Generator –Transformer Unit Fault Identification Using Backup Protection By Generalised Regression Neural Networks

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***Abstract* - This research work describes the fault identification for the Transformer coupled with a generator unit. The reliability and functionality of protection devices are improved with the help of backup protection scheme. Magnetizing inrush, normal and over-excitations are some of the different operating system used in transformer. This research work is simulated using the PSCAD/EMTDC software with artificial neural network. The proposed research work uses the independent amplitude of the current waveform. The signal extracted from these models can be used to prepare training sets for pattern matching algorithm. Hence, Generator-Transformer unit is developed into PSCAD models for either single phase or three phase fault magnetic inrush and for no fault condition. Therefore, fault and normal operating conditions are categorized by using mho circle and current waveform at various global resistance condition. Similarly, faults and normal operating conditions classified by resilient back propagation using Generalised Regression Neural Networks (GRNN). Using electro-magnetic transient program PSCAD/EMTDC, a fragment of power system is modeled.**

Keywords: backup protection scheme, PSCAD/EMTDC, Generalised Regression Neural Networks Neural Networks , fault current identification in transformer

I. Introduction

This research work is based on the independent amplitude of the current waveform. The signal extracted from these models can use to prepare training sets for pattern matching algorithm. Hence, Generator-Transformer unit is developed into PSCAD models for either single phase, three phase fault magnetic inrush and no fault condition. Therefore, fault and normal operating conditions are categorized by using mho circle and current waveform at various global resistance condition. Similarly, faults and normal operating conditions classified by resilient back propagation using Generalised Regression Neural Networks (GRNN). Using electro-magnetic transient program PSCAD/EMTDC, a fragment of power system is modeled.

Transformers and generators are the most essential elements of the power system with their protection significance. Backup protection scheme by Javad Zare, Farrokh Aminifar and Majid Sanaye-Pasand [5] detects the fault in line transformer by using positive sequence unit. A synchro phasor protection scheme identifies different faults with short duration and produces higher accuracy. Though, the fault communication and measurement devices are failed in the proposed backup protection scheme. The differential relays should be considered in a behavior that it does not mal-operate during magnetizing inrush and over excitation conditions of transformer.

Nasser Talebi, Mohammad Ali Sadrnia, and Ahmad Darabi [7] proposed a fault detecting system for wind energy conversion system. They identify the ensued faults at the suitable instance, avoid serious losses and it ensure safe system operation that prevent from damage. Inrush currents are produced after fault authorization and it is considered during the design of relay. Hence, the fault in a transformer is classified into two types namely, internal faults and external faults.

Further internal faults are classified into electrical and mechanical faults that caused during insulation damage of the transformer. Some of the electrical internal faults are Phase to Phase fault, Phase to Ground and Inter turn faults. Particle Swarm Optimization (PSO) method was proposed by Abdallah Chanane, Hamza Houassine and Ouahid Bouchhida [2] for the identification of faults in a transformer winding along with high frequencies. A power transformer in electrical transmission and distribution network consists of various faults. But, winding parameters are required in ladder network for fault identification in transformer.

The high current flow produces between phase to phase or phase to ground connection and it may split down the winding or even it may also damage the core fully. The fault direction is illustrated by Ali Hooshyar, Maher Abdelkhalek Azzouz, and Ehab F. El-Saadany [8] with frequency voltage elements during three-phase short-circuit connection. According to the wave shape properties, fault currents are classified and the decaying pattern of the ac component with key feature. But, substation fault current exceeds its essential amplitude which is not the case for DFIG fault currents. Similarly, external faults are occurred during short circuit in two or three phases of electrical power system. The level of fault current is always high sufficient.

Due to cut off power in a short duration, there may be a fault occurrence known as transient faults. When a fault occurs, equipment used for power system protection operates to isolate the area of the fault. Artificial Neural Network was presented by Balaga and D. N. Vishwakarma and H. Nath [1] with backup protection scheme of generator-transform unit.

They identify the internal faults of transformer and generator based on various fault conditions. However, it is not able to provide primary protection scheme on transformer generator unit. Transformer consists of primary and secondary side in an electrical power system. Hence they act as an inductance when the primary side switch is on and secondary side is kept open. Therefore, the flux in the core also start from its zero value at the time of switching on the transform.

