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WAVELET TRANSFORM AND NEURAL NETWORK-BASED FUZZY LOGIC CONTROLLER FOR POWER TRANSFORMER PROTECTION

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ABSTRACT

Wavelet transforms are fast and efficient means of analyzing transient voltage and current signals. Compare with fast Fourier transform, wavelet transform gives better results in analyzing signals containing sharp spikes. Differential protection schemes are widely used by electric companies to protect power equipments. Normally, various techniques are used in power transformer protection. This paper proposed novel control technique for transformer protection. This protection approach is based on extracting the fundamental components present in differential currents. This paper aims to prove that the Wavelet Transform is a reliable and computationally efficient tool for fault currents. The a neural network based fuzzy logic controller is used to design protection relay for transformer. The simulation is done by MATLAB/SIMULINK software and results are shown clearly in this paper.

Keywords: Fast Fourier transform, wavelet transform, artificial neural network and fuzzy logic controller

1. INTRODUCTION

Transformer is expensive primary plant equipment within a power system network which needs to be isolated quickly and reliably in the event of a fault. Utilities have a responsibility towards the consumer to provide reliable and continuous power in the network without causing a large blackout or cascade power failure. Inrush and fault currents consist of DC component and harmonics and it is a challenging task to estimate and eliminate DC component which occur during transients. Inrush current happening due to switching of a power transformer on no load may lead to resonance. A resonance is said to have occurred in the power system when there is a slow damping of inrush current. It has been observed that during inrush phenomenon, the magnitude of the inrush current depends on the switching angle and switching instance of the circuit breaker. In a typical normal operating scenario, the primary and secondary current of a power transformer maintains equilibrium but when an internal fault occurs, this balance is disturbed. The magnitude of the fault current depends upon zone of occurrence, the type of the fault (i.e. phase to phase, phase to earth etc), vector group of transformer (i.e. star-star, star-delta, delta-star). The magnitude of an inrush phenomenon is usually 10-15 times the normal [1-6].

2. MAGNETIZING INRUSH CURRENT

This occurrence of transient magnetizing inrush occurs in the primary side of transformer when it is switched on. This current appears as a internal fault and it is sensed as a differential current by the differential relay. The value of the first peak of magnetizing current may be as high as several times of the peak of the full load current. The magnitude and duration of magnetizing inrush current is influenced by many factors as described below [7].

- The input supply of voltage level.
- The instantaneous value of the voltage waveform at the moment of closing Circuit Breaker.
- The value of the residual magnetizing flux.
- Depends on the sign of the residual magnetizing flux.
- Type of iron laminations used in transformer core.
- The saturation of flux density in the core of transformer.
- The final impedance of the supply circuit.
- The size of the transformer.

The effect of the inrush current on the relay is false tripping the transformer without of any existing type of faults. From the principle of operation of the differential relay the relay compares the currents coming from both sides of the power transformer. As the inrush current flows through the primary side of the power transformer and therefore the differential current will have a significant value due to the existence of current in only one side. Thus the planning of relay is to recognize that this current is a normal phenomenon and not to trip due to this current.

3. POWER QUALITY PROBLEMS DERIVED FROM MAGNITIZING INRUSH CURRENT

From a power quality perspective, magnetizing inrush current introduces disturbances that can significantly affect system stability and operation. This inrush current, characterized by its non-sinusoidal waveform, gives rise to two primary types of power quality issues:

- Current Unbalance
- Harmonic Distortion

Each of these problems is described in detail below.

3.1 Current Unbalance

While current unbalance is not traditionally classified as a disturbance, it is an important indicator of asymmetrical conditions within a power system. In the case of transformer energization, the magnetizing inrush current often leads to unbalanced phase currents due to asymmetric saturation of the core. This results in varying current magnitudes in each phase during the initial cycles.

The occurrence of current unbalance, alongside the presence of the second harmonic component, can be effectively used to detect and analyze inrush events during transformer energization. These indicators are also essential for distinguishing between inrush current and internal transformer faults.

3.2 Harmonic Distortion

The magnetizing inrush current contains a broad spectrum of harmonic components due to the non-linear behavior of the transformer core during saturation. Although multiple harmonic orders may be present, only a few play a significant role in power quality issues. These include:

I. DC or Offset Component:

A DC component is typically present in all three phases during inrush, though its magnitude may vary. This component is primarily influenced by the residual magnetic flux in the core prior to energization and can result in waveform asymmetry.

