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ANALYSIS OF MODERN DIGITAL DIFFERENTIAL PROTECTION FOR POWER TRANSFORMER

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Keywords:.

ABSTRACT

This paper presents the analysis of digital differential protection for three phase power transformers. Power transformer is the key element in electrical power system. Proper protection is needed for economical and safe operation of electrical power system. Power transformer protective relay should block the tripping during external fault or magnetizing inrush and speedily operate the tripping during internal faults. The foremost objective of this paper is to analyze digital differential protection during internal and external fault and to operate the relay with proper fault discrimination.

INTRODUCTION

Power transformer is a static piece of apparatus with two or more windings which, by electromagnetic induction, transforms a system of alternating voltage and current into another system of voltage and current usually of different values and at the same frequency for the purpose of transmitting electrical power.‖ (IEC 600761 standard). Power transformer protective relay should block the tripping during magnetizing inrush and rapidly operate the tripping during internal faults [1]. IEEE defines a protective relay as ―a relay whose function is to detect defective lines or apparatus or other power conditions of an abnormal or dangerous nature and to initiate appropriate control circuit action. The power transformer is one of the prominent elements in power system. Electrical protective relaying of power transformer, in which transient magnetizing inrush and internal fault must be distinguished, is based on a percentage differential relaying technique [2]. Power transformers are subject to different natures of transient disturbances including internal fault, magnetizing inrush, and external fault and through-fault currents. Harmonic-restrained differential relay is centred on the fact that the magnetizing inrush current has a large second harmonic component, and nowadays the above technique is widely applied [3]. But this technique must be customized because harmonics occur in an ordinary state of power system and the magnitude of second frequency component in inrush state has been decreased because of the advancement in core steel. There are cases in which the presence of differential currents cannot make a clear perception between fault and inrush. New relaying technique with high reliability is required for flexibility in spite of change of condition in power system.

GENERAL DESCRIPTION

As the primary protection of power transformers for many years differential protection has been employed. The foremost problem of differential relays is the potential maloperation caused by the magnetizing inrush currents and current-transformer (CT) saturation. Conventionally, the second harmonic restraint method is adopted to prevent the malfunctioning of differential relays caused by the magnetizing inrush current [3-6]. Nevertheless, during internal faults, the second harmonic component may also exist due to the CT saturation, the existence of a shunt capacitor, or the distributed capacitance of the long ultra-high voltage (UHV) transmission line to which the transformer may be connected [6]. The percentage restraint characteristic of differential relays is broadly used to reduce the possible maloperation caused by CT saturation, but the reliability of differential relays cannot be guaranteed when CT becomes severely saturated [7].

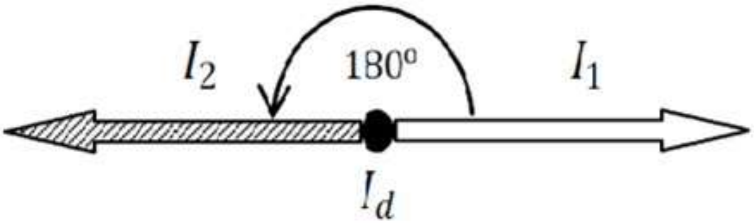

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Figure 2. Output currents of the CTs are equal in magnitude and opposite in direction

