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A Statistical Approach to Discriminate the Magnetising Inrush Current and Internal Fault Current of a Transformer

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***Abstract:** The transformer is one of the important elements of electrical power system. So, it is required to provide the good protection scheme for transformer, which enhance the reliability & economy of the system. There are many methods available for the protection of transformer out of which differential protection is the most commonly used method. It is observed that the conventional differential protection scheme mal-operates during the magnetizing inrush current. The mal-operation of differential relay will affect the continuity of supply to customer and hence the economy of our system. To avoid such type of mal-operation of the relays, proper discrimination between the magnetising inrush current and fault current is required. This paper presents Teager Energy Operator (TEO) and Statistical parameters based novel approach for the discrimination between the magnetizing inrush current and the internal fault current of a transformer.*

In this paper, TEO of the differential current of the transformer is calculated and compared with its threshold value to detect the abnormal condition. When TEO is more than threshold, statistical parameters like variance & standard deviation are calculated and if the calculated value is more than the threshold then it's an internal fault condition and hence relay gives the trip signal. Else relay does not issue the trip signal. The suggested algorithm is tested using the experimental data. The results demonstrated that the suggested algorithms are capable of accurately differentiating between the transformer's internal fault current and inrush current.

Keywords: Internal Fault Current, Magnetizing Inrush current, Standard Deviation, Variance, Teager Energy Operator.

I. INTRODUCTION

The transformer is considered to be the heart of power system. The AC power transmission over a long distance is possible only because of transformer. It helps to improve the safety and the efficiency of our power systems by increasing and decreasing the voltage levels as per the need. They are utilised in a variety of domestic and commercial applications, with the distribution and control of electricity over large distances being their primary and possibly most significant purpose. As it is used continuously in the power system and as it is the important part of our power system, we need to protected it from the abnormalities. Because failure of transformer may lead to interruption in the continuity of supply which may result in heavy loss. Buchholz relay and differential protection is most common scheme used for the protection of transformer.

Differential protection is a unit-type protection used for a specified zone or part of equipment. It is based on the fact that the differential current value will be high only in case of internal fault. The differential current, however, can occasionally be significant even in the absence of an internal fault.

With the exception of the inrush and overexcitation currents, rest of the faults are covered by the percentage differential relay. In the percentage differential relay two restraining coils are added with the normal differential relay. Relays with percentage restraint differential protection have been in use for a long time. In differential elements, an operating current is compared with a restraint current. The differential current is zero in case of normal condition while it is proportional to the fault current in case of internal faults.

Compared to other protection strategies, the transformer's differential protection has significant benefits. The differential relays often react to faults that happen within the protected zone of transformer.

In the differential protection the relay compares the primary current and secondary current of a transformer, if any unbalance is found in the primary and secondary currents the relay will generate the trip signal. In three phase transformers the phase shift in the primary and secondary currents corresponds to star-delta connection of winding is compensated by connecting the CT secondaries in delta and star as shown in figure 1.

The differential current of a transformer rises to a high value due to CT saturation, variation in the turn's ratio, or magnetizing inrush current. The differential protection scheme can't discriminate this condition and issues a trip signal. This false tripping of relay will trip the breakers under the normal condition which leads to the interruption in the continuity of supply. So, there is a need to develop a robust and reliable protection scheme which can discriminate the inrush and internal fault current of a transformer. This paper presents a novel approach for discriminating the inrush and internal fault current of a transformer.

