TRANSFORMER PROTECTION IMPROVEMENT USING FUZZY LOGIC

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Abstract

The power transformer needs fast protection as well as continuous monitoring since it is an important electrical equipment as well as essential element for power system to perform effectively. For the protection of the power transformer various methods are available. Percentage differential logic is the most common technique used for the protection of the transformer as it can easily provide discrimination between different operating conditions and internal fault. But some operating conditions of the power transformer significantly affect the differential logic behavior and hence the power system stability. In this study it has been proposed the development of an algorithm to improve the protection performance by using fuzzy logic and dq0 transform. By the use of MATLAB software, an electrical power system was modelled to obtain the operational conditions and fault situations needed to test the algorithm.

Keywords: Differential Protection, dq0 transform, Energization, CT saturation, Fuzzy logic.

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1. Introduction

In electrical power system, power transformers are expensive as well as one of the most critical equipment. The failure of such an equipment will have a severe negative impact on the power supply. This may even lead to high maintenance costs and even massive power blackouts. So to maintain the reliability of power transformers should be considered as priority in the electrical power system. Different suitable methods for the protection and to detect fault, must be ensured for stable as well as reliable energy delivery [1], [21].

The percentage differential logic is the common protection technique used for transformer protection as shown in Fig. 1. This protection technique can distinguish between normal operating condition, an external fault and internal fault. But, simply to detect a differential current will not be sufficient to differentiate between internal faults from other similar situations which can produce such currents. Few of the situa-tions may appear when transformer energization (inrush currents) take place, over excitation, among others, these can result in wrong tripping. For modern protection of the power transformer, fast and correct distinction of internal faults from the other similar situations mentioned is a great challenge. Different algorithms developed re-cently to differentiate between internal fault current and other similar situations which can produce similar current should be understood so effective maintenance of transformer will be possible [2], [21].

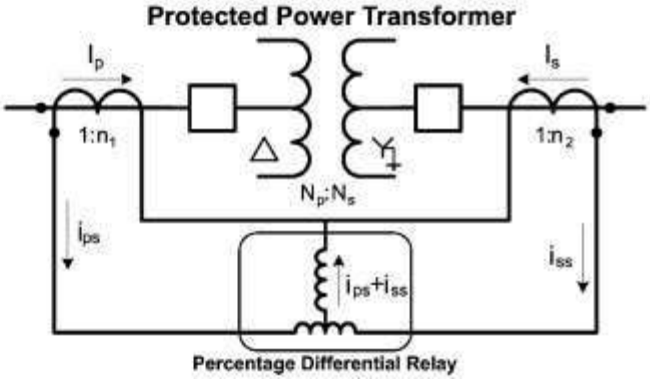


Figure 1. Differential relay connection diagram.

Different methods have been developed to improve the differential protection [3]- [14], used for power transformer. Some have implemented the same [4]- [6], by using of wavelet transform and other various transform [8], [9]. Few have used hybrid systems and restraint method [3], [2]. For correct operation of differential protection, distinction between the magnetizing inrush current and the internal faults in trans-former is necessary [14]- [16], as the reliability enhances are discussed. Various methods are available for avoiding [33], [38], detecting [32], [37], [39], correction/ compensation [34]- [36] of CT saturation.

Here in this paper a different power transformer differential protection is proposed. This method uses dq0 transform along with the fuzzy logic for the protection purpose. Along with the energization and over excitation, which are abnormal condition which leads to mis-operation of differential relay, CT saturation detection is also considered.

2. Method Proposed

A. Flowchart of Relay

The implementation of proposed algorithm was done in MATLAB Simulink and it is illustrated in Fig. 2. The current signals values are acquired from transformer by the use of current measurement blocks. After collecting the current data, the differential currents are calculated by processing using Clarke’s transformation. These differential currents obtained are sent to the fuzzy system. The threshold value of 0.5 is set for the fuzzy system. If fuzzy output is higher than threshold value, i.e. 0.5, the relay will send signal to trip the circuit breaker. Simultaneously CT saturation will be detected. If the same is present it will be displayed, which shall be rectified for the next operation.

