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Discrimination Between Inrush Current from Interturn Fault Current in Transformers based on the Non-Saturation Zone

Prof. P. R. Bharambe[1], Mr. V. S. Karale[2], Shivani Manatkar[3], Komal Tayade[4], Abhishek Patil[5], Adarsh Moon[6], Sumit Mahajan[7], Ashwini Rajagur[8]

Department of Electrical Engineering, S.S.G.M. College of Engineering, Shegaon, India[1,2,3,4,5,6,7,8]

Abstract: *When we give a supply to a transformer, the occurrence of magnetizing inrush current occurs. The magnitude of inrush current as high as ten times or more times of rated current which may lead to malfunction of the differential relay causing the problem of unnecessary disconnection of the transformer from the supply mains. So, for safe running of a transformer, it is necessary to discriminate inrush current from fault current in order to avoid malfunction of the differential relay and for the proper operation of the transformer. The second harmonic restraint relay is used usually but as size of power system network is becoming so huge & more and more convoluted and some drawbacks of usual system are slowly recognized. So, to shield the evolving power system and its important components like a transformer, we need fast-stable & dependable protection system. Current transformer saturation and large inrush current are the most notified cause of the discrimination algorithms malfunction. This paper deal with structured way to discriminate internal faults from switching conditions in the power transformers which can solve these problems Therefore, the ongoing research is now concentrated on evolving new algorithms for proper discrimination between inrush current and internal fault current which increases the efficiency in Electrical Power system.*

Keywords: Transformer, Internal Fault, Inrush Current, Differential Protection, etc.

I. Introduction

Transformer protection is always a difficult problem for protection engineers. It is a highly structured static electrical machine that plays an important role in the power system. It is important component of power system, so it is necessary to have a fast and proper operating protection scheme for the safety and appropriate functioning. There are two types of faults occur in a transformer that is internal faults and external faults. The faults, which occurs inside the transformer are known as internal fault Winding short circuit also called as the internal faults, generally result from failure of insulation due to temperature increase or decrease of transformer. The faults which occur outside the transformer or at the terminals of the transformer are called as external faults.

Internal faults cause serious damage to the transformer winding within a short duration if appropriate care is not taken by the protection system Protection system of transformer depends upon the transformer rating, working condition, tap changing scheme and loading condition of the transformer. In small rating distribution transformers high voltage fuses are used for the protection. Buchholz relay protection is used for transformer having rating above 500kVA.Buchholz relay provides the protection against the fault occur in the transformer. The traditional method used for transformer protection is current differential protection, which is used for protecting the transformer windings against internal faults based on the simple property that the ratio of current entering and leaving the transformer is equal to the inverse of the transformation ratio. The ratio is affected either by internal fault or inrush current during transformer magnetization. Differential protection is an equipment protection. The primary and secondary current of the power transformer is compared by the differential relay and if any difference found in the current then the relay will give trip signal to both primary and circuit breakers. The magnitude of magnetizing inrush current is as high as compared to the internal fault current of transformer.