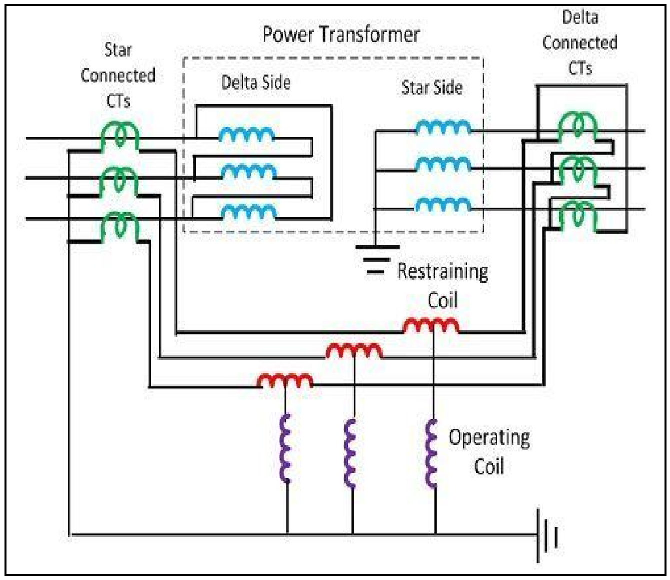

Fig. 1 Differential Protection of Transformer

II. TEAGER ENERGY OPERATOR (TEO)

The signal $x(t) = ACos(w_c t + \emptyset)$ TEO ψ[x(t)], is expressed as

$$\varphi[x(t)] = [\dot{x}(t)]^2 - x(t) * \ddot{x}(t) = A^2 w_c^2 \tag{1}$$

Equation (1) is represented in discrete form by utilising approximation

$$\dot{x}[n] \approx \frac{x[n]-x[n-1]}{T} \tag{2}$$

When T is low, it can be defined as

$$\Psi[x(n)] = ([x(n)]^2 - x(n-1)x(n+1))/T^2 \tag{3}$$

where T is the time interval between consecutive samplings, $x(n)$ & $x(n+1)$. Due to the availability of information in the discrete domain after time interval T, the assumption of T=1 is appropriate in the majority of circumstances. As a result, the TEO discrete form representation is given by

$$\Psi[x(n)] = [x(n)]^2 - x(n-1)x(n+1)] \tag{4}$$

Equation (3) provides data on the sinusoidal signal's amplitude and frequency. Only three discrete-time signal samples are needed. The separation method is used to calculate the frequency (Ωc) and amplitude (A) of the TEO $\psi[x[n]]$ of the signal [3].

Let represent the signal with amplitude and frequency is denoted as $x(n) = A\ Cos(\Omega_c n + \emptyset)$ Therefore the discrete -time TEO is given by

$$\psi[x(n)] = A^2 sin^2(\Omega_c) \tag{5}$$

Equation (6) and equation (7), respectively, determine the TEO amplitude and frequency of the discrete TEO signal.

$$A = sqrt\left(\frac{\psi[x(n)]}{sin^2(\Omega_c)}\right) \tag{6}$$

$$\Omega_c = cos^{-1}\left(1 - \frac{\varphi[x(n)-x(n-1)]}{\varphi[x(n)]}\right) \tag{7}$$

In this paper, the TEO is determined by using equation (6).

III. STATISTICAL ANALYSIS

The two key statistical parameters utilised in statistical analysis are variance and standard deviation. It measures how evenly statistical data are distributed.

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A. Variance

It is a measurement of how widely a set of data is dispersed. The variance is said to be zero if all the data values are the same. Variances that are not zero are all regarded as positive. A small variance shows that the data points are near the mean and one another, whereas a large variance shows that the data points are far dispersed from the mean and one another. The variance is basically the average of the squared distances between each point and the mean.

$$Variance\,(\sigma^2) = \frac{\sum_{i=1}^{n}(xi - \bar{x})^2}{N} \qquad (8)$$

B. Standard Deviation

The square root of the variance is used to calculate the standard deviation, a statistic that expresses how widely distributed a dataset is in relation to its mean. Therefore, the standard deviation will be bigger the more dispersed the data. The standard deviation is computed by calculating the square root of a value obtained by comparing individual data points to the population's overall mean.

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(xi \quad x)}{n \quad 1}} \qquad (9)$$

IV. PROPOSED ALGORITHMS

The experimental setup used in this study provides the necessary data for differentiating between a transformer's internal fault current and inrush current. The two novel algorithms proposed in this paper.