II. Second Harmonic:

The second harmonic is consistently observed in the inrush current of all three phases. Its presence is a direct result of core saturation and is often used as a key diagnostic feature in transformer protection schemes.

III. Third Harmonic:

The third harmonic can appear with magnitudes comparable to the second harmonic. It arises due to symmetrical saturation of the transformer core and contributes to the distortion of the current waveform.

IV. Higher-Order Harmonics:

Although higher-order harmonics (beyond the third) are present during inrush events, their amplitudes are generally low and can often be neglected in power quality assessments.

4. TECHNIQUES TO DISTINGUISH INRUSH AND FAULT CURRENT

There are several ways of discriminating fault and inrush condition for protection purpose[9-10].

- Desensitization method is no longer being practised.
- Wave shape recognition methods are still relatively new and not widely practised.
- Harmonic based methods

These methods are widely practiced. The inrush current has a large harmonic component which is not present in fault currents. Inrush currents generate harmonics with second harmonic amplitudes as high as 65% of the fundamental. Thus SHR (second harmonic ratio) is used to discriminate inrush current from fault current such that, if SHR is less than threshold value then that condition can be considered as fault and if SHR is more than threshold value then there is inrush current condition Using artificial intelligent technique New techniques like artificial intelligent technique (fuzzy logic controller) can help to discriminate between magnetization and fault conditions. Let us elaborate this technique and evaluate its advantages over others.

5. THE FUZZY LOGIC CONTROLLER

The concept of fuzzy logic was first introduced by Lotfi Zadeh and has since evolved into a powerful tool for controlling systems characterized by non-linearity, imprecision, and uncertainty. Fuzzy logic controllers (FLCs) have been successfully applied across various domains, particularly where conventional control strategies struggle to cope with dynamic or uncertain environments.

One of the most commonly used structures is the error-feedback-based fuzzy logic controller. Within this category, there are further variants such as the proportional-derivative (PD), proportional-integral (PI), and proportional-integral-derivative (PID) types of FLCs. These controllers mimic the behavior of classical control systems but enhance flexibility by incorporating linguistic rules and fuzzy reasoning, which allow for smoother transitions and more adaptable control logic.

The functioning of an FLC typically involves four key stages. The first is fuzzification, which is the process of converting crisp numerical input values into fuzzy sets. This allows the controller to interpret inputs in a way that reflects real-world vagueness or ambiguity, such as defining a temperature as "high" or "moderate" rather than assigning an exact number.

Next is the knowledge base, which includes both the data base and the rule base. The data base provides the necessary parameters and membership functions for fuzzification and defuzzification processes, while the rule base encapsulates expert knowledge in the form of "if-then" rules. These rules govern how the system responds under various conditions and represent the heart of the decision-making process in fuzzy logic control.

Discrete Wavelet Transform (DWT)

In the realm of signal processing for power system protection, especially differential protection of transformers, traditional techniques based on the Fast Fourier Transform (FFT) often fall short. These methods tend to overlook high-frequency transient components and are limited by their reliance on fixed windowing techniques, which can introduce time delays and reduce detection accuracy during fast-changing events.

By decomposing signals into orthogonal wavelets at various scales and positions, the DWT allows for multi-resolution analysis, providing a detailed representation of signal features at different frequencies and times. This makes it ideal for real-time fault detection, especially in systems where rapid and accurate decision-making is critical.

Wavelets are inherently suitable for analyzing non-stationary signals and have been widely used across fields such as audio processing, image compression, and biomedical signal analysis. In power systems, the application of DWT significantly enhances the ability to detect, classify, and respond to abnormalities with higher precision and reduced latency compared to traditional Fourier-based methods.