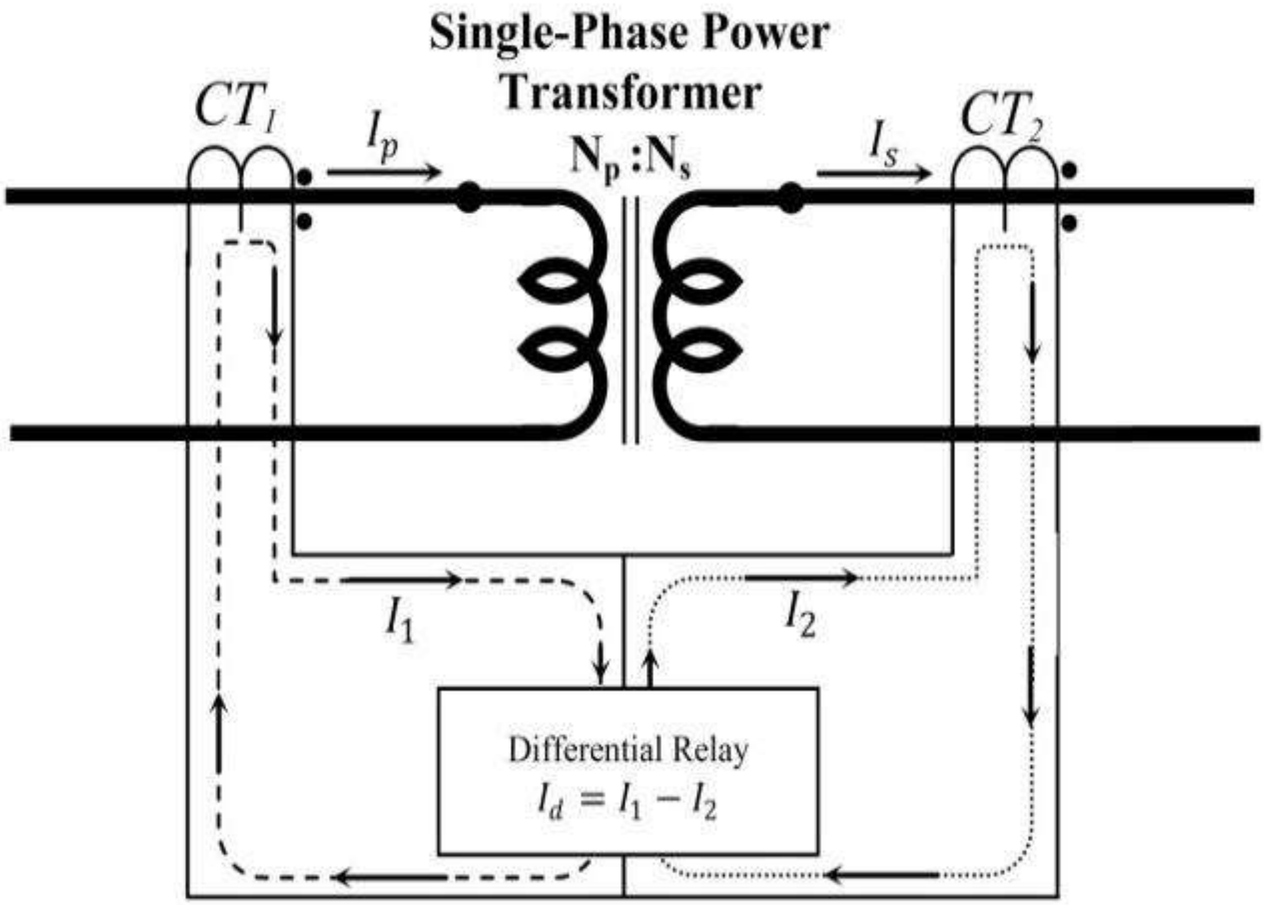

Figure-1. Differential Relay Connection Diagram

The differential protection converts the primary and secondary currents to a common base and compares them. The distinction between these currents is small during normal operating conditions. The variance is also small for external faults, but is larger than the difference for normal operating conditions. However, difference becomes significant during an internal fault in a transformer. The differential protection is then based on matching the primary and secondary current of the transformer for ideal operation. Transformer core generally retains some residual flux when transformer is switched off. Later, the core is likely to saturate when the transformer is re-energized. If the transformer is saturated, the primary windings draw large magnetizing currents from the power system [8]. These results in a large differential current which cause the differential protection relay to operate. The design is implemented to protect the power transformer against internal faults and prevent overreaction or malfunctioning due to inrush currents [9]. A simplified diagram of differential protection for power transformer is as shown in the figure 1. The current in the primary side of transformer is denoted by I1 and the current flowing in the secondary side of transformer is denoted by I2 as shown in the figure 2. The connections of both the CTs are such that the current I1 and I2 are having a phase difference of 180°.