II. Generator-Transformer Model For Fault Identification

High Impedance Fault (HIF) using Wavelet Transform (WT) was designed by Jichao Chen, Toan Phung, Trevor Blackburn, Eliathamby Ambikairajah and Daming Zhang [3] to detect the fault occurrences. A signal with various frequencies is recognized for network protection and to remove the network features. But, it does not able to detect the on-line faults in a transformer winding. Neutral Grounding Resistors were introduced by A.R. Sultan, M.W. Mustafa and M. Saini [4] for the identification of single line to ground fault and configuration of transformer. Here, maximum fault current is produced in each winding and no current flow through the neutral networks. However, huge harmonics is produced during generator-transformer unit.

The design of minimal-order residual generators by H. M. Tran and H. Trinh [6] based on a parametric approach detects and isolates the fault in dynamical system. However, the selection of the robust threshold is doubt in generator. With the mixture of S-Transform (ST) and Probabilistic Neural Network (PNN) methods, a new security scheme was proposed by Zahra Moravej, Jamal Dehghani Ashkezari and Mohammad Pazoki [9]. These proposed methods recognize proportioned faults through power swing situations. The main objective of proposed method is to extract the faults under different conditions.

Raidson Jenner Negreiros de Alencar and Andre Mauricio Damasceno Ferreira [10] designs Wavelet Energy Gradient to discriminate transformer inrush currents from internal faults using the root-mean-square. However, traditional differential protection method does not react properly to internal faults which use the harmonic restraint method. Transfer function was designed by Xiao Lei, Jian Li, Youyuan Wang, Sibei Mi and Chengmeng Xiang,[11] to detect the inter-turn faults based on improved lumped circuit. The severity of the fault can be predictable previously when the winding structure parameters are Kefei Zhang, Fang Yuan, Jiang Guo1 and Guoping Wang [12] develops an Fuzzy C-means Clustering algorithm implemented for identifying transformer fault.

Different fault currents are recognized by Multi-Level Fault-Current Indicator presented by Jen-Hao Teng, Shang-Wen Luan, Wei-Hao Huang, Dong-Jing Lee and Yung-Fu Huang [13]. However, high impendence fault current is not identified. Frequency response analysis by Seema Arora, Bhavna Srivastava, Priyanka, Raghav Parashar and Shivangi Gaur,[14] identifies the mechanical faults in power system by analyzing the winding phase. Artificial Neural Network (ANN) and Particle Swarm Optimization (PSO) techniques were presented by Hazlee Azil Illias, Xin Rui Chai, Ab Halim Abu Bakar and Hazlie Mokhlis [15] to predict the transformer fault. However, the implementation of response analysis is difficult.

Veilleux Veilleux, E., & Lehn, P. W. [16], presented direct wind turbines using series direct current configuration. presented converter and intersection wind configuration. wind turbines need either alternative current transformer for transmitting offshore platform base both wind turbines supply concentrated on 5-MW characteristics. Simulation results provide both turbines independent peak power tracking.

Burke, C. H., & Smith, P. W [17] proposed minimum range fast switches, voltage triggering with probably unit concept. In this paper provides a 100kV maximum voltage trigger generator and switch module is the maximum current producer charged to 6kV. The maximum gain auto transformer is secondary and IGBT is primary this primary and secondary configuration connected to the output segment. This easily triggered by the TTL input pulse and delay throughput also genera jitter. Result presents the primary and secondary rise time based on the trigger generator are pulse sharpening simple circuit included ≥ 150 newton/second which is minimized the multi channeling in trail gaps.

Braun, D., Delfanti, M., Palazzo, M., & Zich, R. [18] Presented high frequency transient reduction over voltage in power transformers. In generator and associated step up transformer is spread maximum direction. Processor concept presents the better security PS .Insertion of the switching component link triggering and step up transformer type with a magnitude of overvoltage is occurring. This research work is triggering the overvoltages also evaluated the impact capacitor triggering breaker circuit is surveyed.

Stator winding faults of synchronous generator are measured serious problems because of the damage associated with high fault currents and high cost of maintenance. Three phase faults, phase-phase and double phase to ground faults are detected with the help of bias differential relay. Detection of single line to ground faults depends on the generator grounding type which can be classified into low and high impedance grounding. In case of low impedance grounding, a differential relay can detect and provide protection of only about, 95% of the windings. Therefore, tripping for normal unbalance power is avoided with minimum sensitivity by using differential relays.