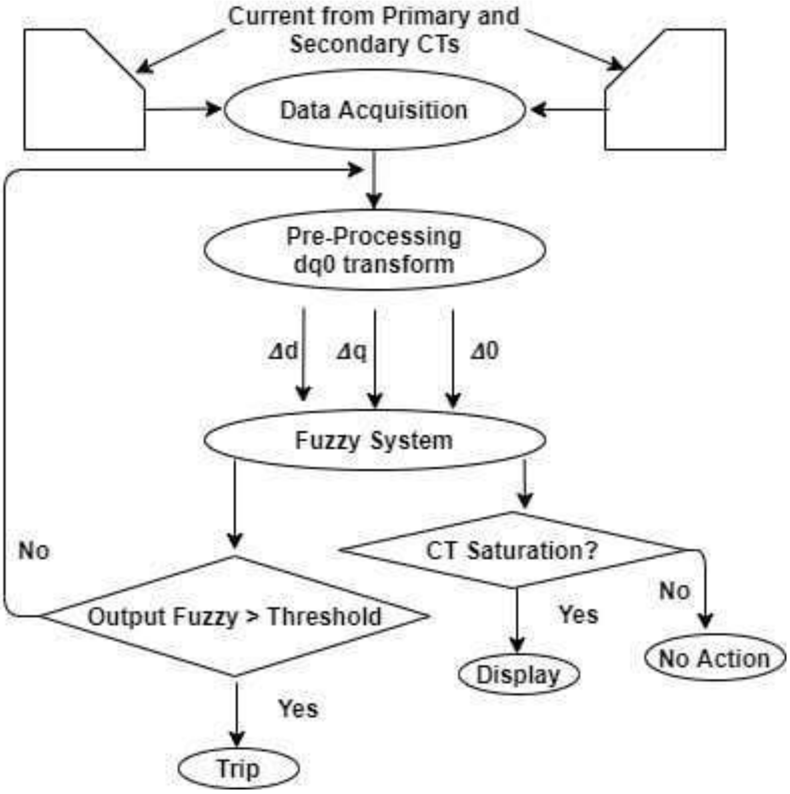


Figure 2. Basic relay algorithm

Each block is described in the following section:

B. Data acquisition

For the proposed method, data acquisition is done for currents from the secondary of the CTs connected on primary side and even secondary side of power transformer, which is required for differential protection. Currents data is obtained from current measurement block.

C. Pre-processing: dq0 transform

As the data has been acquired, a preprocessing will be executed, to obtain the desired signals for the fuzzy logic system. The signal will be acquired by applying dq0 transform to the 3-phase currents in secondary winding current of the CT in both transformer ends.

The dq0 transform can be used to both phasor as well as instantaneous values. The main concept of using dq0 transform is to discriminate normal operation, internal faults, energization, over-excitation and CT saturation. The differential d-q-0 components of the current are used.

$$\Delta d_{ph} = \left|\sum_{k=0}^{N}[I_d(k) + i_d(k)]\right| \quad (1)$$

$$\Delta q_{ph} = \left|\sum_{k=0}^{N}[I_q(k) + i_q(k)]\right| \quad (2)$$

$$\Delta 0_{ph} = \left|\sum_{k=0}^{N}[I_0(k) + i_0(k)]\right| \quad (3)$$

where $I_d(k), I_q(k), I_0(k), i_d(k), i_q(k)$ and $i_0(k)$ are d-q-0 current components of the primary current and secondary current acquired by a power transformer and N is the number of samples used to get the values.

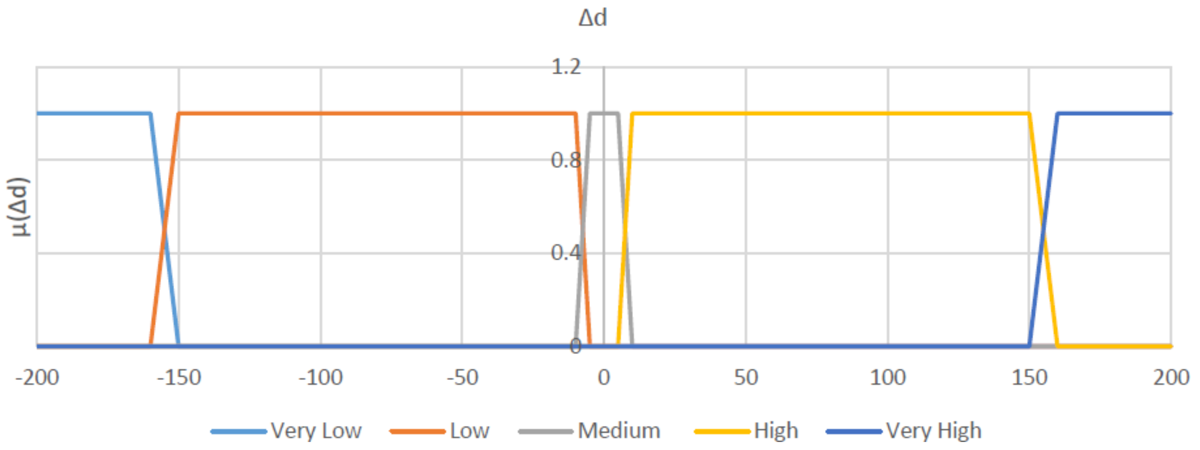
The values computed of the differential d-q-0 components of the phase currents approaches zero during a normal operation and for different specific situations fluctuation is observed in differential current values. Hence, various phenomena of pow-er transformer could be distinguished. With input of the differential d-q-0 components of the current, fuzzy system is used so the fault condition can be determined accurately compared to the conventional methods, which has predefined rules to discriminate between steady state and fault conditions.