The currents I1 and I2 are no longer equal in magnitude and opposite in direction if there are any disturbances or fault in the power transformer protected zone. That means the differential current I1 and I2 has a significant value as shown in figure. 3

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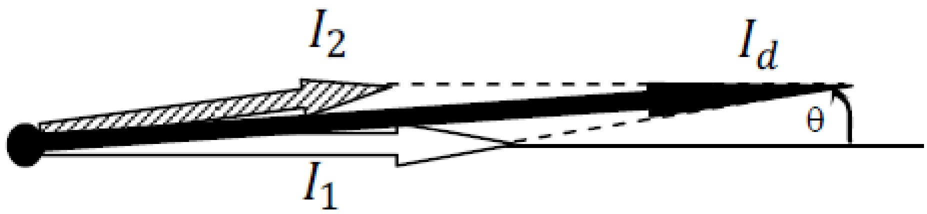

Figure 3. Output currents of the CTs under faulty conditions

The differential relay actually compares between primary current and secondary current of power transformer, if any unbalance found in between primary and secondary currents the relay will actuate and sends the trip signal to both the primary and secondary circuit breaker of the transformer. A generalized flowchart for the implementation of digital differential relay for power transformer is as shown in the figure 4.

PROPOSED ALGORITHM

In the first step the data is acquired from primary and secondary of power transformer. After acquiring the data from both primary and secondary of power transformer, the signals are processed and differential currents are calculated. The differential current (also called operating current) Id be obtained as the sum of currents entering and leaving the protected zone, according to Id = I1- I2 (1) These data are the inputs of the fuzzy system. The fuzzy system is designed to make a distinction between internal faults and other operating conditions of power transformer.

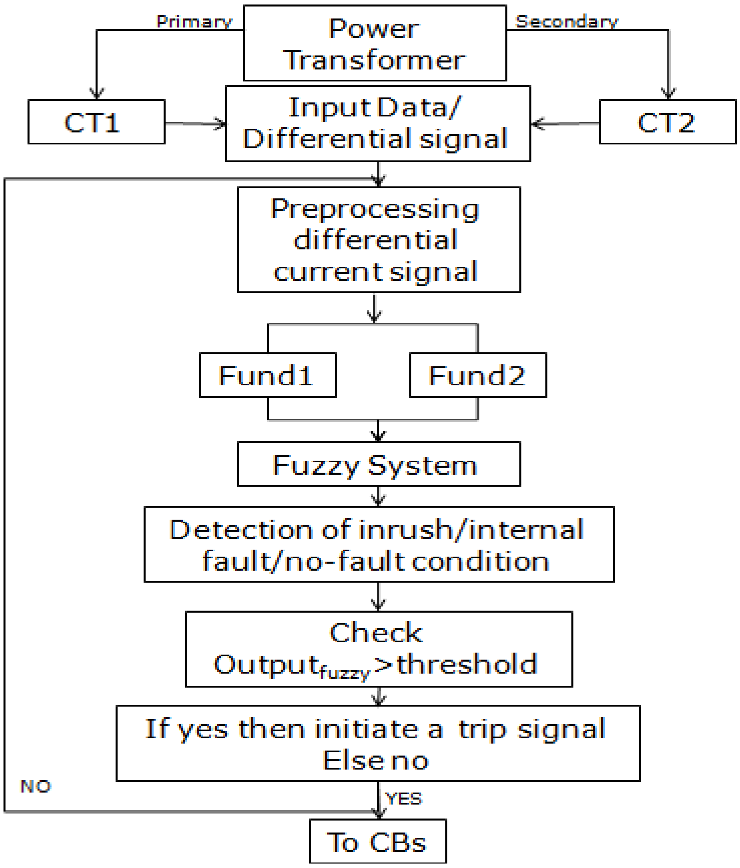

Figure 4. Basic steps involved for implementing the digital differential protection for transformer

If the output of the fuzzy system is greater than the threshold value the relay sends a trip signal to the circuit breaker.

Fuzzy Logic-Based Protective Relay [11, 12, 15, 17]

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The relay logic part of the scheme accepts the phasor current values of the fundamental, second and fifth harmonic components from the relay algorithm. A trip decision is made based on these phasors. The trip decision is based on the relative amplitude of the fundamental component compared to the second (Feven) harmonic components of differential current signal. The process in the fuzzy inference system involves the following sections.