A. Generator model

A synchronous generator or commonly called an alternator is an electromechanical device that converts mechanical energy to alternating current electrical energy. Alternators generate electricity by the same principle as DC generators, namely, when the magnetic field around a conductor changes, a current is induced in the conductor.

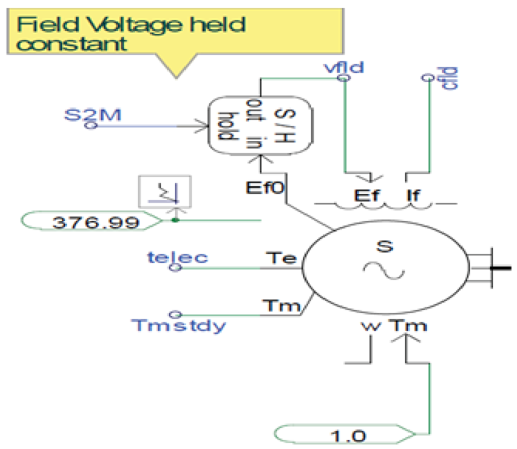

Fig 1 Synchronous Generator Model

Fig. 1 explains the basic synchronous generator model. Automotive alternators consistently use a rotor winding to control the alternator generated voltage by varying the current in the rotor field winding.

$$\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix} \quad (1)$$

B. Transformer model

Its EMF equation provides ,

$$E_{\text{rms}} = \frac{2\pi f N a B_{\text{peak}}}{\sqrt{2}} \approx 4.44 f N a B_{\text{peak}} \quad (2)$$

The equivalent circuit of transformer is estimated with various methods that depending on the winding structure. One of the most commonly used equivalent circuit of transformer known as T model emphasizes the unity of the magnetizing current and resolves the leakage inductance into primary and secondary components. Transformer model consists of series resistor-inductor branches for the primary and secondary windings, representing the copper losses and leakage flux.

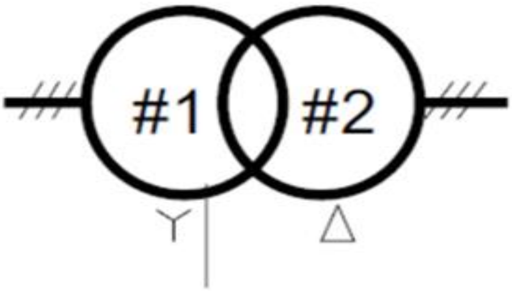

Fig 2 Three Phase Component of General Transformer Model

Fig. 2 shows the three phase components of transformer model. Inrush currents from transformer energizing and overvoltage caused by Ferro resonance or faults are some of the examples of such studies. Therefore the half-cycle average voltage E_{avg}.

$$E_{\mathrm{avg}} = 4fNaB_{\mathrm{peak}} \qquad (3)$$

II. TECHNIQUES USED IN POWER SYSTEM PROTECTION

A. *Generalised Regression Neural Networks*

Generalised Regression Neural Networks are comparatively simple electronic models based on the neural structure of the brain. Neural networks have been developed in a wide variety of configurations, where each of them has its individual characteristics, advantages and disadvantages. Among these configurations the multi-layer feed forward network, which exceeds all of others. It computes an output pattern as a response to some input pattern.

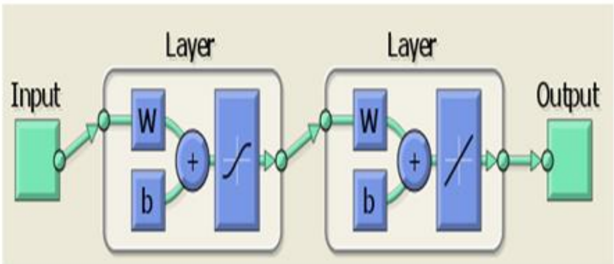

Fig 3 Neural Networks

From fig.3, Neural network was used to refer as network or circuit of biological neurones, but modern usage of the term often refers to GRNN. GRNN is mathematical model or computational model for an example of information processing i.e. inspired by the way biological nervous system, such as brain information system.

B. *Back propagation*

Back propagation is a general technique of preparation generalized regression neural network with an optimization method such as gradient descent used in conjunction. The method calculates the gradient of a loss function with respect to all the weights in the network.