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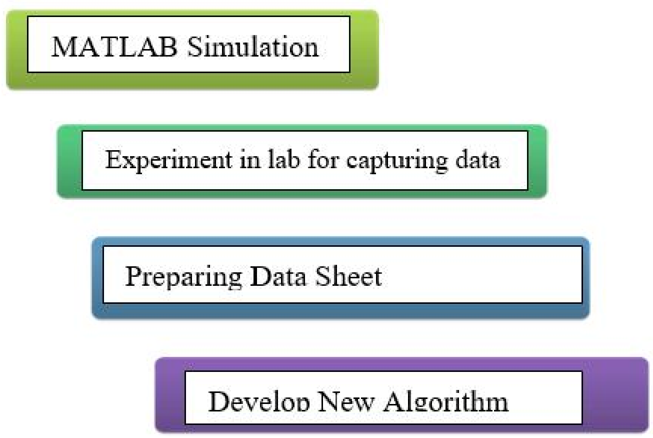
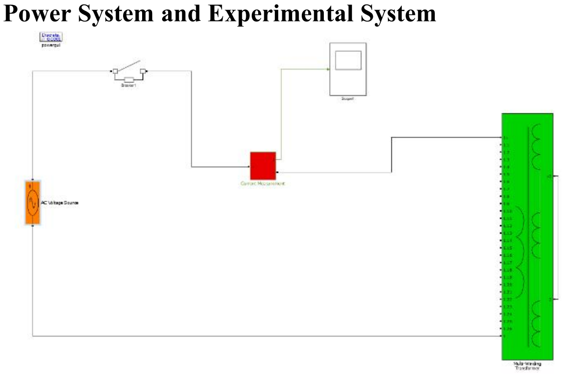
Some approaches such as harmonic restraint, voltage and flux restraint, inductance-based method, pattern recognition method and artificial Intelligence methods such as neural network and fuzzy logic have been developed for discrimination between inrush & internal fault current of transformer. These methods have their benefits as well as their limitations.

This paper presents a novel way that is algorithm for discrimination between magnetising conditions and internal faults based on feature of non-saturation zone. In this method, first the normalised differential current is calculated within the first cycle after a disruption occurs. Then, the incremental normalised differential current is calculated and arranging ascending based on the samples total value. By selecting the first quarter-cycle of the created signal and calculating the summation of the selected samples, a predictive norm is obtained. In case of internal faults, the calculated index shows much higher amplitudes than a pre-set value; however, in case of switching condition the calculated index is smaller than a pre-set threshold. The results verify the efficiency of the proposed method in case of deep CT saturation and large inrush current. Also, the results verify the efficiency and simplicity of application the suggested algorithm for industrial applications. Here, the flow of work is given below:



1.1 Introduce the Simulated Power System and Experimental System



Simulation of Inrush Current in Single Phase Transformer

Transformer

Power and Frequency = (1000VA ,50Hz)

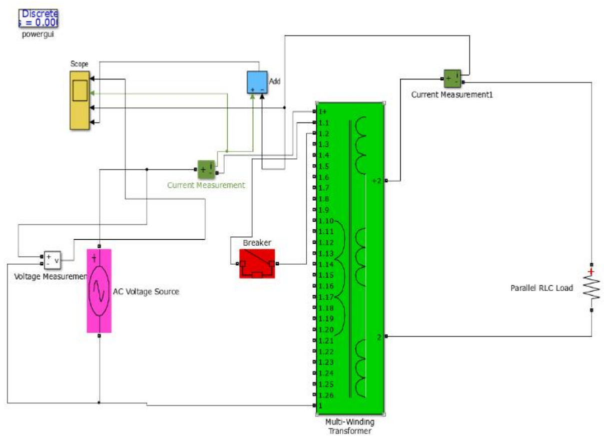
Winding Nominal Voltage (220v ,220v)

No of Taps = 26

AC Voltage Source =230v

We have done the simulation of Inrush Current in Single Phase Transformer. The various components of this circuit are Circuit Breaker, Current Measurement, Scope, AC voltage source & Multi-winding Transformer. In this simulation of inrush current of Single-Phase Transformer, we connect AC voltage source of 230V to supply power to given circuit.

The role of circuit breaker is to trip the circuit when fault occurs & it avoids the malfunction of the circuit. The role of Current Measurement is to measure the flowing current in the circuit. The role of Multi-Winding Transformer is used to provide a step-up, a step-down, or a combination of both between various windings. The winding nominal voltage is 220V and the number of taps is 26. And with the help of scope, we can see the various waveforms of Inrush current.



