Protection of power transformer based on modeling and simulation of transformer faults using MATLAB/SIMULINK

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Abstract: The magnetizing inrush current of power transformers poses a significant challenge to the differential protection relay's successful identification of internal fault currents. To differentiate between these two types of currents, this paper proposes an approach that uses wavelet coefficients and relies on feature extraction based on discrete wavelet transforms. The wave shape recognition criteria generated from instantaneous differential currents are used to determine the discriminating function. The most serious problems in transformers are issues with their internal windings. To protect transformers, differential protection schemes are commonly used. However, a differential overcurrent relay may not detect an internal fault early on because the increase in current is too small when only a few turns are shorted. Due to the seriousness of internal winding problems, the distribution system must be shut down, and the transformer can be completely damaged. Conducting real-life experiments on these defects isn't practical because it could ruin the transformer. Therefore, computer simulations are used to study these issues. Most studies on internal winding failures in transformers use EMTP simulations. In these studies, the transformer is represented using equations and its equivalent circuit. The primary voltages are used as inputs, and the secondary currents are the outputs. MATLAB/SIMULINK is used to model and simulate transformer inter-turn failures. The simulations use equations to represent these faults, and the results confirm the accuracy of the model.

Keywords: Transformer differential protection, inrush currents, Inter-turn faults, Modelling, MATLAB.

I. INTRODUCTION

The power transformer plays a critical role in today's technology-driven world, serving as a vital component of the power system. Without it, the current power utilities would not be possible. However, differential relays can malfunction in the presence of transformer inrush currents, which result from transients in transformer magnetic flux. To prevent tripping during magnetizing inrush conditions, the conventional approach employs the second harmonic component of differential currents to restrain the operation of the differential relay. Nonetheless, harmonic restraint methods may not always be effective in preventing differential element operation for unique cases with low harmonic content in the operating current. Therefore, modern methods are required to distinguish inrush current from fault current to ensure security while maintaining fast and dependable operations when energizing a faulted transformer. To achieve this, high-performance relays are essential, especially in terms of operating speed. Magnetizing inrushes also exhibit a peaked wave characteristic caused by asymmetric saturation of the transformer core. Identifying magnetizing inrushes by these characteristics opens up a new avenue of research to improve the operating speed of relays.

II. LITERATURE REVIEW

The use of the presence of a second harmonic component in the magnetizing inrush current to distinguish between magnetizing inrush current and internal fault is no longer reliable, as the second harmonic component can also be present during internal faults caused by other factors such as current transformer saturation or the presence of a shunt capacitor [4],[13]. Transformer protection methods include considering the transformer inductance during saturation, calculating flux from the integral of voltage, and using differential current. New methods such as ANN and fuzzy logic have been adopted, and techniques have been developed to identify magnetizing inrush and internal faults [16], [12]. The wavelet-based signal processing technique is an effective tool for analyzing and extracting features from power system transients [4]. The wavelet-based method can be used to identify both inrush current and internal faults. The second harmonic component is used as a characteristic component of the asymmetrical magnetization peculiar to the inrush. The wavelet transform concept is used, which provides multi-resolution in time and frequency, allowing for accurate time location of transient components while retaining information about the fundamental frequency and its lower-order harmonics, facilitating the detection of transformer inrush currents. The technique detects inrush currents by extracting wavelet components from the line currents using a data window of less than half a power frequency cycle. The results demonstrate that the proposed technique can offer the desired responses and can be used as a fast and reliable method for distinguishing between inrush magnetizing and power frequency faults [8].

III. METHODOLOGY

A turn-to-turn fault in a transformer happens when there's a problem with its windings. The windings are coils of wire with many turns, and a fault means there's a short circuit between two or more turns in one of these coils. Detecting and isolating these faults early is crucial to prevent damage. To protect a transformer from these faults, it's important to identify which specific coil or winding has the problem. Turn-to-turn faults can be caused by issues like insulation failure or a short circuit between two turns. These faults can hinder the transformer's ability to transfer energy efficiently and disrupt the flow of electrical current. To understand the impact of such faults on the transformer's performance, you can conduct experiments or simulations. By analysing data like voltage and current waveforms, you can determine the severity of the issue and how it affects the transformer. Based on this analysis, you can decide the appropriate course of action.

IV. MODELING OF POWER SYSTEM COMPONENTS

The electric power system discussed in this study was designed using MATLAB/Simulink blocks. To provide a visual representation, Matlab/Simulink model are shown in Fig. 1. The system is composed Y/Y power transformer with two windings and a grounded neutral. The transformer has a rated capacity of 50 MVA and rated voltages of 132/33 kV. The simulation considers different power system conditions, such as energizing conditions and internal faults at the power transformer terminals, to account for various possible scenarios.