In the first algorithm, the data acquisition system is used to record the differential current of a transformer. The TEO is further computed using this differential current. Comparison is made between the calculated TEO value and the threshold value (0.1). When the value of TEO surpasses the threshold, an anomaly has occurred (inrush current or internal fault current). Following the identification of the anomaly, the detection flag is set, and the variance for the specified data set is determined using the differential current for the quarter cycle following the instant of abnormality. The estimated variance value is then compared with the threshold value (1500). If the estimated value is below the threshold, then there is no need to trip the circuit breaker because it is a case of magnetising inrush current. The protection scheme will send out a trip signal to operate the breaker and isolate the transformer if the value of variance is higher than the threshold, as this is a sign that an internal fault on the transformer has occurred. The proposed algorithm's flowchart is shown in Figure 2.

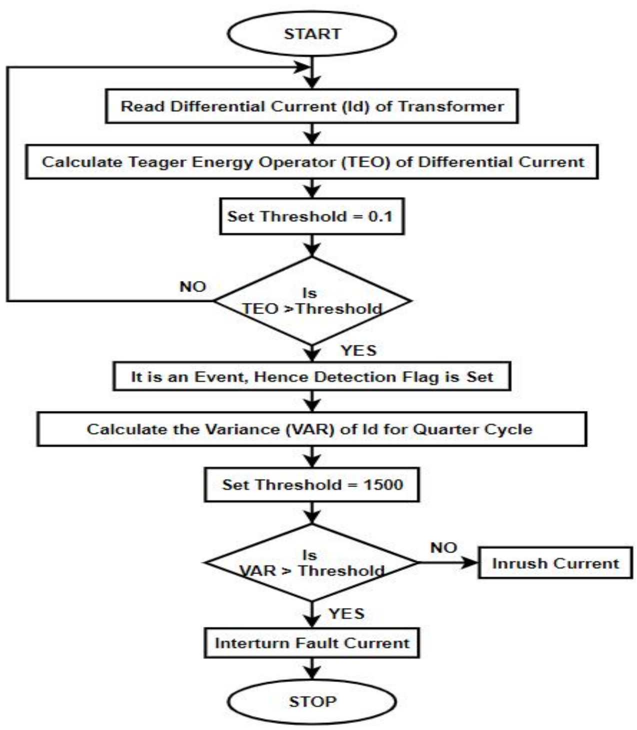

Fig. 2 TEO & Variance based Algorithm to discriminate between inrush and internal fault current

The second algorithm employs a data acquisition system to record a transformer's differential current. The TEO is further computed using this differential current. Comparison is made between the calculated TEO value and the threshold value (0.1). When the value of TEO surpasses the threshold, an anomaly has occurred (inrush current or internal fault current). The differential current data set is used to calculate the standard deviation value for the quarter cycle starting at the instant the abnormality is discovered and the detection flag get set. The standard deviation's estimated value is compared to its threshold value (35). If the estimated value falls below the threshold, it is a magnetising inrush current event and the circuit breaker does not need to trip. To open the circuit breaker and isolate the transformer, the protection scheme will send out a trip signal if the SD value is higher than the threshold, which denotes an internal fault. The proposed algorithm's flowchart is shown in Figure 3.