D. Design of fuzzy system

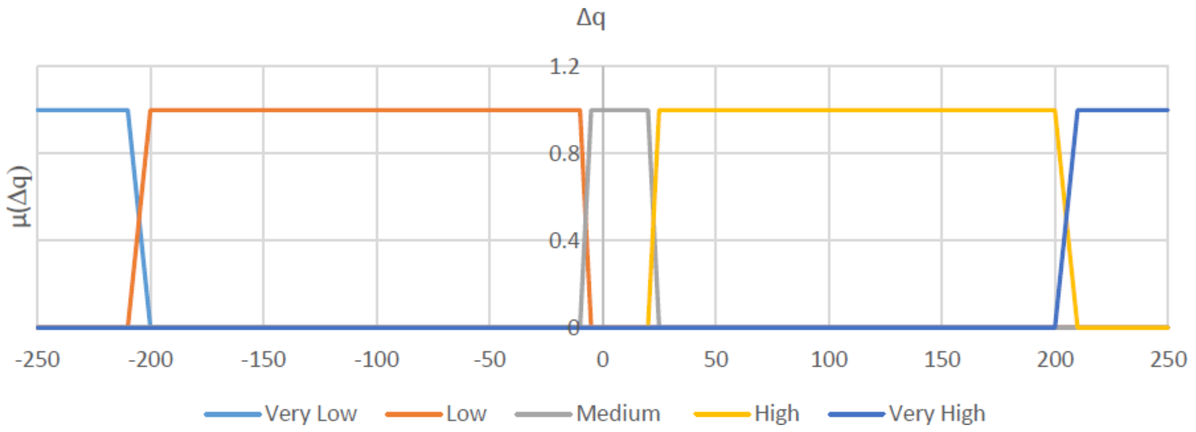
To point out the fault condition by considering all data and accurately the fuzzy logic system is used. Steps used for the fuzzy logic are:

1) Fuzzification: In proposed method three fuzzy inputs for the fuzzy system: 1) Δd; 2) Δq and 3) Δ0. These are obtained from equations (1) -(3). Figure 4(a)-(c) shows the inputs membership functions. For fuzzification of input variable from equation (1), a range is between -60000 to 120000 and the membership value range from 0 to 1, but for simplicity figure shows the range of -200 to 200. The remaining two variables from equation (2) and (3), are having range -10000 to 11000 and -9000 to 4000, respectively and the figure displays the range of -250 to 250 and -100 to 100, respectively. The range of fuzzy inputs were amplified for better analysis. Figure 4(d) shows the output variable for two membership functions that determine block or trip signals. The range for membership functions are obtained by considering most of the fault that can

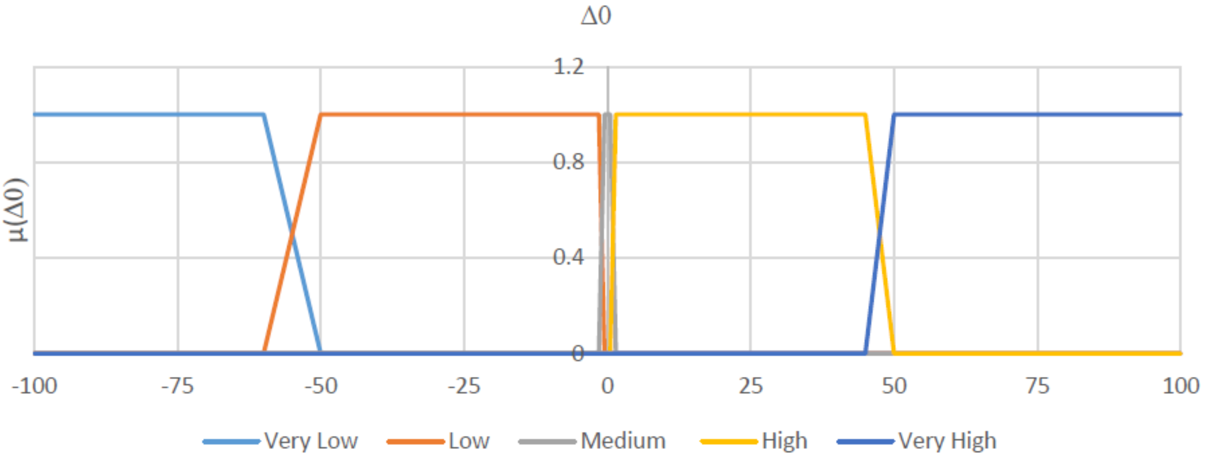
occur in the power transformer. The range are mentioned above.