C. *Resilient Back Propagation*

Resilient Back Propagation is a modification of the normal gradient descent back-propagation. The basic principle of Resilient Back propagation (RPROP) is to remove the harmful influence of size of partial derivative on the weight step. As a consequence, only sign of the derivative is considered to indicate the direction of the weight update but not the magnitude. Back propagation measures the derivatives of performance with respect to the weight and bias variables. The fault of differential backup protection scheme for generator-transformer unit is identified with the help of resilient back propagation neural network method.

Training can train any network as long as its weight, net input, and transfer functions have derivative functions. Back propagation is used to calculate derivatives of performance perf with respect to the weight and bias variables X. Each variable is adjusted according to the following:

dX = deltaX.*sign(gX);

where the elements of delta X are all initialized to delta0, and g X is the gradient. At each iteration, the elements of delta X are modified.

If an element of g X changes sign from one iteration to the next, then the corresponding element of delta X is decreased by delta_ dec. If an element of gX maintains the same sign from one iteration to the next, then the corresponding element of deltaX is increased by delta_inc..

Training stops when any of these conditions occurs:

- The maximum number of epochs (repetitions) is reached.
- The maximum amount of time is exceeded.
- Performance is minimized to the goal.
- The performance gradient falls below min_grad.
- Validation performance has increased more than max_fail times since the last time it decreased (when using validation).

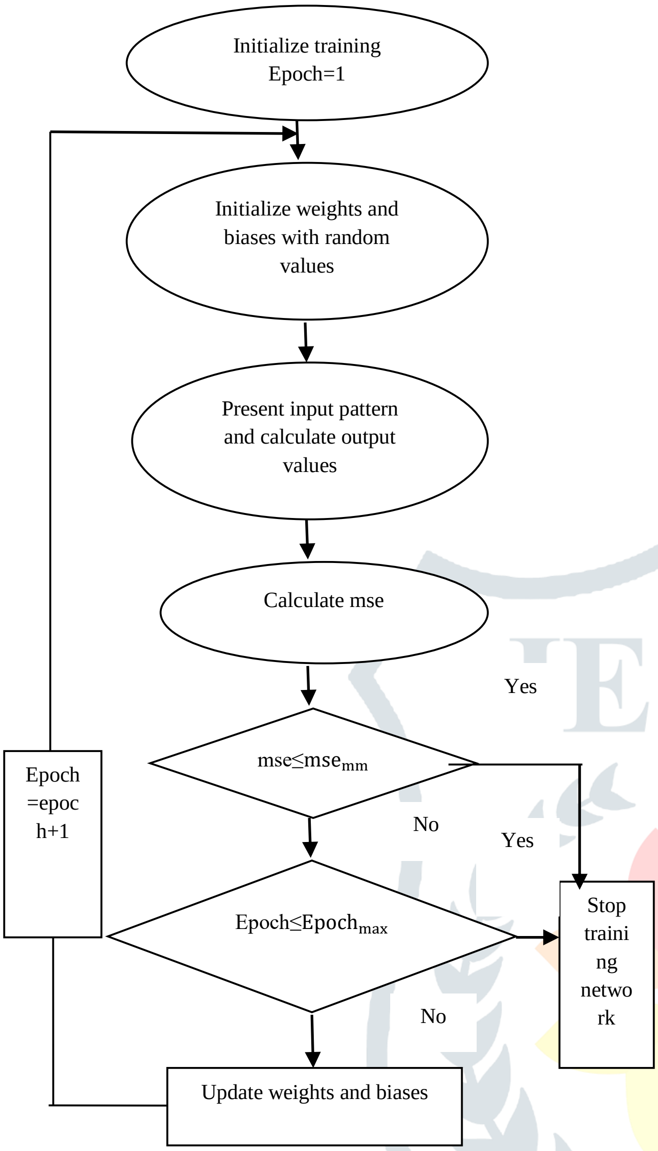

Fig 4 Flow chart for Back Propagation

If an element of g X changes sign from one iteration to the next, then the corresponding element of delta X is decreased by delta_ dec. If an element of gX maintains the same sign from one iteration to the next, then the corresponding element of deltaX is increased by delta_inc..

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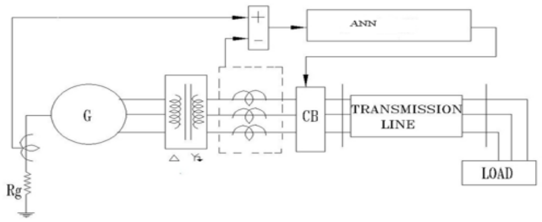
III. Result And Discussion For Fault Identification

Power transformers are devices that require special maintenance due to their importance to the electrical system. Generally, differential relays are used for the primary protection of large transformers. In such relays, differential currents are checked considering a percentage differential characteristic with operation and restraining zones.