A. Fuzzification:
Fuzzy logic uses linguistic variables as an alternative of numerical variables. In the real world, measured quantities are real numbers (crisp). The procedure of converting a numerical variable (real number) into a linguistic variable (fuzzy number) is called fuzzification. It is the arrangement of input data into suitable linguistic values or sets. Figure 5 (a)–(c) demonstrate the membership functions of the inputs and the output fuzzy set. For fuzzification of a defined input variable Ffund, a range is set between 0 and 100 and the membership values range from 0 to 1. For the input variable F2, a range is set between 0 and 100. The output variable is shown in Figure 5 (c) ranging from 0 to 1 for two membership functions that determine block or trip signals.

B. Inference Method
Fuzzy inference is a process that makes a conclusion in parallel. In accordance with this property, there is no data loss throughout the course of action and so final fault detection will be far more specific than that of conventional relaying techniques.

C. Defuzzification:
The method needed a crisp value for control purposes. The technique applied a centroid of area method.

D. Membership Functions of Proposed Approach
A membership function is a function that defines how each point in the input space (universe of discourse) is mapped to a membership value varies between 0 and 1. The section of membership function type depends upon the designer skill and the problem under consideration.

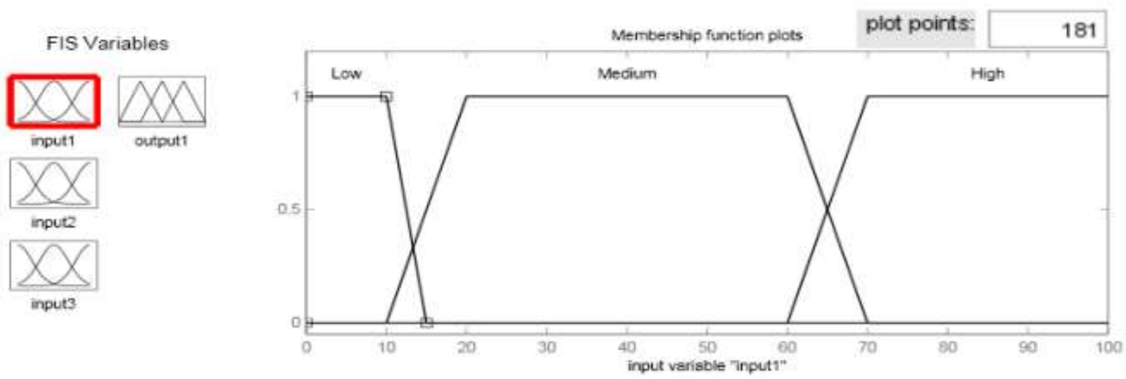

Figure 5(a). Input Variable Feven

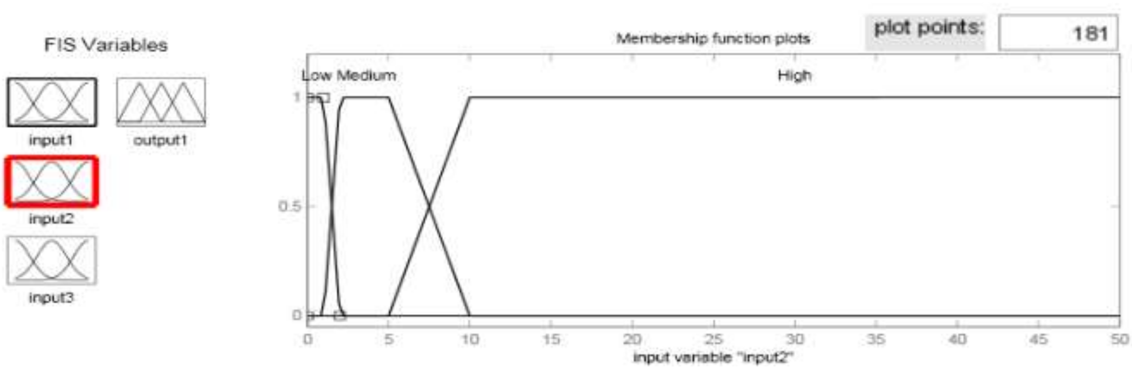

Figure 5(b). Input variable Feven

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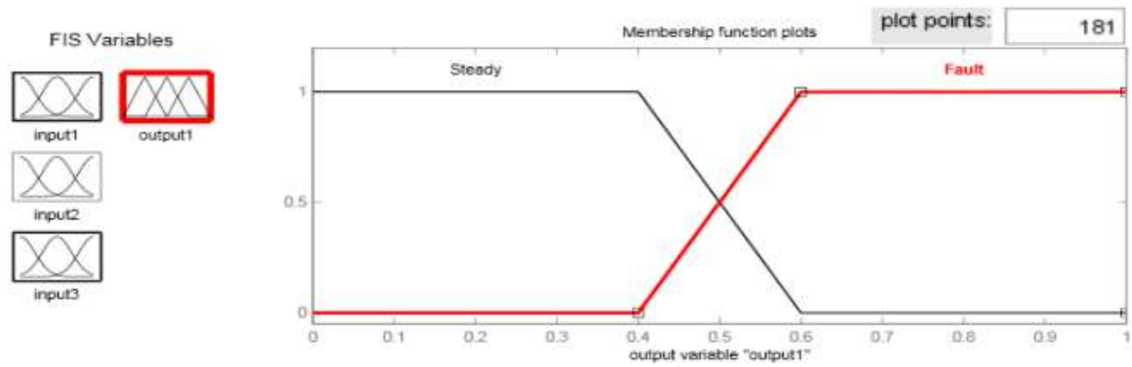

Figure 5(c). Output Variable

The output of proposed fuzzy based relaying result from the centroid of area defuzzification method.

$$Output = \frac{\sum_{j=0}^{n} y_j \mu_j (y_j)}{\sum_{j=0}^{n} \mu_j (y_j)}$$