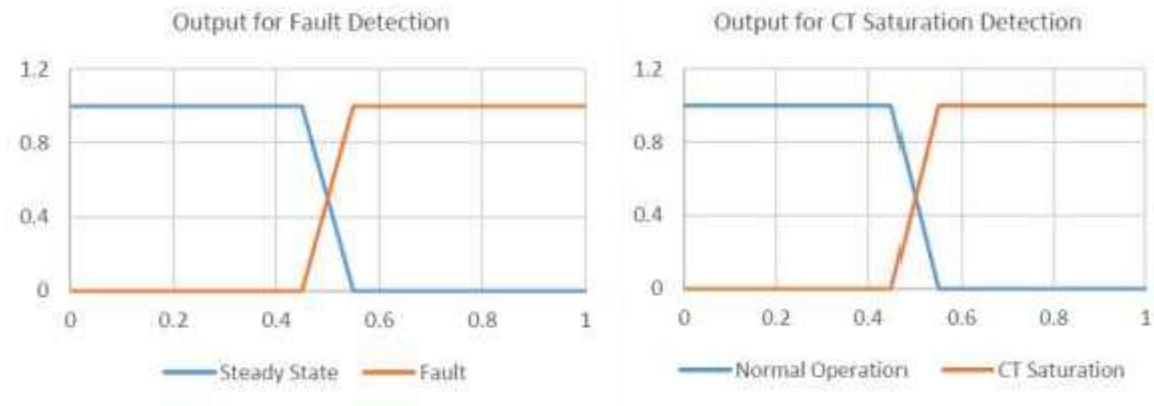
(a)



(b)



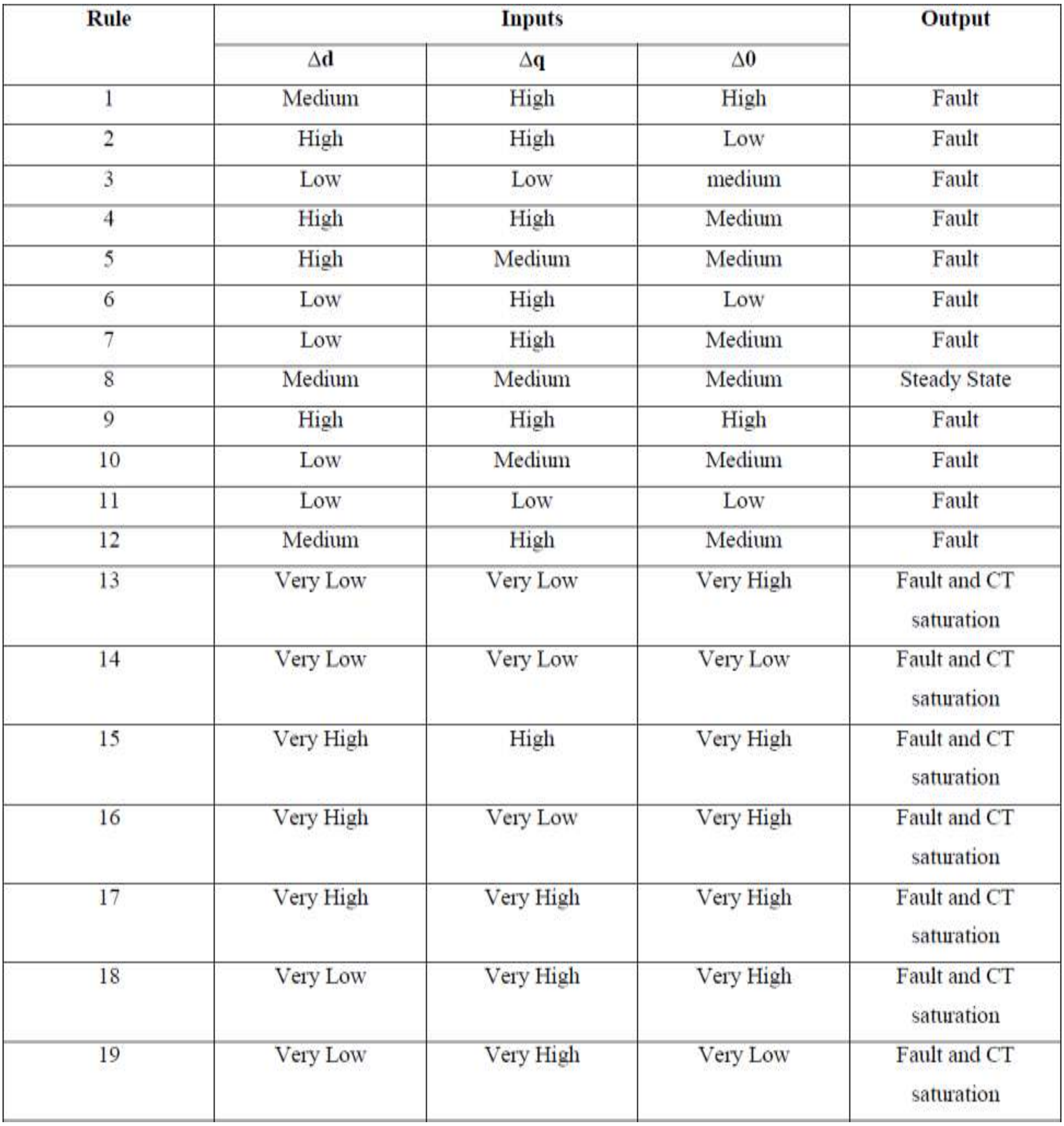
(c)