Fig.5



Differential Protection Scheme of Generator- Transformer Unit

The synchronous generator with three-phase power system includes a 120MVA, 13.8KV generator and a 100MVA 33/230KV δ-yg transformer. Circuit breaker will check the ON OFF status. The fault resistances are 0.001 ohm till 10 ohm. Timed fault logic is to control the fault signal. The number of conductors in transmission lines is three.

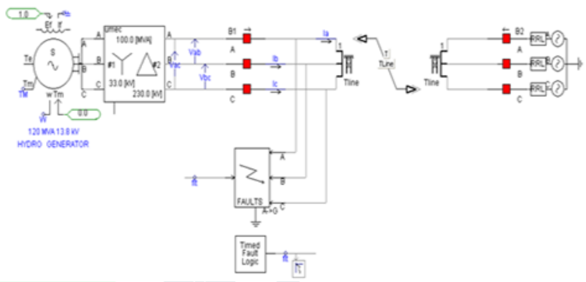


Fig.6 Differential Protection Scheme of Generator- Transformer Unit

Three-phase power system, including a 100MVA, 13.8kV Generator and a 200MVA 13.8/132kV Δ-Yg Transformer along with a 150 km transmission line has been used to produce the required test and training patterns. Fig. 6 shows the scheme of the unit protection system.

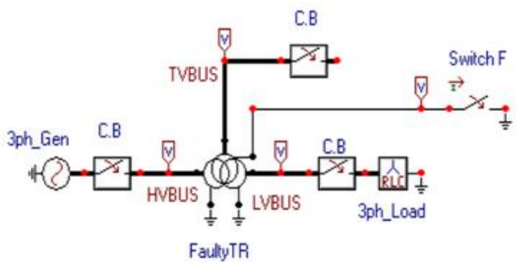


Fig. 7 Three phase EMTP/GRNN simulation of Faulty transformer identification

Different types of faults are created at different locations. All the generator faults are assumed to occur at 100% of the stator winding. Also, inrush current and over excitation conditions are simulated at different voltage angles and with different loads. The generated waveforms are then sampled to feed the neural networks to be tested with two different sampling rates. EMTP software tool is used in PS. In fig. 7 three phase EMTP/GRNN developed based on fault identification in current resistance transmitter.

IV. Performance Analysis

As in Simulink, multiple modules can be built inside a single project, and each module can contain other modules. This provides a hierarchical modeling capability. PSCAD has an interface to Simulink, but it is not suitable for continuous and simultaneous simulations. PSCAD calls Simulink, which runs a whole simulation and then returns the result to PSCAD. Table 2 shows the model of generator, here the data's and units of generator are mentioned in per unit.

TABLE I. Generator Model

Armature Resistance [R_a]	0.005 [pu]
Portier Reactance [Xp]	0.163 [pu]
D: Unsaturated Reactance [Xd]	0.9631 [pu]
D: Unsaturated Transient Reactance [Xd']	0.3447 [pu]
D: Unsaturated Transient Time (Open) [Tdo']	7.1800 [s]
D: Unsaturated sub-Transient Reactance [Xd"]	0.2857 [pu]
D: Unsaturated sub-Transient Time (Open) [Tdo"]	0.0700 [s]
Q: Unsaturated Reactance [Xq]	0.6973 [pu]
Q: Unsaturated sub-Transient Reactance [Xq"]	0.2857 [pu]
Q: Unsaturated sub-Transient Time (Open) [Tdo"]	0.1100 [s]
Air Gap Factor	1

Table 2 shows the transformer mode and the transformer ratings and details are mentioned below.