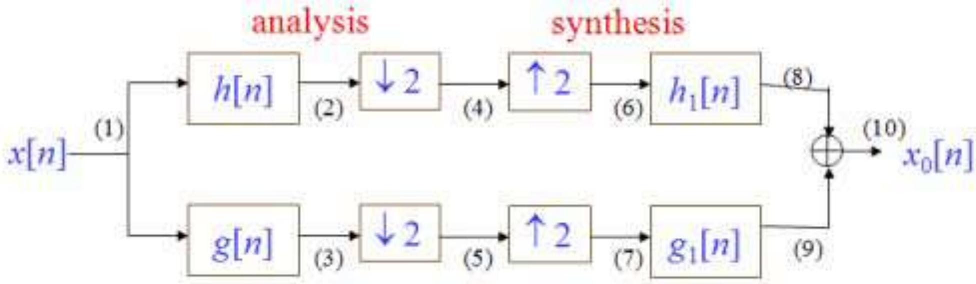

Figure2: Wavelet transform

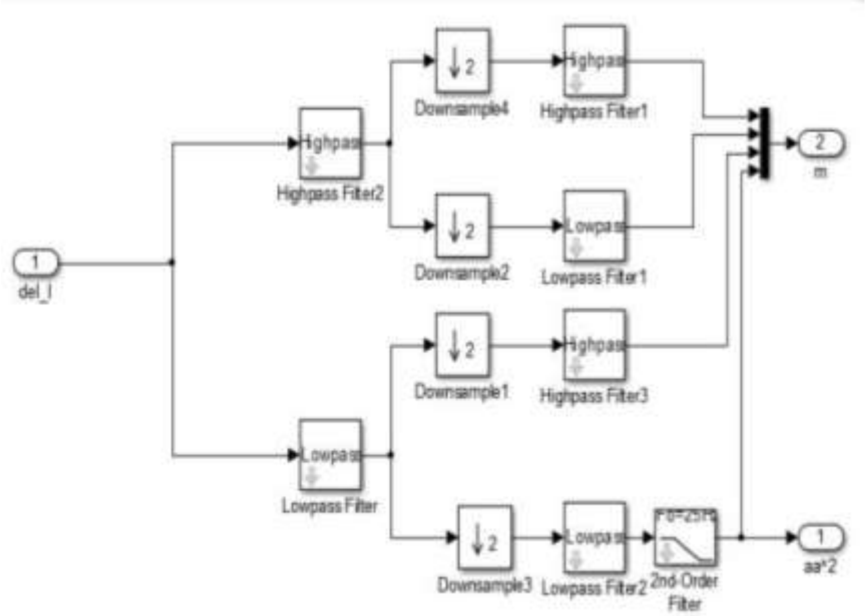

Figure 3: Simulink model of wavelet transform

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6. SIMULATION AND RESULTS

The 13.8/138V system is modeled by using MATLAB/SIMULINK software. As shown in Fig.5The source issimulated by an equivalent 50 Hz 30MVA Synchronousmachines with 500 MVA transformer and 50 MW load isconnected in parallel. A .8(13/138) kV star to delta connectedtransformer is employed with its neutral grounded. The generator *X/R*ratio is 7. The primary winding voltage *R*(*pu*) and *L*(*pu*)are 13.8 kV.0.0078 and 0.259 respectively, and secondarywinding voltage is *R*(*pu*) and *L*(*pu*) are 138 k.V 0.0078 and0.259 respectively. The load taken hereis 50 MW and 10 MVAR.

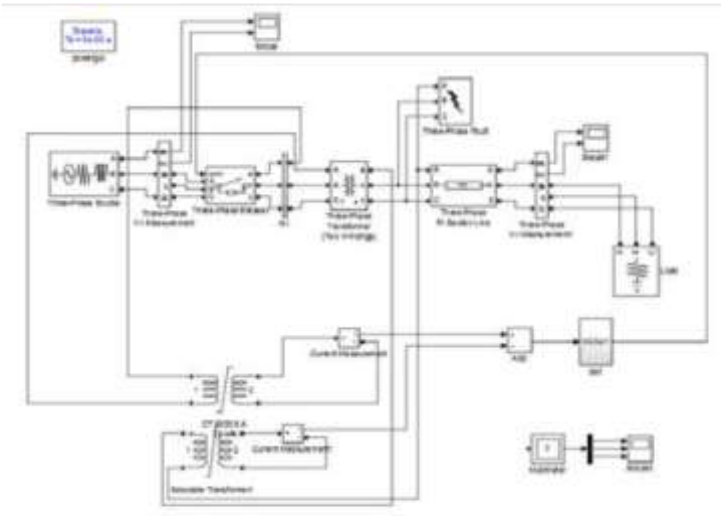

Figure 4: Matlab Simulink Model

6.1 Simulation of Neuro fuzzy controller

To identify the fault currents in transmission system various technique are used. The current in primary and secondary side of the transformer are measured by using current transformer. As shown in fig.3 From this differential current approximation and detailed coefficients were detected by discrete wavelet transform. From the approximation coeffitients relaying algorithm is derived by using Neuro fuzzy.