Simulation of Internal Current on Primary Side of Single-Phase Transformer

Transformer
Voltage, Frequency = (2000VA ,50Hz)
Winding Nominal Voltage (220v ,220v)
No of Taps = 26
Series RLC load
V=220v, P=1000W
AC voltage Source = 220V

We have done the simulation of Internal Current on Primary side of Single-Phase Transformer. The various components of this circuit are Circuit Breaker, Current Measurement, Scope, AC voltage source & Multi-winding Transformer, Voltage Measurement, Parallel RLC Load, Adder. In this simulation of Internal current of on Primary side of Single-Phase Transformer, we connect AC voltage source of 230V to supply power to given circuit. The role of circuit breaker is to trip the circuit when fault occurs & it avoids the malfunction of the circuit. The role of Current Measurement is to measure the flowing current in the circuit. The role of Multi-Winding Transformer is used to provide a step-up, a step-down, or a combination of both between various windings. The winding nominal voltage is 220V and the number of taps is 26. The role of voltage measurement is to measure the voltage. And with the help of scope, we can see the various waveforms of Internal current like as shown in figure 1. a.

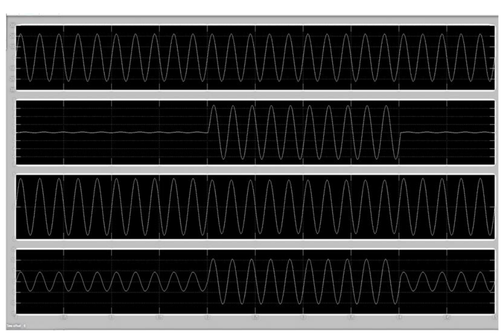
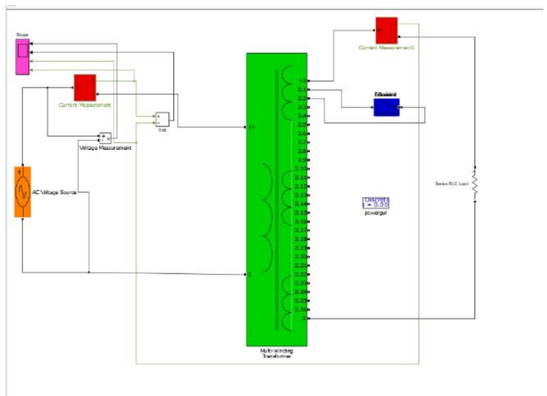


Figure 1.a:



Simulation of Interturn Current on Secondary Side of Single-Phase Transformer

Transformer
Voltage, Frequency = (2000VA ,50Hz)
Winding Nominal Voltage (220v ,220v)
No of Taps = 26
Series RLC load
V=220v, P=1000W
AC voltage Source = 220

We have done the simulation of Internal Current on Secondary side of Single-Phase Transformer. The various components of this circuit are Multi-winding Transformer, Voltage Measurement, Series RLC Load, Adder. In this simulation of Internal current of on Secondary side of Single-Phase Transformer, we connect AC voltage source of 230V to supply power to given circuit. The role of circuit breaker is to trip the circuit when fault occurs & it avoids the malfunction of the circuit. The role of Current Measurement is to measure the flowing current in the circuit.
The role of Multi-Winding Transformer is used to provide a step-up, a step-down, or a combination of both between various windings. The winding nominal voltage is 220V and the number of taps is 26. The role of voltage measurement is to measure the voltage. And with the help of scope, we can see the various waveforms of Internal current on Secondary side of Single-Phase Transformer as shown in figure below.

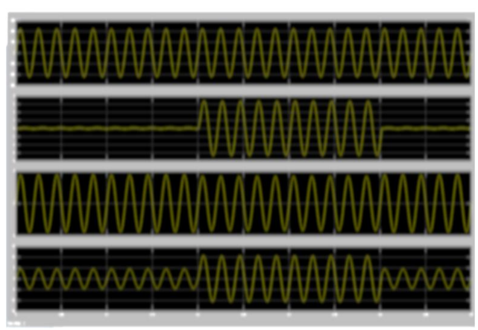


Figure 1.b:

This proposed method is compared with five well-known algorithms including conventional and new methods.