TABLE II. Transformer Model

Parameter	Value
Rating	250 MVA
Operating Frequency	50 Hz
Winding #1	Delta
Winding #2	Star
No-load losses	0.02 p.u

A. Transformer Fault in Current resistance

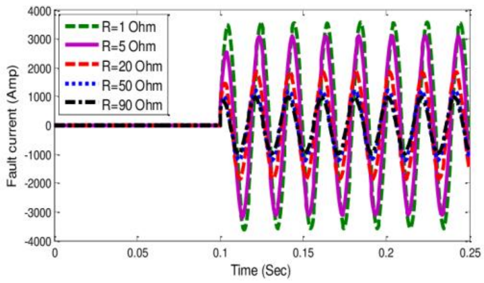


Fig. 8 EMTP/GRNN Simulated fault current waveform at various global resistance

Here, a faulty short circuited transformer is compared to the leakage impedance of that one transformer. The no load current of transformer is significantly affected because of internal faults in transformer.

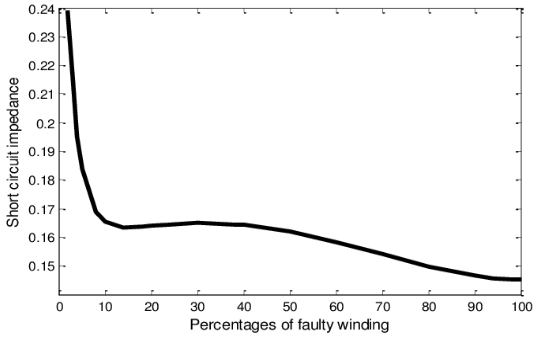


Fig.9 The short circuit impedance of the 3 phase three winding transformer at various % of fault winding.

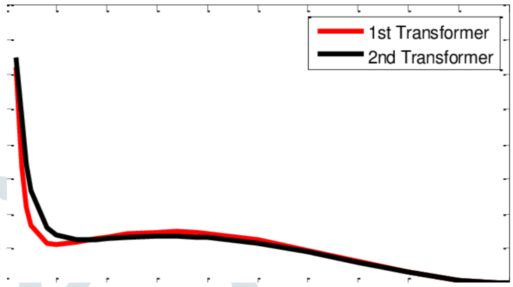


Fig.10 The short circuit impedance at various % of faulty winding.

Symmetrical apparatus simulation scheme the base impedance and base current are determined as follows:

$$Z_{base} = \frac{(b * kV)^2}{MVA} \quad ohm \qquad (4)$$

$$I_{base} = \frac{MVA}{\sqrt{3} * b * kV} \quad kA \qquad (5)$$

Current sequence positive and negative segments are estimated as following equation

$$I_{a0} = I_{a1} = I_{a2} = \frac{V_{pu}}{Z_0 + Z_1 + Z_2} \qquad (6)$$

Where,

$$Z_1 = (jX_{g1} + jX_{F1}) // (jX_{R1} + jZ_L) \qquad (7)$$

$$Z_2 = (jX_{g2} + jX_{F2}) // (jX_{R2} + jZ_L) \qquad (8)$$

$$Z_0 = [((3R_{ng} + jX_{g0} + jX_H) // jX_T) + 3R_{ntr} + jX_{Lf}] // (jX_{R0} + Z_L) \qquad (9)$$

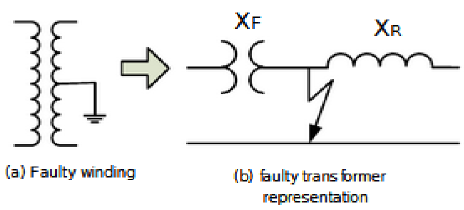


Fig.11. Intimation of faulty transformer

The fault current If is calculated as follows

$$I_f(pu) = 3I_{a0} \tag{10}$$

$$I_f(kA) = I_f(pu) * I_{base} \tag{11}$$

TABLE III. PROPOSED WORK ESTIMATION

Fault Winding	Simulated Fault Current (Amp)	Calculate Fault Current (Amp)	Error %
10%	217.8	221.3	1.61
40%	851	876.7	3.02
70%	1377.8	1430	3.79
90%	1620	1684	3.95

A. *Transformer Fault in R-Phase*

Different faults results into different% THD in no load line current. This paper shows the effect of fault and winding fault on no load current.

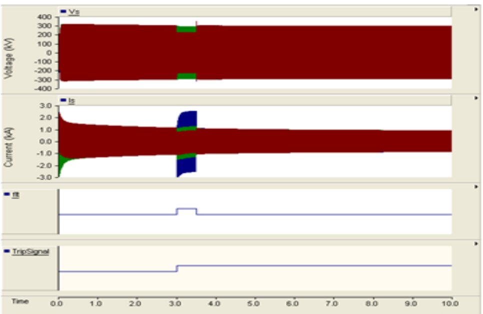


Fig. 12. Transformer fault in R-phase

Here the duration of fault is o.5[s], and time to apply fault is 3[s], where x axis represents time, y axis represents V_s (voltage KV), I_s (current KA), fault and trip signal. Fig.12 shows Transformer fault in R-phase.

