s)	Conventional short circuit of transformer fault detection (%)	Intelligent telemetric short circuit of transformer fault detection (%).
1	23	21.4
2	23	21.4
3	23	21.4
4	23	21.4
5	23	21.4
6	23	21.4
7	23	21.4

Table 7 the highest conventional short circuit transformer fault is23% while that when an intelligent telemetric is injected into the system is 21.4%. With these results obtained, it shows that the percentage of reduction of short circuits experienced in transformer when an intelligent telemetric is injected into the system is 1.6%, while the graphical analysis was presented in figure 12;

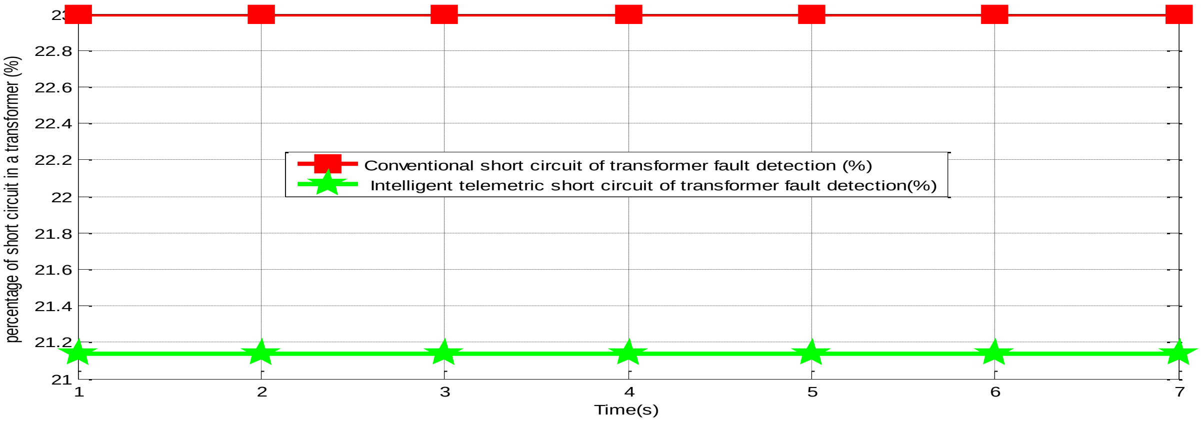

Fig 12: Comparing conventional and intelligent telemetric short circuits of transformer fault detection.

Table 8: Comparing conventional and intelligent telemetric short circuits of transformer fault detection time.

Number of days (days)	Conventional short circuit of transformer fault detection time(s)	Intelligent telemetric short circuit of transformer fault detection time (s).
1	7	6.44
2	7	6.44
3	7	6.44
4	7	6.44
5	7	6.44
6	7	6.44
7	7	6.44

Table 8 shows that the conventional time of a short circuit in a transformer fault is 7 s while that when an intelligent telemetric is incorporated in the system is 6.44s. The percentage of early detection and correction of short circuits experienced in transformers is 0.56s, while the graphical analysis was presented in figure 13;

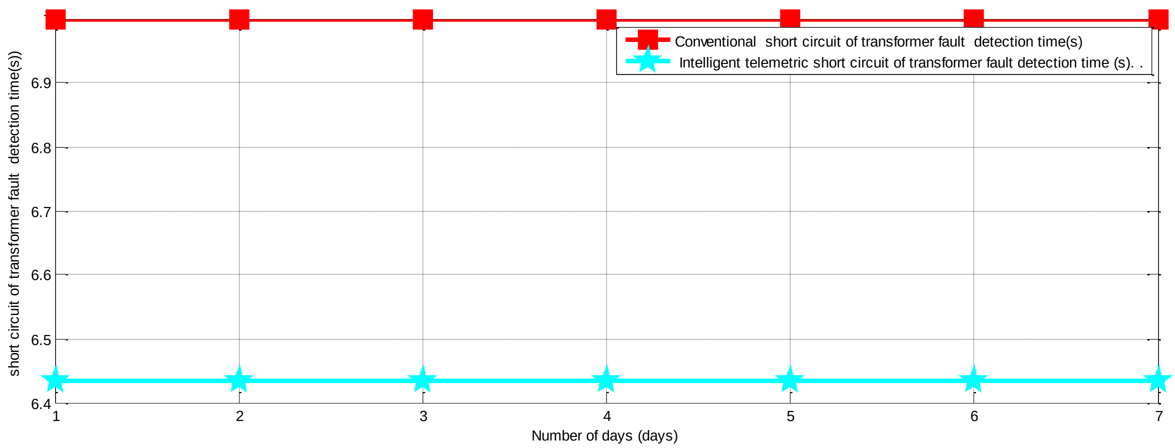

Fig 13: Comparing conventional and intelligent telemetric short circuits of transformer fault detection time.

5. CONCLUSION

The late detection of transformer faults has led to intermittent power supply in the country. This is surmounted by improving the accuracy of fault detection in a distribution transformer using an intelligent telemetric scheme. The results obtained are that the percentage of conventional oil leakage is 36% while that when an intelligent telemetric technique is incorporated into the system is 33.1%. With these results obtained, it shows that the percentage improvement in the reduction of oil leakage in a transformer when an intelligent telemetric technique is incorporated into the system is 2.9%. The conventional time for detecting oil leakage in a transformer is 4s. On the other hand, when intelligent telemetry is imbibed in the system its time of detecting and correcting oil leakage in a transformer is 3.68s.With these results achieved, it shows that the percentage improvement in detecting and correcting oil leakage in a transformer when an intelligent telemetric was incorporated in the system was92%, the conventional percentage of the burning of the transformer was 26% while that when an intelligent telemetric is incorporated was23.9%. This obtained result shows that the percentage improvement in the reduction of the burning of transformer insulation when an intelligent telemetric scheme is incorporated was2.1% which is translated as 92%, the conventional time the transformer burn is 6s while that when an intelligent telemetric technique is inculcated in the system was5.52s. With these results obtained, it signifies that the percentage time improvement in the detecting burning of a transformer when an intelligent telemetric scheme is imbibed in the system was92% and the conventional time of short circuit in a transformer fault was 7 s while that when an intelligent telemetric is incorporated in the system was 6.44s. The percentage of early detection and correction of short circuits experienced in the transformer was 8.1% which is translated as 92% accuracy.

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