(d) (e)

Figure. 4. Membership functions of Fuzzy. (a) Δd, (b) Δq, c) Δ0, (d) Output fuzzy for fault detection, (e) Output fuzzy for CT saturation detection

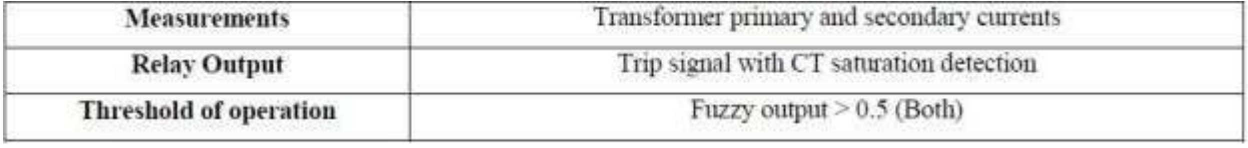
2) Inference method: Here proposed method will use 19 rules to distinguish between steady state and internal faults conditions with CT saturation, if present, Mamdani method was chosen [17], to perform the mathematical operation. Table 1 gives the rules used in proposed relay and Table 2 gives the specification of the proposed relay.



Rule	Inputs			Output
	Δd	Δq	Δ0	
1	Medium	High	High	Fault
2	High	High	Low	Fault
3	Low	Low	medium	Fault
4	High	High	Medium	Fault
5	High	Medium	Medium	Fault
6	Low	High	Low	Fault
7	Low	High	Medium	Fault
8	Medium	Medium	Medium	Steady State
9	High	High	High	Fault
10	Low	Medium	Medium	Fault
11	Low	Low	Low	Fault
12	Medium	High	Medium	Fault
13	Very Low	Very Low	Very High	Fault and CT saturation
14	Very Low	Very Low	Very Low	Fault and CT saturation
15	Very High	High	Very High	Fault and CT saturation
16	Very High	Very Low	Very High	Fault and CT saturation
17	Very High	Very High	Very High	Fault and CT saturation
18	Very Low	Very High	Very High	Fault and CT saturation
19	Very Low	Very High	Very Low	Fault and CT saturation

Table 1. Summary of Fuzzy Rules

Table 2. Specification of the proposed relay



Measurements	Transformer primary and secondary currents
Relay Output	Trip signal with CT saturation detection
Threshold of operation	Fuzzy output > 0.5 (Both)

3) Defuzzification: Here the method requires a crisp value for the control purposes. The technique used is centroid according to [18]

$$\mathrm{Output} = \frac{\sum_{j=0}^{N} y_j \mu_F(y_j)}{\sum_{j=0}^{N} \mu_F(y_j)} \qquad (4)$$

Where y_j is the value of every point on a domain of final output fuzzy set

$\mu_F(y_j)$ is membership value at every point.

3. The Simulated Power System

The MATLAB software was used to simulate the electrical system. Fig. 5 shows the simulated power system to generate data for the fuzzy system developed. It is a complete differential protection scheme for a power transformer. The composition of electrical system is given in Table 3. The power transformer has a delta connection in the primary winding and a star connection in the secondary winding. In accordance with the winding CTs connected for protection are star in primary side and delta in secondary side.