where, yj is the value of each point on a domain of a final output fuzzy set and $\mu F(yj)$ is the membership value at each point.

E. Control Rule Base of the Proposed Approach

The control rule base's content is a linguistic description to achieve the control function. This linguistic based description take the form IF primes then consequent rule. Number of fuzzy inference rules for the proposed relaying for transformer protection is 18 rules. The proposed relay uses robust rules to make a distinction between two operating conditions i.e.

a) Steady state, and

b) Internal faults.

The 18 fuzzy inference rules are classified to three categories depending on the matrix of input variable. In this work, the compositional fuzzy inference matrix were using, where (Max-Min) method is chosen to perform a mathematical operation. The fuzzy rules are tabulated as follows:-

Table –I Implication of Fuzzy Rules

S No	F1	Feven	Output	Trip/No Trip
1	Low	Low	Steady	No Trip
2	Low	Medium	Steady	No Trip
3	Low	High	Steady	No Trip
4	Medium	Low	Fault	Trip
5	Medium	Medium	Fault	Trip
6	Medium	High	Steady	No Trip
7	High	Lw	Fault	Trip
8	High	Medium	Fault	Trip
9	High	High	Fault	Trip

RESULTS AND DISCUSSION

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For analysis purpose the data from a 10MVA, 11kV/132kV, 50Hz, star/star connected Power Transformer is used in this system. The implementation is done using Matlab/Simulink environment. The main idea of this segment is to present quite a few results regarding the algorithm. A variety of different tests were simulated for distinct operating conditions of power transformer. For briefness, only few cases are reported here.

Case I
Fault outside the protected zone (external fault) :- For an external fault, the simulated result is as shown in figure 6 (a), and the relay output is as in the figure 6 (b). The relay output value zero concludes that in case of fault outside the protected zone, i.e., external fault, the proposed relay is not giving any trip signal to the circuit breaker