1.2 Studied Algorithms

a. Instantaneous-Inductance-based Technique: This technique is based on equivalent instantaneous inductance. In this method inherent difference of inrush current and internal fault during saturation and unsaturation is used. The recognition norm obtained by calculating the variation of EII.

b. Second-harmonic based Technique: This method uses the ratio of second harmonic component of differential current to the fundamental component. An inrush current is identified, if calculated ratio exceeds a present threshold.

c. Flux restraint-based method: The recognition norm in this method protection is obtained by checking the association between the transformer mutual flux linkage and differential current(I).

d. Differential current gradient-based method: The angle of gradient vector of differential current in case of inrush current between 0 and 90 degrees. Total values of the calculated angles are near 90 degrees. So, variation of the angles is used as discrimination norm.

II. New Algorithm for Discrimination between Inrush Current and Internal Fault Current

For protection of transformer, we have to check and observe the condition of transformer time to time. Because if we don't check transformer repeatedly there is a possibility of occurring fault such as interturn fault, short circuit fault, internal fault etc. During this fault current in transformer increases rapidly up-to high magnitude (7 to 8 times of normal current). For sensing this high magnitude current, we use protective device in power system, but power system element can't discriminate inrush current and internal fault current for this purpose we have developed a new algorithm. The basic flowchart of an algorithm is given below:

There are five steps in algorithm, in first step consider one sliding window after sudden change, we consider a maximum value within first cycle. In second step calculate normalized differential Fault current. Then calculate incremental normalized differential fault current in third step. In fourth step we have to arrange this incremental normalized differential current in ascending order base on its absolutes value, at the last step a proper method is applied to discriminate inrush current and internal fault current using dead angle period. The above five steps are described in detail given below:

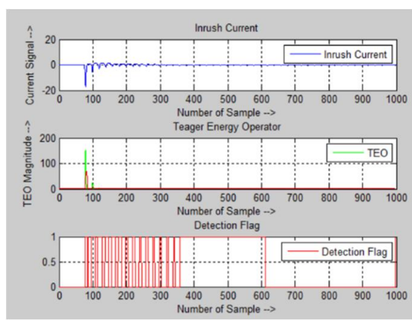


Figure 2.a:

In above figure 2.a first waveform represent the inrush current signal between 100 to 300 samples and second waveform represent TEO(Teager Energy Operator) in between 0 to 100 samples it's trigger upto more than 90 TEO magnitude. Third waveform represent the detection of flag for fault situation between 100 to 350 samples, from that select 20 samples for further calculation.

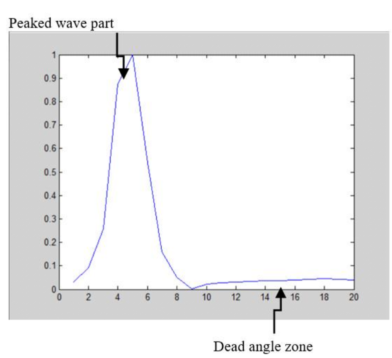


Figure 2.b:

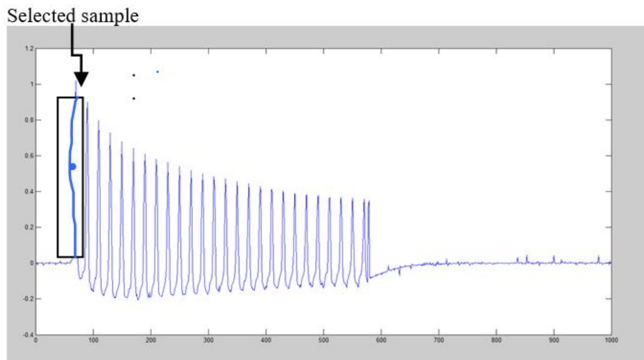


Figure 2.c:

2.1 For Normalised Differential Current

At the instant of transient condition, an algorithm is activated and one cycle sample is considered from sliding data window.by using maximum absolute value of differential current in first cycle the differential current is normalised.

$$I_N(n_s) = \frac{I_{diff}(n_s)}{\max(I_{diff})}$$

Here,

I_{diff} = Differential Current.