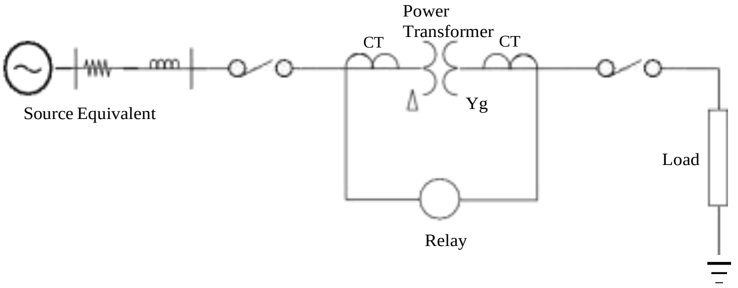
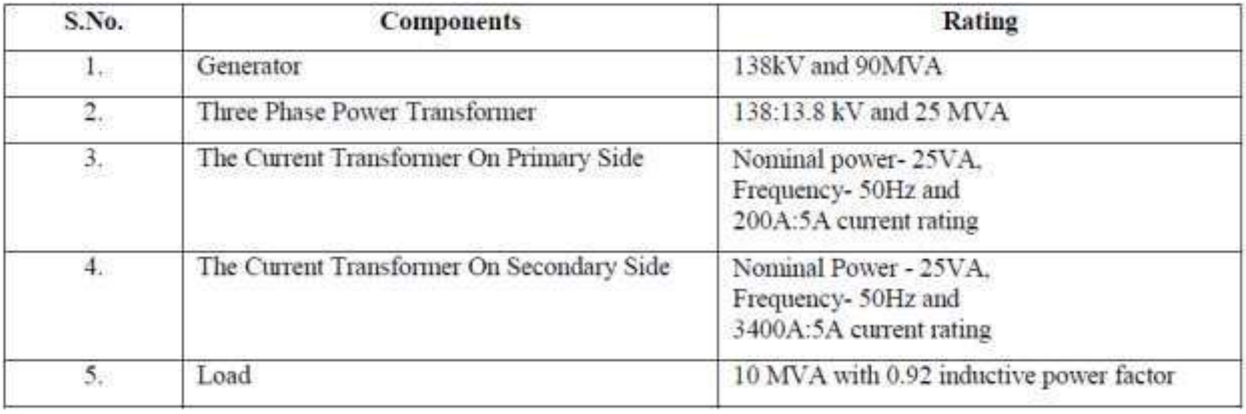


Figure. 5. Line diagram of power system considered

Table 3. Electrical system composition

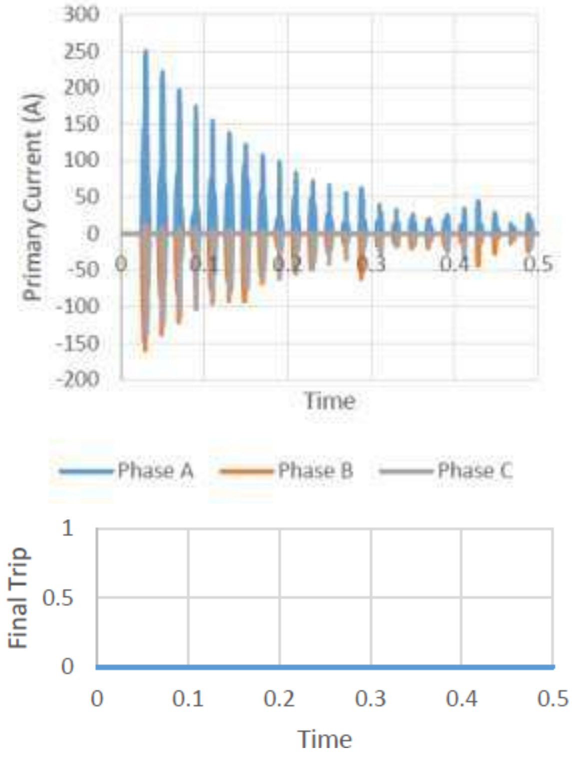


S.No.	Components	Rating
1.	Generator	138kV and 90MVA
2.	Three Phase Power Transformer	138:13.8 kV and 25 MVA
3.	The Current Transformer On Primary Side	Nominal power- 25VA, Frequency- 50Hz and 200A:5A current rating
4.	The Current Transformer On Secondary Side	Nominal Power - 25VA, Frequency- 50Hz and 3400A:5A current rating
5.	Load	10 MVA with 0.92 inductive power factor

3. Results

In this section, different results are presented for few conditions that can occur in the power transformer during its operation.