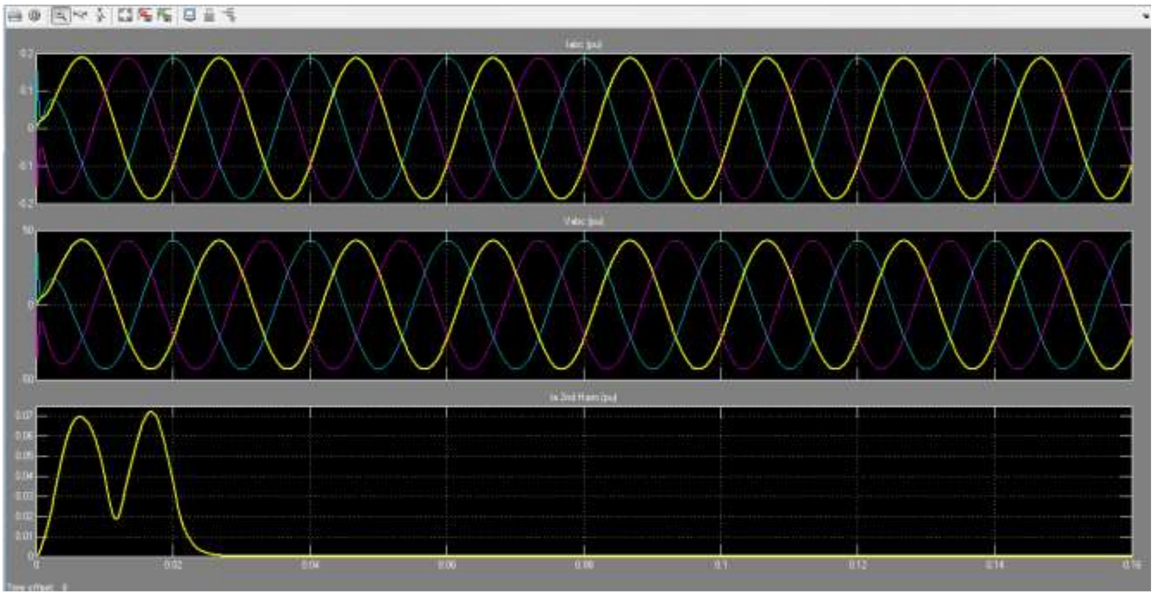

Figure 6(a). Simulated result for external fault and the relay output(trap signal)

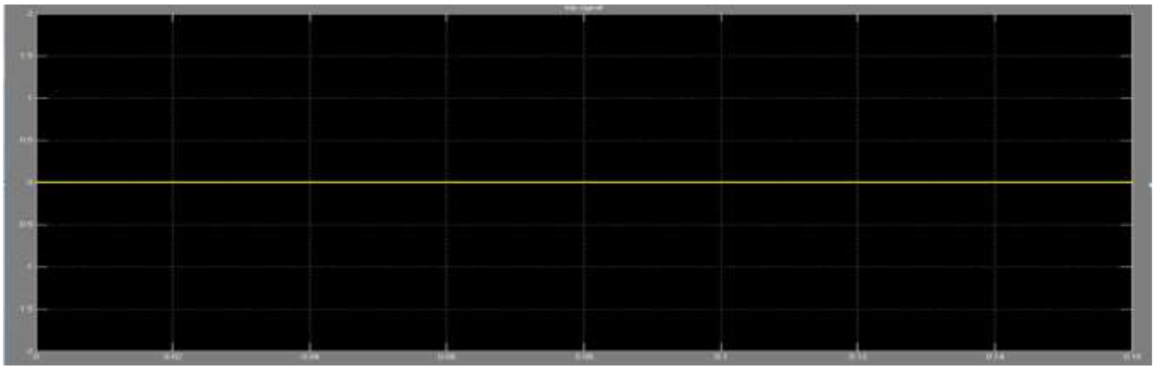

Figure 6(b). Simulated result for external fault and the relay output (trap signal)

Case II
Fault within the protected zone (internal fault): - For an internal fault (three phase fault), the simulated result is as shown in figure 7 (a), and the relay output is as in the figure 7 (b). The relay output value one concludes that in case of fault within the protected zone, i.e., internal fault, it attains the value above the threshold value, so it gives the trip signal to the circuit breaker.