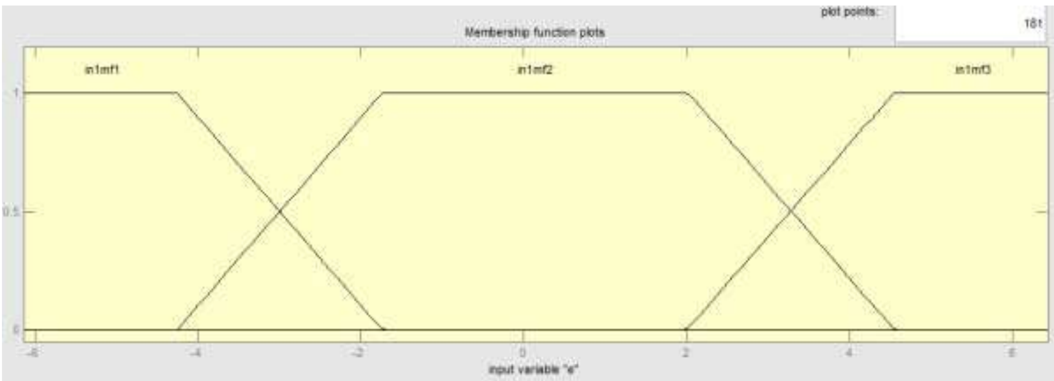

Figure 5 (a) Membership function of e

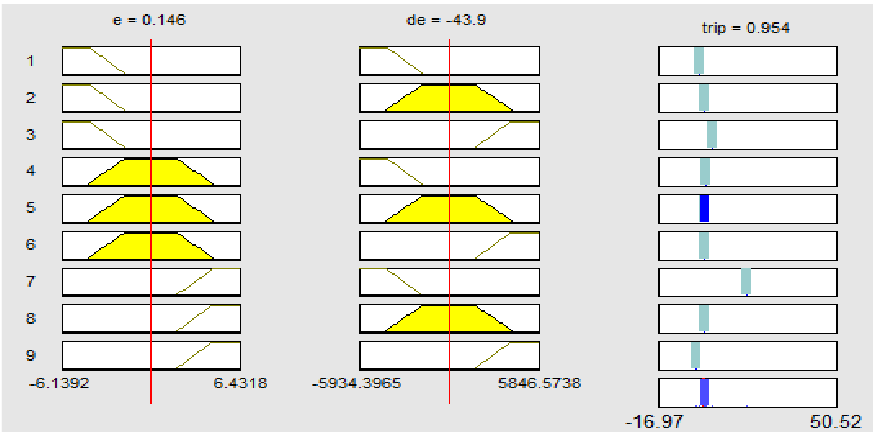

Figure 6: Rule viewer

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Results The Voltage and current waveforms for various conditions (without fault, with fault and with tripping algorithm) are shown in the figures below. Fig.10(a) - (b) and Fig.11(a) – (b) represented Voltage and current waveforms under normal condition at no fault in a transmission line.