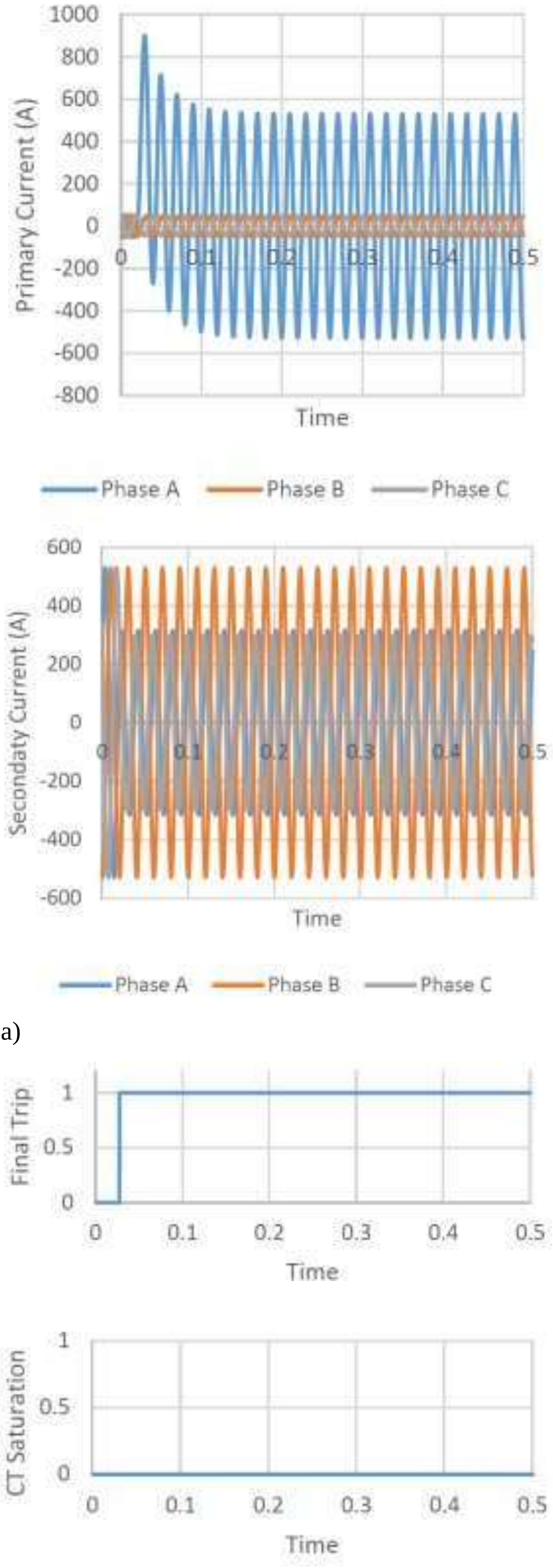
Figure 6(a) shows the primary current when an unloaded transformer (secondary winding open) is energized at zero crossing. For the same no trip signal was obtained, Figure 6(b) from the proposed method. The conventional method used to give false tripping during energization, so different algorithms [14], [15] were developed only to avoid energization.



(a) (b)

Figure. 6. Energization at zero crossing of unloaded transformer
(a) Primary current (b) Final Trip

When LG fault occurs in primary phase A of the power transformer, the primary as well as the secondary current waveforms are shown in Figure 7. The fault is created at 0.02 second and the fault is detected as early as 0.0277 second, Figure 7 (c). Figure 7 (d) shows no CT saturation was detected due to its absence in this fault. The fault is detected within one cycle itself, which is considerably fast.