Max (I diff) = Maximum value of the differential current in a window with length equal to one cycle starts from an abrupt change.

2.2 Calculate the Increasing Normalised Differential Current

Above method is used for calculating the incremental differential current. The incremental differential current provides the probability of repeated checking of transformer condition. The consistency and equilibrium condition of the differential current can be removed by applying this scheme. The increasing normalised differential current is calculated by

$$\Delta IN(n) = IN(n) - IN(n - N)$$

Here,

IN(n) is normalised differential current in nth sample.

IN (n − N) is the normalised differential current in (n − N)th sample.

N is the number of samples in selected cycle.

2.3 Procedure for Samples Selection

The incremental normalised signal is sorted in ascending order based on the value of the observation window for recognizing the samples of dead angle zone for calculating the incremental normalised signal. That's why a new AS created, based on the samples absolute value. The current waveform in each cycle sorting in ascending order, the peak wave part will be located at the end of the signal and the dead angle zone will be located at the beginning of the signal. For inrush current, the starting part of AS signal have characteristic of non-saturation zone which is almost equal to zero. For internal fault the starting part of the AS curves increases continuously. On this fact, the above method is defining a criterion for discriminate internal fault from magnetising condition.

2.4 Define a Proper Individual Criterion

After selecting the lowest magnitude samples of the AS curve, distinguish criterion is achieved by calculating the summation of the selected samples from inrush current waveform. Since at the starting of the calculated AS curve contain feature of non-saturation zone of the differential current, in case of inrush current the values of samples are almost close to zero in Figure 2.c. and there is rapid increase in inrush current for few second as show in figure 2.c.

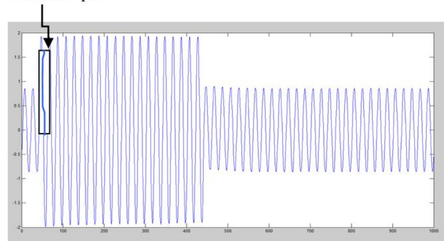


Figure 2.d:

In case of internal fault, selected value encompasses different value as shown in Fig2. d. Therefore, a reliable discriminative index is acquired by calculating and adding the selected samples of the AS curve. The calculating benchmark of faulted phases indicate much higher magnitude than the threshold value and a trip command is applied. However, for an inrush current case the calculating benchmark is smaller than threshold. The summation of selected samples is defined as: -

$$S = \sum_{N=1}^{i} AS(N)$$

Here,
i is the number of first selected samples of AS curve.

2.5 Select Appropriate Threshold

Selection of precise threshold for the discrimination strategy by the criterion is an important issue. Based on the simulation and laboratory results, the proper threshold range is selected. The results indicate that in the worst case for an internal fault, the calculated criterion is >3.9 and in the worst case for an inrush current, the calculated threshold is <2.7. Therefore, the threshold can be chosen between 2.7 and 3.9. the middle value of this band (2.9) is selected as a proper threshold. Fig2. e shows the proper course of action of the proposed algorithm in a following flowchart.