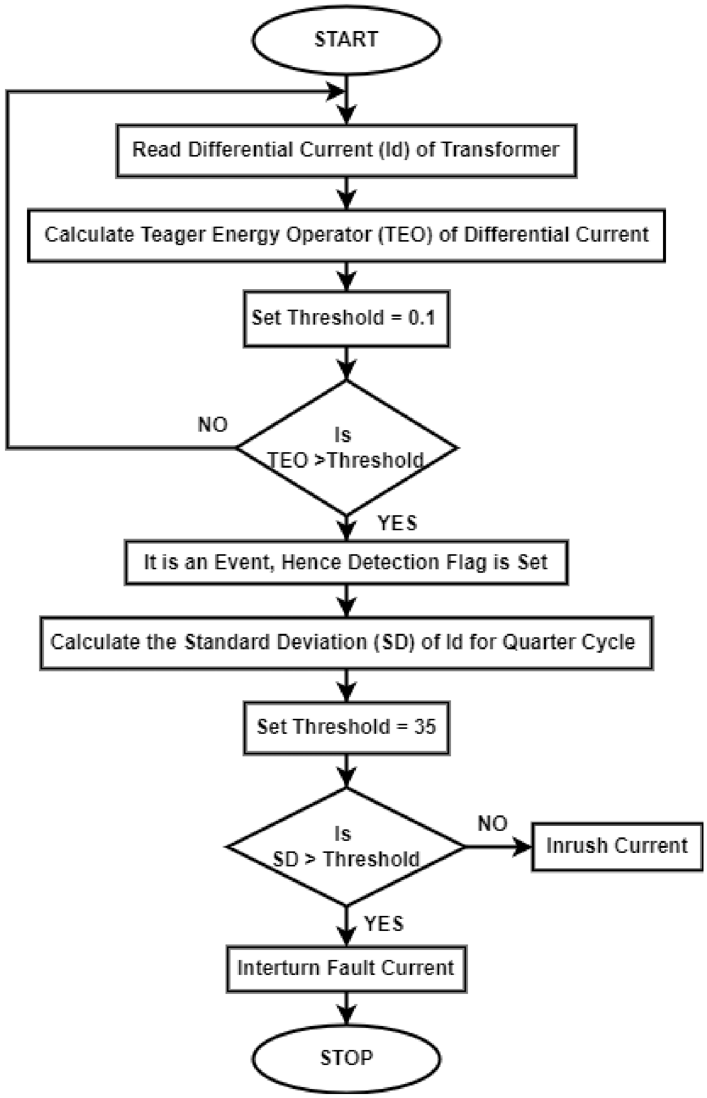

Fig. 3 TEO & Standard Deviation based algorithm to discriminate inrush and internal fault current

V. EXPERIMENTAL SETUP

The A single-phase isolation transformer with a rating of 2KVA, 230/230V, 50Hz, and one-to-one tapings on both of the transformer's sides to produce an internal fault makes up the experimental apparatus employed in this study. A resistive load is attached to the transformer during the experiment. The differential current of a transformer is recorded using the Adlink Data Acquisition System. A 1 kHz sample frequency has been chosen. The magnetising inrush current of a transformer is collected under no-load conditions, and the internal fault current is captured during loading conditions by short-circuiting a few numbers of turns of transformer winding. A block diagram of the experimental apparatus is shown in Figure 4. and the experimental set-up utilised to record the transformer's internal fault current and inrush current is shown in Figure 5 in an image.