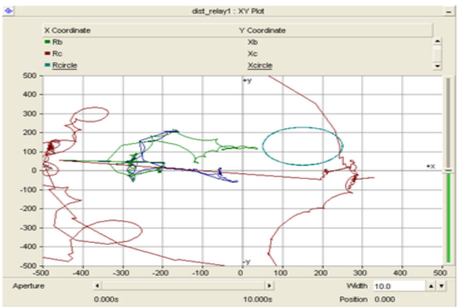


Fig.13. Mho circle fault in R-phase

In mho circle, x coordinates R_a, Rb, R_c and y coordinates X_a, X_b, X_c. similarly, R represents resistance and X represents reactance. Above fig. 13 shows mho circle fault in R-phase.

B. *Transformer Fault in Y-Phase*

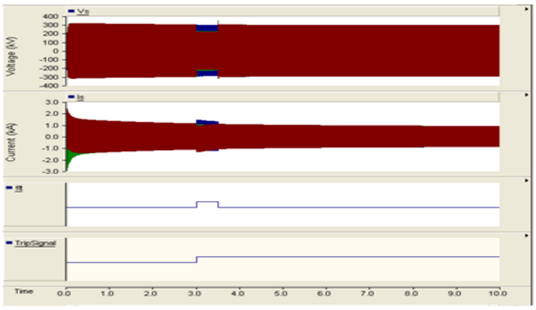


Fig.14. Transformer fault in Y-phase

Here the duration of fault is o.5[s], and time to apply fault is 3[s], where x axis represents time, y axis represents V_s (voltage KV), I_s (current KA), fault and trip signal. Fig. 14 shows Transformer fault in Y-phase.

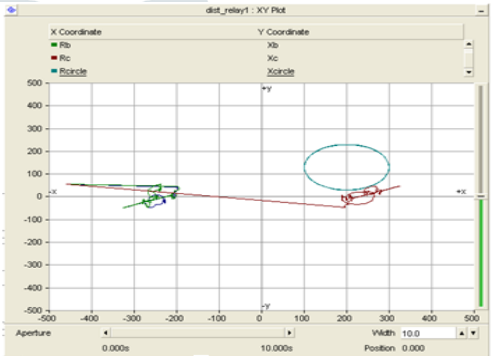
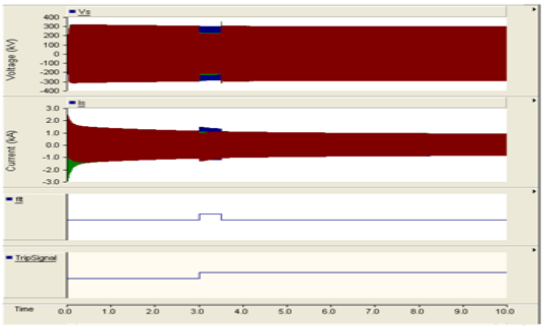


Fig.15 Mho circle fault in Y-phase

In mho circle, x coordinates R_a, Rb, R_c and y coordinates X_a, X_b, X_c. similarly, R represents resistance and X represents reactance. Above fig. 15 shows mho circle fault in Y-phase.

C. *Transformer Fault in B-Phase*



D. Fig.16. Transformer fault in B-phase

Here the duration of fault is o.5[s], and time to apply fault is 3[s], where x axis represents time, y axis represents V_s (voltage KV), I_s (current KA), fault and trip signal. Fig.16 shows Transformer fault in B-phase.

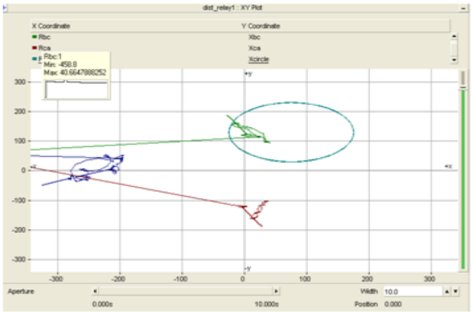


Fig.17 Mho circle fault in B-phase

In mho circle, x coordinates R_a, Rb, R_c and y coordinates X_a, X_b, X_c. similarly, R represents resistance and X represents reactance. Above fig.17 shows Mho circle fault in B-phase.