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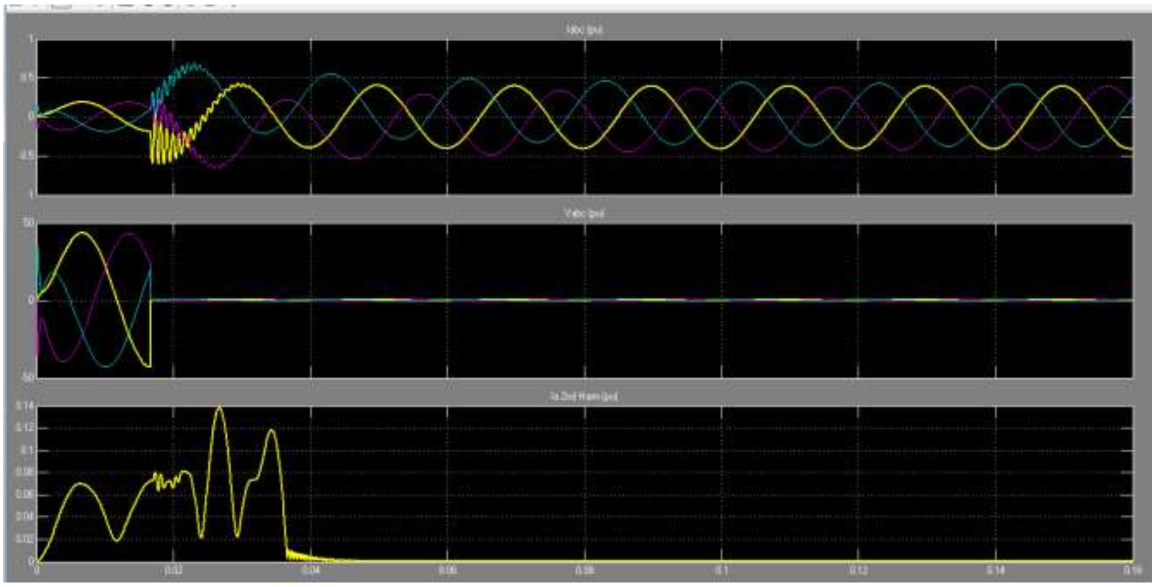

Figure 7 (a). Simulated result for internal fault and the relay output

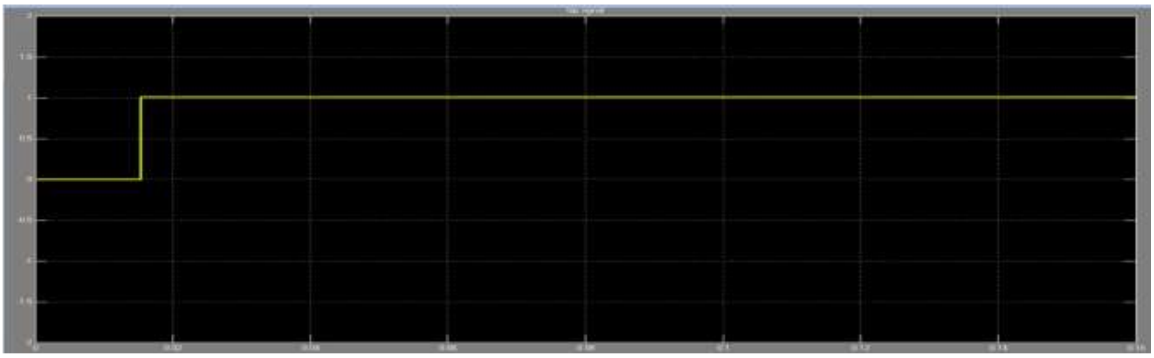

Figure 7(b). Simulated result for internal fault and the relay output

The relay send a trip signal to circuit breaker under faulty condition and circuit breaker isolates the transformer from the system. The proposed approach has no trip output signal for start of operation and external faults cases, while in cases of internal faults it has trip output signal. Table-III shows the relay output for the anticipated modelled relay. These are given below: -

Table III Specifications of Proposed Relay

Measurements	Transformer Primary and Secondary Current
Relay output	Trip on No Trip
Threshold of operation	0.50
Decision Speed	Less than one cycle

CONCLUSION

In this paper, an attempt has been made through the use of MATLAB/SIMULINK to analyse modern digital differential protection relay for a large power transformer. This algorithm is developed on the Fuzzy based system. The proposed digital differential relay will design using a simulation technique in MATLAB Simulink environment. The basic approach is to protect the power transformer against internal faults and prevent interruption due to other operating conditions. The obtained result illustrate that the proposed fuzzy based differential relay represents an appropriate action. The proposed relay was able to discriminate between inrush, fault and no-fault conditions.

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