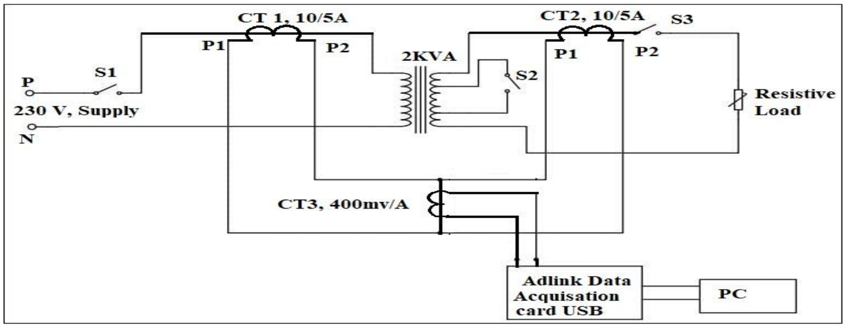

Fig. 4 Circuit diagram of Experimental Setup

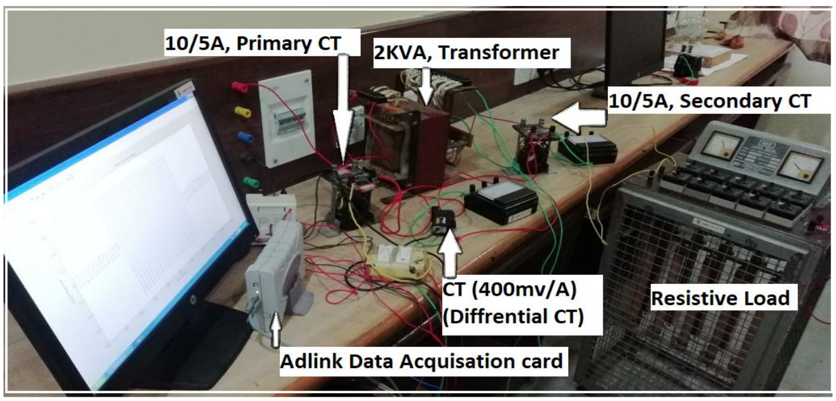

Fig. 5 Photograph of Experimental Setup Developed in the laboratory

VI. RESULTS AND DISCUSSION

A. *Results of Abnormality Detection*

1) *Transformer Energization Case:* The transformer considered in the experimental setup is energized in this case. To determine the TEO value, the differential current associated with the magnetising inrush is recorded from the experimental setup and then analysed. The TEO value and the threshold value are compared, and if the TEO value is greater than the threshold value, a detection flag is set. This suggests the emergence of an abnormal situation. The differential current's variance and standard deviation value are computed for a quarter cycle after the moment an anomaly is discovered. These statistical parameters are utilized to generate the features required for training and testing the ANN. A TEO study of differential current in case of Transformer Energization conditions is shown in Figure 6.

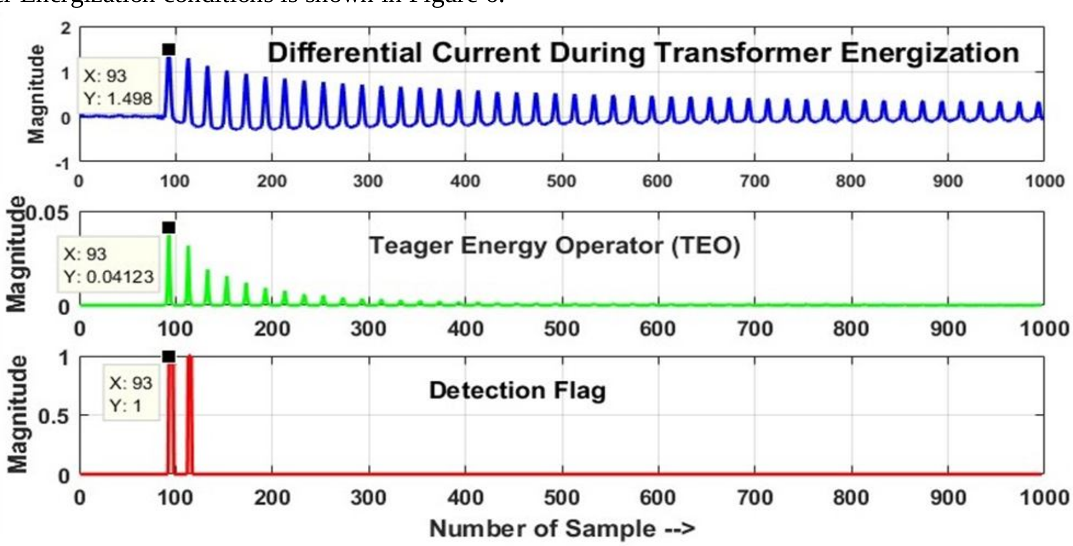

Fig. 6 TEO analysis of Differential Current under Transformer Energization Condition