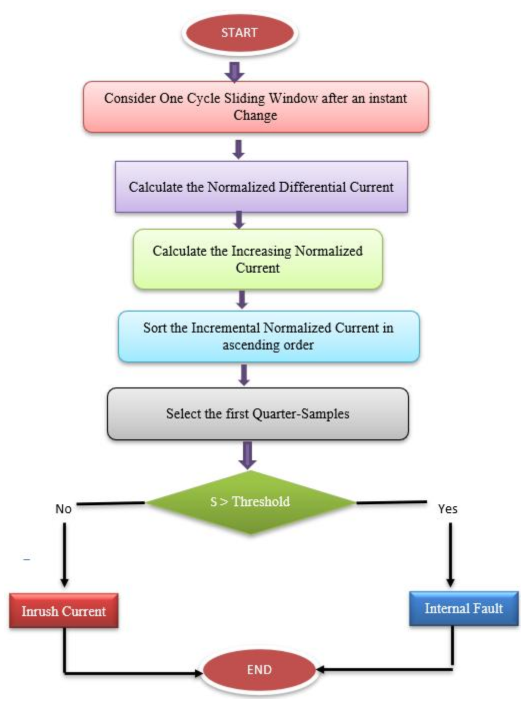


FIGURE 2.E:

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III. Experimental Set-up

A transformer during operation experiences any one of the following conditions Normal condition, magnetizing inrush/Sympathetic inrush condition, and internal fault condition. To evaluate new developed algorithm, experimental tests were performed in laboratory with setup of 230V/230, 5KVA, 50HZ Transformer with accessible taps on both primary and secondary winding to introduce internal fault whose Experimental set up is shown in figure 3.a and experimental set up for inrush current is shown in Figure 3.b.

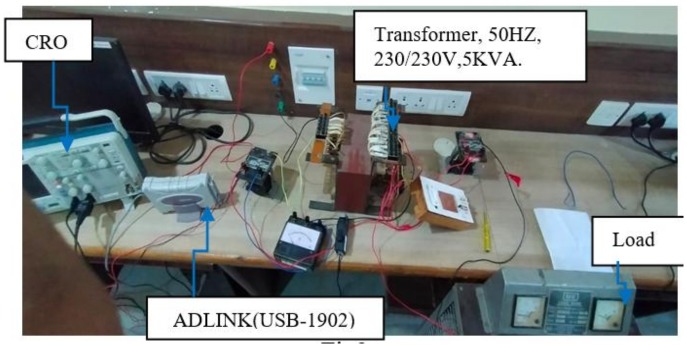

Figure 3.a

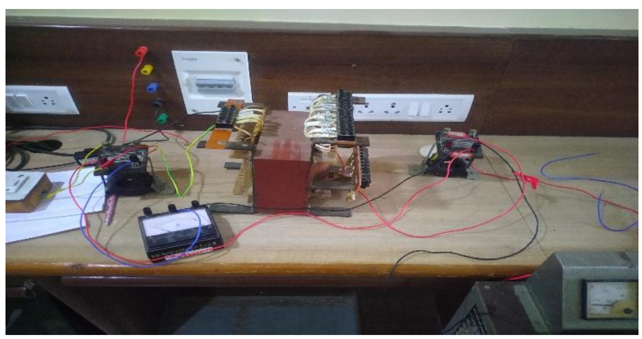

Figure 3.b

ADLINK(USB-1902) with digital CT used for converting Digital to Analog signal. Two CT (10/5 ratio) is used to calculate differential current with the help of ammeter connected between them. By doing short circuit of two tapping on secondary winding with the help of variable load, interturn fault can be occurred and capture differential current waveform as show in fig4. b. The Inrush current is captured keeping secondary winding open circuited for this give supply of 230V, 50HZ AC supply and capture inrush current waveform by using ADLINK, Digital CT and PC.