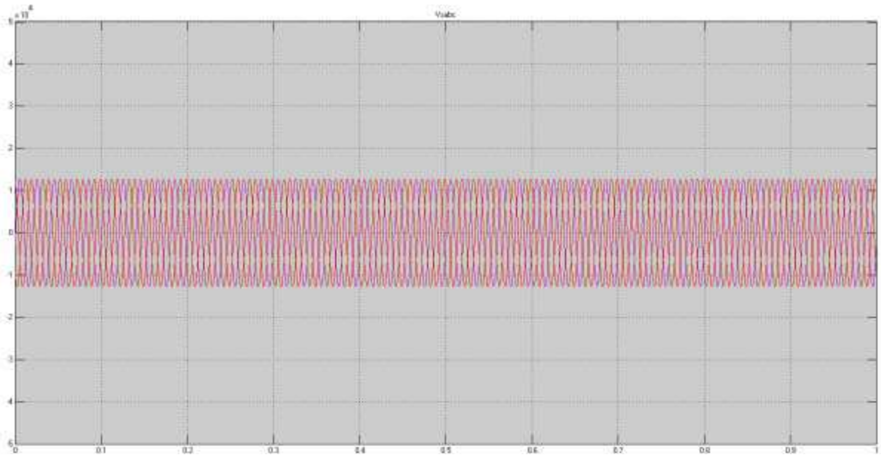

Figure 7: (a) Grid V under normal condition

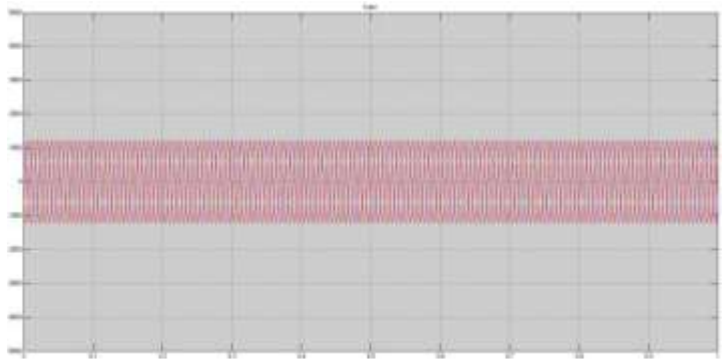

Figure 8: (b) Grid I under normal condition

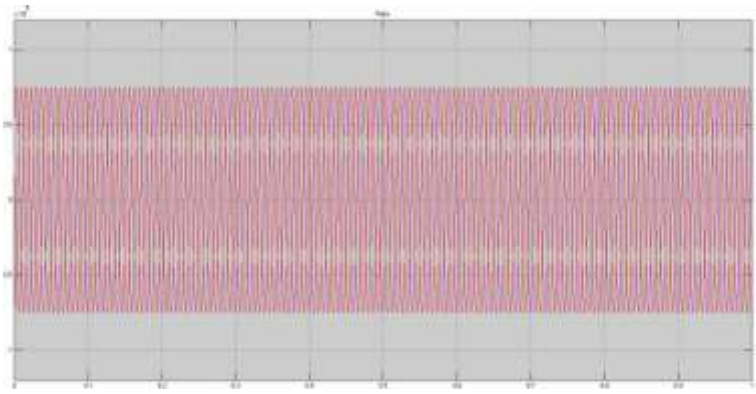

Figure 9: (a) The Load V under normal condition

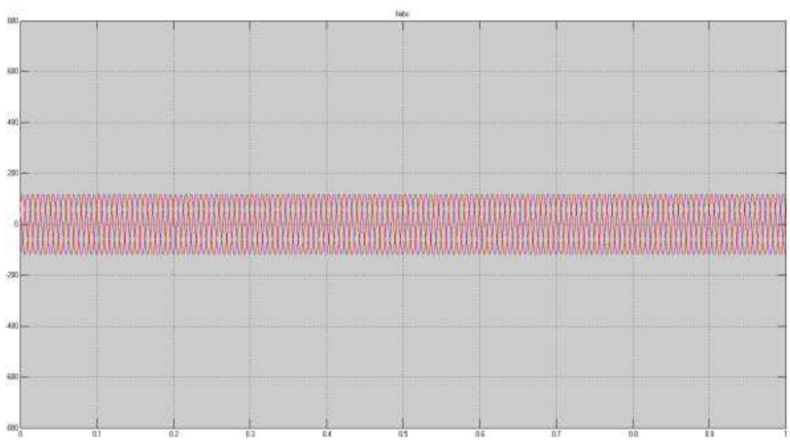

Figure 10: (b) The Load I under normal condition

7. CONCLUSION

In the present work wavelet transform, fuzzy controller and Neuro fuzzy controller are used to protect power transformers from faults. The simulation results show that the protection system based on wavelet transform is suitable for relay protection for all types of fault. A simple decision making logic scheme using fuzzy logic ANFIS is presented for the developed technique for faults identification. The simulation waveforms show that the Neuro fuzzy based relays are tripping properly during the faulty condition. The extensive simulation results presented show that the proposed technique needs very simple input signals.

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