2) *Transformer with Internal Fault Case:* In this case, the transformer considered in the experimental setup is subjected to internal fault. To determine the TEO value, the differential current associated with the internal fault is recorded from the experimental setup and subsequently examined. The TEO value and the threshold value are compared, and if the TEO value is greater than the threshold value, a detection flag is set. This suggests that an abnormal circumstance has arisen. The detection flag stays raised as long as the issue continues. A *quarter* cycle after the moment an anomaly is detected is utilised to compute the standard deviation and variance value of the differential current. These statistical parameters are utilized to generate the feature vector, which is then used for training and testing the ANN. A TEO study of differential current in the presence of an internal fault is shown in figure 7.

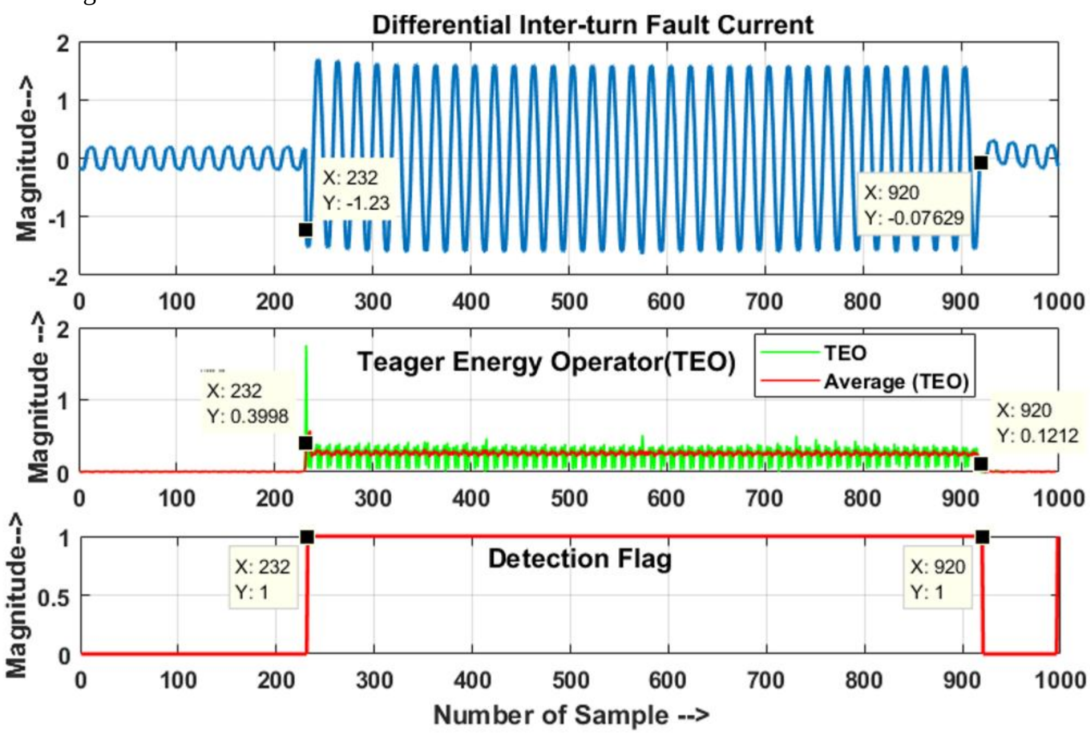

Fig. 7 TEO analysis of Differential Current during Internal Fault

B. *Discrimination Results*

1) *Result of First Algorithm:* When the detection flag was set off, the differential current's variance and standard deviation were calculated for a quarter cycle. The bar chart of Variance value obtained from differential current during inrush and internal fault circumstances is shown in figure 8. Under the inrush scenario, the magnitude of Variance is observed to be below the threshold value, whereas under the internal fault condition, it is observed to be beyond the threshold value. The suggested algorithm will send out a trip signal in the event of an internal fault, as shown in figure 10, while there will be no action in the event of an inrush, as shown in figure 11.