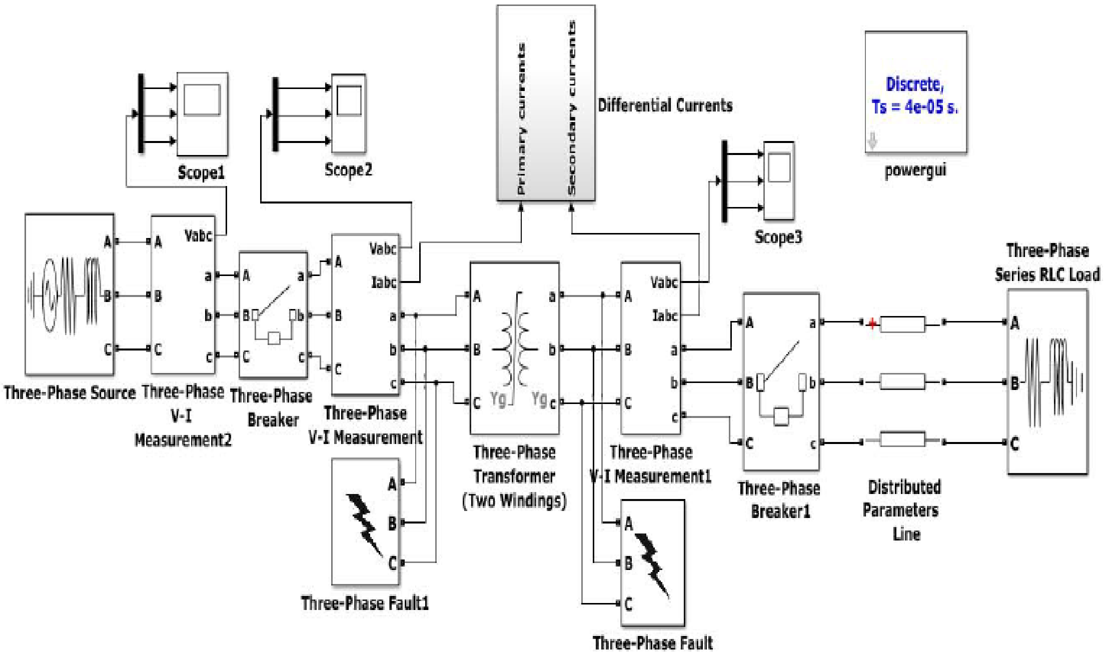

Fig.1. MATLAB /Simulink Model of the proposed system.

V. RESULT & DISCUSSION

Simulations were conducted on a three-phase star-star transformer, focusing on an inter-turn fault in phase B of the primary winding. The simulations used the specifications outlined in Table I. To identify inter-turn faults, four different scenarios were examined. Each scenario varied the number of shorted turns and the fault resistance values, with faults occurring in either the primary or secondary winding of phase B. To evaluate the proposed methodology, three cases of internal faults were examined: line-to-ground, line-to-line, and turn-to-turn faults. The algorithm was implemented using MATLAB.

A: Magnetizing Inrush Current

When a transformer is turned on, a temporary current called magnetizing inrush current flows until normal magnetic conditions are established. Usually, this current is not a problem, but in rare cases, it can temporarily disrupt the system's proper operation. Due to the many factors involved, an investigation was conducted to understand the effects of transformer inrush currents under various system conditions. This paper discusses how inrush currents are generated, the results of tests and calculations, and studies using a miniature-system analyzer. It also covers the factors that influence the significance of inrush currents and methods to reduce or mitigate their effects.