IV. Result

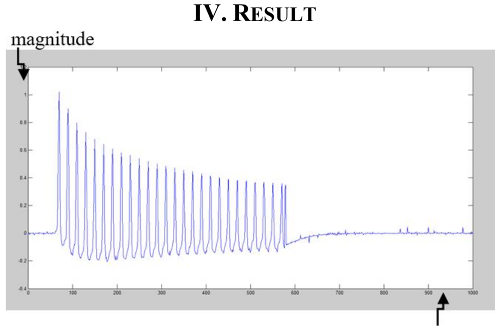

Figure 4.a

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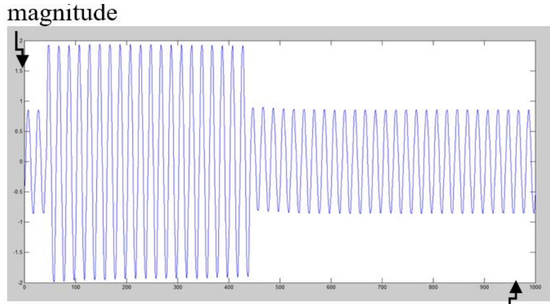

Figure 4.b

In below figure 4.a and figure 4.b contain waveform of inrush current and differential fault current. In figure 4.a from samples 100 to 600 have high magnitude waveform and at sample 100 have highest magnitude of current. After 600 samples it will settle down and comes to normal condition. Like that in Fig4.b between samples 0 to 450 have high magnitude differential current waveform after that it will come to its normal condition. From the below waveform any human being can easily discriminate which is inrush current waveform and which is fault current waveform, but protection system element can't. For that purpose, a new algorithm is design that shows in figure 2.e. by using this scheme protective system element can easily discriminate both the current.

Table 1

No of Reading	Quarter Cycle	Full Cycle
1	0.0091	2.0159
2	0.0809	2.7789
3	0.0298	2.5145
4	0.0327	2.4773
5	0.0231	2.0812
6	0.0228	2.0112
7	0.0166	2.0574
8	0.0266	1.7285
9	0.0991	2.0159
10	0.0278	2.1125
11	0.0313	1.7623
12	0.0065	2.2341
13	0.0110	2.1120

Table 2

No of Reading	Quarter Cycle	Full Cycle
1	0.1160	3.2427
2	0.1586	3.6476
3	0.1678	3.0788
4	0.4182	4.3810
5	0.1615	3.6275
6	0.1276	3.2477
7	0.1517	3.2010
8	0.2140	3.6753
9	0.1634	3.4062
10	0.1276	3.2362
11	0.1486	3.1936

12	0.1568	3.0449
13	0.3848	3.9676
14	0.1552	3.6537
15	0.1398	3.2095
16	0.1419	3.3884
17	0.2190	3.6188
18	0.1266	3.2958

Table 1 and Table 2, contains simulation and experimental results of above-mentioned method. Table 1, contains the readings of inrush current for quarter cycle and full cycle and Table 2, contains readings of internal fault current for quarter cycle and full cycle. For fair comparison set one threshold by calculating and observing readings from Table 1 and Table 2.

In Table 1, there are some readings of inrush current from that refer full cycle for further calculation. First, take the average of full cycle reading, the average comes to be 2.1117. And Table 2, contain readings for internal current, by referring full cycle reading, then calculate the average of full cycle that is 3.4577. by referring full cycle readings from Table 1 and Table 2 select a maximum value from both the table and set a threshold i.e., 2.9. Then compare every reading with selected threshold value, if value is less than 2.9 then this will be inrush current and if greater than 2.9 in that case it will be internal fault current. By using above mention criteria, we can easily discriminate inrush current and internal fault current in the Transformer.

V. Conclusion

Power transformers is very important component of power system and without transformer it is difficult to operate power system. Hence, it's protection is the essential issue to assure secure and reliable operation of the power system. Formation of inrush current is one of the major causes for mal-operation of the protection system. Hence accurate & fast discrimination method is necessary to discriminate inrush current & fault current. A new algorithm based on non-saturation zone method is present in this paper. With the help of this algorithm, we can protect and avoid the mal-operation of differential relay. The above method is compared with some well-known methods containing similar data. The results confirm the accomplished stability of the proposed algorithm against large inrush current situation in compare with other methods. Perfection in all situation, clarity and noise immunity of proposed scheme make it reliable and alternative approach for practical used.

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