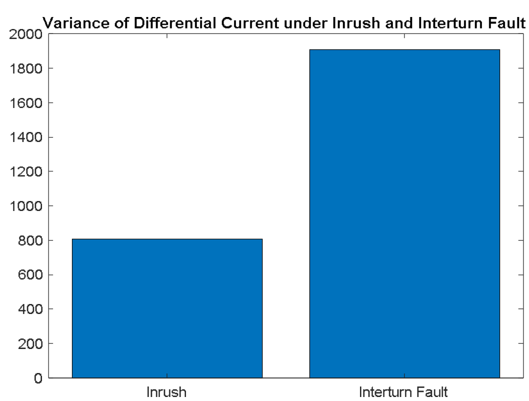

Fig. 8 Variance Value of Differential Current corresponds to inrush and internal fault current

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2) *Result of Second Algorithm:* The bar chart of the Standard Deviation value obtained from differential current under inrush and internal fault circumstances is shown in Figure 9. Under the inrush situation, the magnitude of the standard deviation is observed to be below the threshold value, while under the internal fault condition, it is observed to be over the threshold value. The suggested algorithm will send out a trip signal in the event of an internal failure, as shown in figure 10, while there will be no action in the event of an inrush, as shown in figure 11.

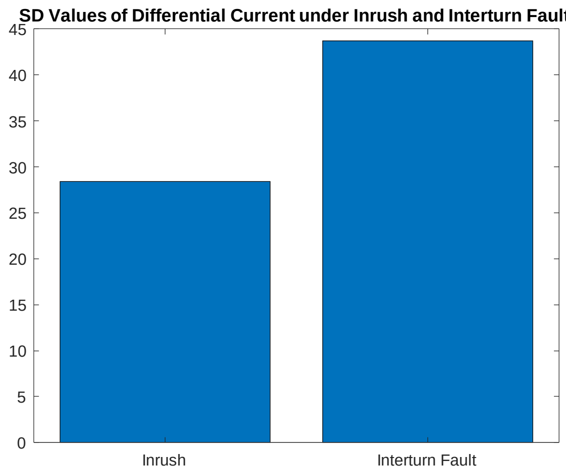

Fig. 9 Standard Deviation Value of Differential Current for inrush and internal fault current

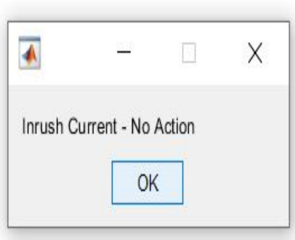

Fig. 10 Result of the discrimination algorithms in case of inrush current

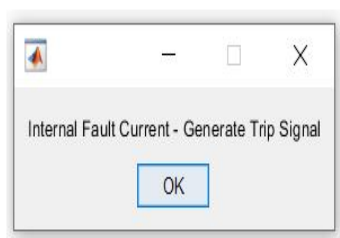

Fig. 11 Result of the discrimination algorithms in case of internal fault current

VII. CONCLUSIONS

The research work presented in this research paper is summarised in this section. In order to distinguish between a transformer's internal fault current and inrush current, this research suggests two unique algorithms. The first algorithm proposes the use of a TEO-based threshold in combination with a variance threshold and in the second algorithm, a combination of the standard deviation threshold and the TEO based threshold is proposed. These two combinations are proven to be effective in differentiating between internal fault current and magnetising inrush current of transformer. For feature extraction in these algorithms, a quarter cycle of differential current is used. Therefore, the execution requires relatively little computation time and is also less difficult. As a result, this algorithm's implementation is easy and simple. These algorithms effectively and accurately distinguished between the transformer's internal fault current and inrush current. These proposed algorithms work accurately during testing in the lab with experimental data. There is a scope to extend this work to discriminate the Inrush and fault current in online mode.

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