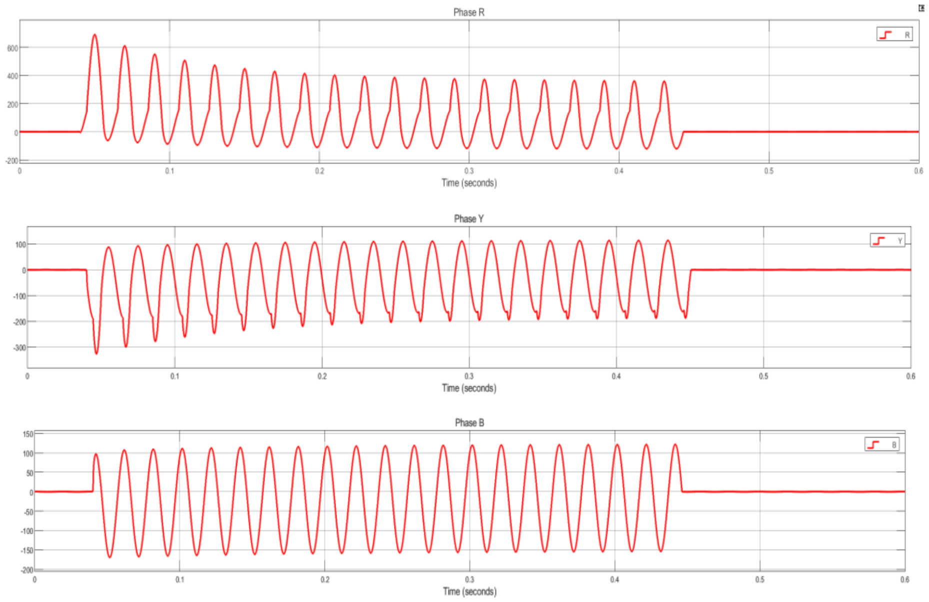

Fig.2. Magnetizing Inrush Current

B: Phase to Ground Fault

Consumers are more likely to experience problems due to faults in energy distribution systems than in production and transmission systems. Production and transmission systems are arranged in a way that ensures not all parts fail at once, so there's always an alternative power supply available. A short-circuit occurs when insulation breaks down between phase conductors or between phase conductors and the ground in grounded networks. This can also happen due to incorrect operations in electrical installations, causing a large current surge. Electrical equipment in the system is designed to handle the highest possible short-circuit current. When choosing and setting fuses and protection devices, the lowest short-circuit current is considered.

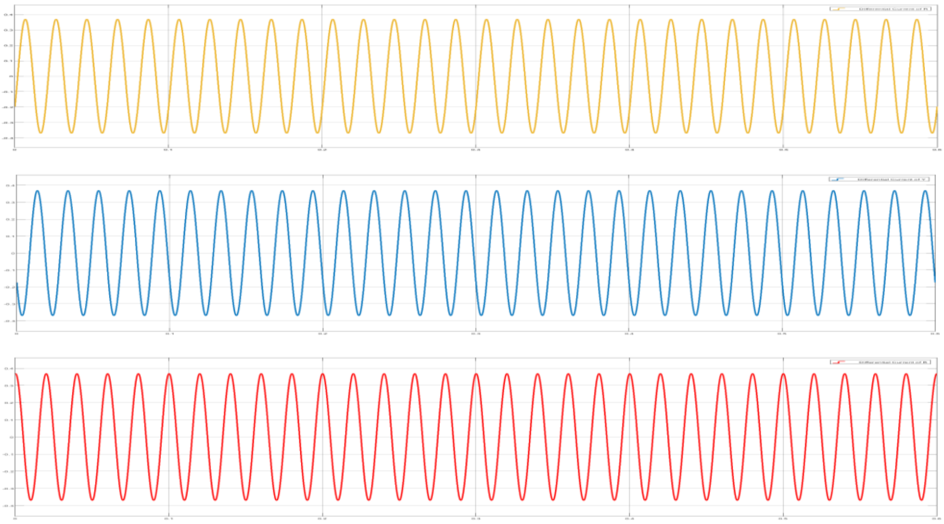

Fig.3. Phase to Ground Fault

C: Turn to Turn Fault

The model includes inductance for both the healthy winding turns and the short-circuited turns, which is important for accurate fault analysis. The resistance in the model represents the copper losses in the windings and any extra resistance due to the fault. This low resistance between the short-circuited turns leads to high fault currents. The model also includes the voltage source supplying the transformer or motor and the connected load, which affects fault current levels and system response. Simulating turn-to-turn faults with this model helps predict fault currents, identify hot spots, and assess the thermal and mechanical stresses on the electrical equipment. This analysis is crucial for designing protective measures and improving the reliability of power systems.