E. *Transformer Fault in Magnetic Inrush*

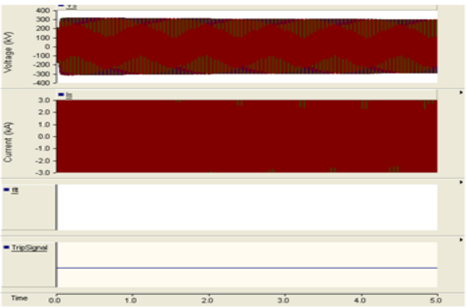


Fig.18. Transformer fault in Magnetic Inrush

Here the duration of fault is o.5[s], and time to apply fault is 3[s], where x axis represents time, y axis represents V_s (voltage KV), I_s (current KA), fault and trip signal. Figure 5.11 shows Transformer fault in magnetic inrush.

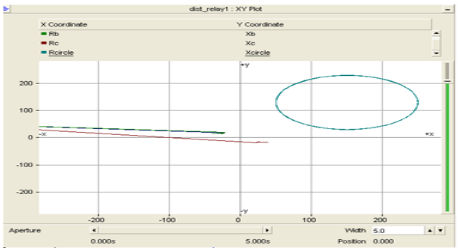


Fig.19. Mho circle fault in Magnetic Inrush

In mho circle, x coordinates R_a, Rb, R_c and y coordinates X_a, X_b, X_c. similarly, R represents resistance and X represents reactance. Above fig. 19 shows mho circle fault in magnetic inrush.

F. *Transformer Fault in Winding Fault*

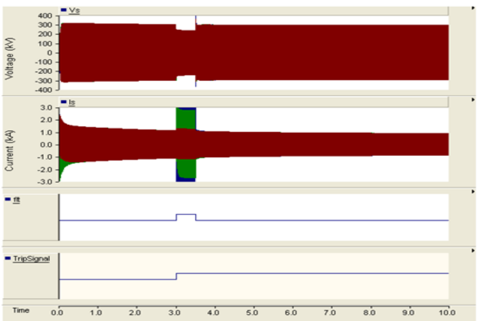


Fig.20. Transformer fault in Winding Phase

Here the duration of fault is o.5[s], and time to apply fault is 3[s], where x axis represents time, y axis represents V_s (voltage KV), I_s (current KA), fault and trip signal. Fig. 20 shows Transformer fault in winding phase.

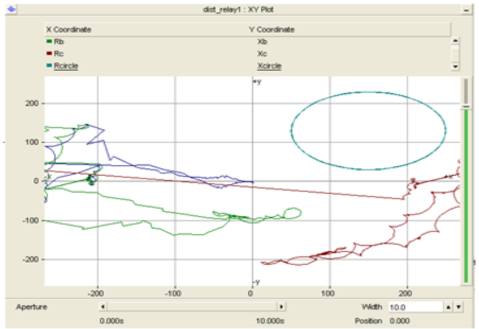


Fig.21. Mho circle fault in Winding Fault

In mho circle, x coordinates R_a, Rb, R_c and y coordinates X_a, X_b, X_c. similarly, R represents resistance and X represents reactance. Above fig. 21 shows mho circle fault in winding phase.

TABLE IV. SIMULATED FAULT CURRENT COMPARISON

Fault Winding	Proposed Simulated Fault Current (Amp)	Existing Simulated Fault Current (Amp)
10%	217.8	106.7
40%	851	740
70%	1377.8	1255
90%	1620	1410

V. CONCLUSION

Transformers are designed to transmit and distribute electrical power. In this paper the proposed work identifies different faults in transformer by using Generalised Regression Neural Networks. The purpose of the resilient back propagation (Rprop) training algorithm in proposed unit is to eliminate the harmful effects of the magnitudes of the partial derivatives. Only the sign of the derivative is used to determine the direction of the weight update; the magnitude of the derivative has no effect on the weight update. The size of the weight change is determined by a separate update value. The technique is very reliable for detecting any short circuit to the winding and discrimination of inrush currents, Single , three phase fault, magnetic inrush and no fault condition. Discrimination of fault and normal operating condition by resilient back propagation using GRNN is identified. Performance results are shown by the graphical representation demonstrate the efficiency of the proposed work.

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