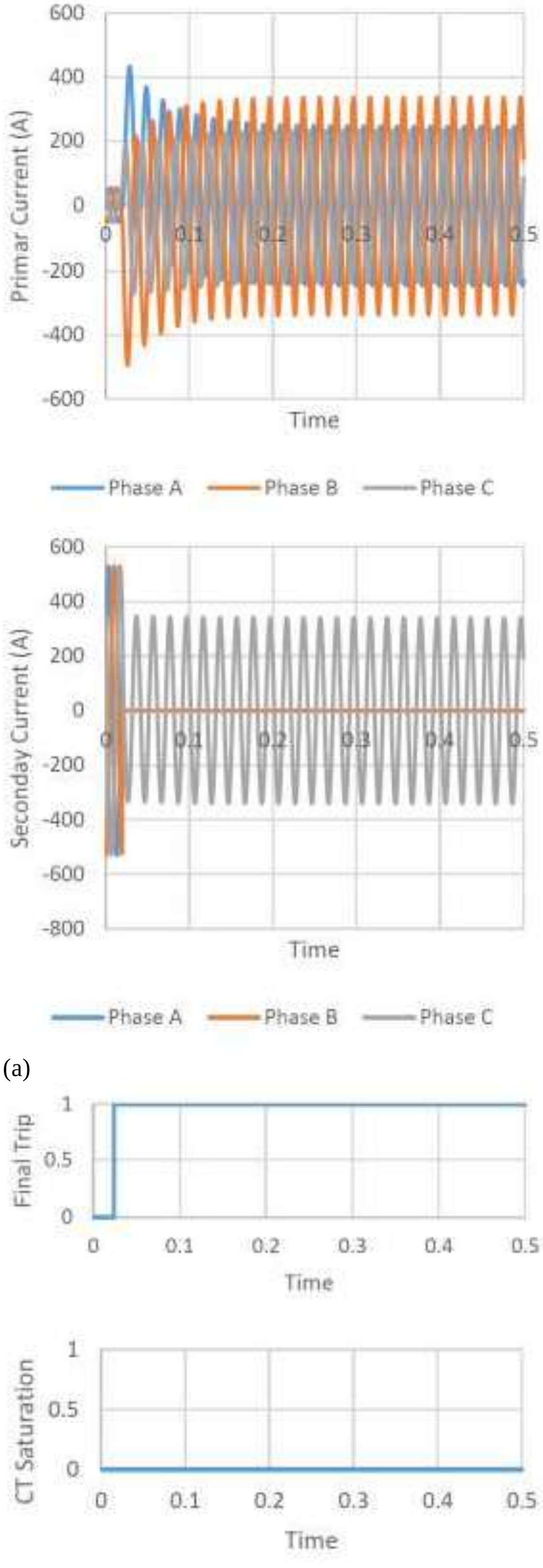
(a) (b)

(c) (d)

Figure. 7. LG fault in phase A on primary of Transformer
(a) Primary current (b) Secondary current (c) Final Trip (d) CT saturation detection

Figure 8. shows the primary as well as secondary currents respectively, when LLG fault, phase A and phase B, occurs on the secondary of the power transformer. The fault was again developed at 0.02

second and the fault is detected at 0.02415 second, Figure 8 (c). Again no CT saturation is detected as shown in Figure 8 (d), again due to the absence of the same during the fault. Fault is again detected within one cycle of fault occurrence.

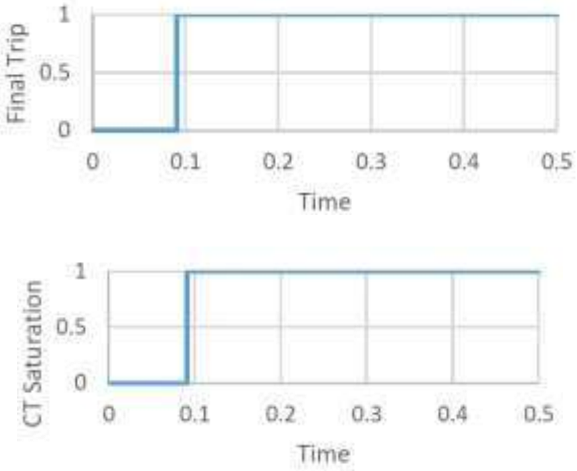


(a) (b)

(c) (d)

Figure. 8. LLG fault on Secondary of Transformer (a)Primary current (b) Secondary current (c) Final Trip (d) CT saturation detection

Figure 9, shows the trip signal for the above fault, LLG fault in phase A and phase B, but along the CT saturation which is developed by adding decaying DC component along with the fault. The fault was developed at 0.02 second, which was detected along with CT saturation at 0.09095 second. During this fault along with CT saturation, as can be observed, takes couples of cycles to detect, which is mostly undetected in the conventional differential protection of the transformer.



(a) (b)

Figure. 9. LLG fault on Secondary of Transformer
(a) Final Trip (b) CT saturation detection

4. Conclusion

The paper presents a different method for power transformer protection. The protection is done by a-b-c to d-q-0 transformation and fuzzy logic. The d-q-0 components were helpful for discrimination between different faults from other operating conditions like energization, overexcitation along with CT saturation detection. During energization and overexcitation the presented method was able to avoid the trip and was efficiently able to detect the various faults within the protected region and even detect CT saturation, if present. By observing the results for different faults it can also be concluded that most of the faults were detected within half cycle of fault development, which is considerably fast. But the CT saturation detection was detected within few cycles, which is not at all detected in conventional protection method.

The algorithm is also advantageous as it does not use the harmonic components as the basis of relay decision as in most of the algorithm for energization detection and it is a simple method which can be easily understood.

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