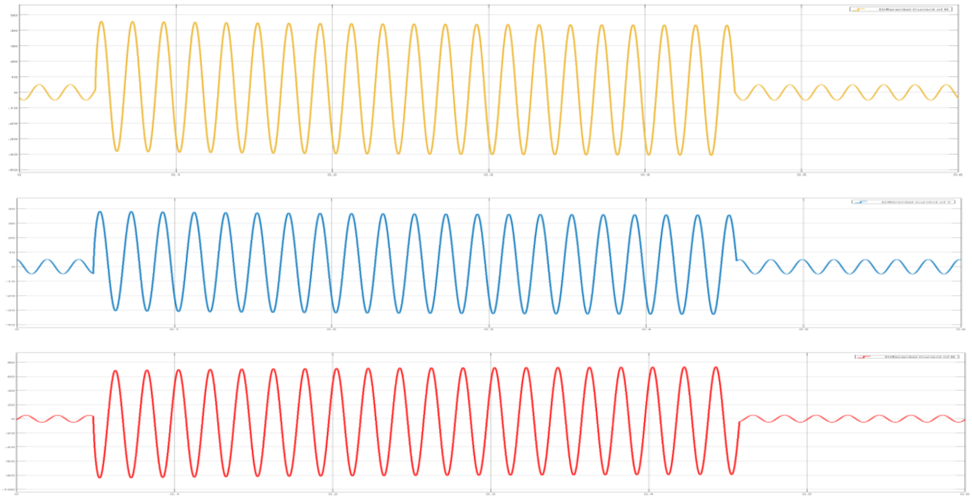

Fig.3. Turn to Turn Fault

The healthy portion of the faulty winding under various shorted turns is shown in Fig. 4, a column chart, together with the increase in flux of shorted turns. It indicates that a faulty winding with more shorted turns will have a greater flux in those turns. Likewise, an increase in the shorted turn causes a decrease in the flux of the transformer's healthy portion of the faulty phase.

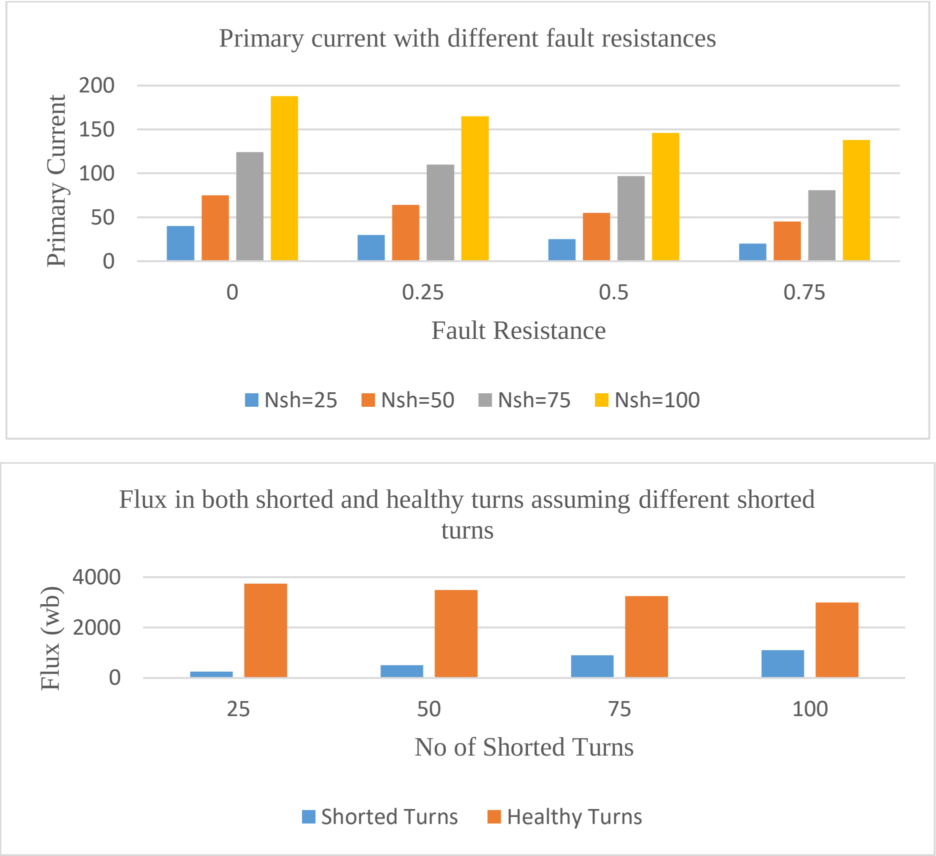

Fig.4. Healthy portion of the faulty winding under various shorted turns

VI. CONCLUSION

The suggested model was tested under both healthy and faulty conditions. It was found that faults, whether on the primary or secondary side, cause a significant circulating current, which increases the primary side current of the faulty phase. When the fault is on the primary side, it has no noticeable effect on the secondary side current. It was observed that fewer shorted turns result in a greater circulating current due to reduced winding impedance. Also, the primary current decreases with fewer shorted turns because a healthy winding allows more flux to flow through it than a shorted winding. Adjusting the fault resistance can control the primary phase current, fault current, circulating current severity, and the flux density around the core. Lower fault resistance leads to higher fault currents, and more shorted turns result in higher current flow. The study also assessed the performance of differential and over-current relays during three-phase faults. MATLAB-generated signals with 20 dB SNR noise were used to test the method. Multiple scenarios, including internal faults and inrush currents, were simulated to evaluate the method's effectiveness and accuracy. Various case studies demonstrated the approach's effectiveness and reliability.

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