Flux Based Technique to Identify the Location of Inter Turn Faults in Transformer

Imran S. Mulani[1], Swapnil Y. Gadgune[2]

[1]M.Tech Student Department of Electrical Engineering, PVP Institute of technology, Budhgoan, Maharashtra, India [2]Department of Electrical Engineering, PVP Institute of technology Budhgoan, Maharashtra, India.

[1]imranmulani641@gmaill.com [2]swapnilgadgune@gmail.com

***Abstract*— The internal turn-to-turn faults (TTFs), as a common cause of the transformer failures, result in minor changes on terminal currents/voltages. They maybe undetected by the conventional protective relays. In this study, a simple, sensitive and robust linkage flux based technique is proposed to protect the power transformers against TTFs. In this approach, some separated multi-turn windings as search coils (SCs) have to be wrapped around the transformer core legs to sense the related passing flux. Since passing equal flux through a transformer core leg in normal condition induces equal voltages in the related SCs, variation of the induced voltages indicates the fault occurrence in that phase. Against the traditional differential protection schemes, current transformer error and saturation, tap changer operation, energizing inrush current, over-fluxing etc. cannot impact the proposed technique performance. Therefore, it can be introduced as a comprehensive protection technique for power transformers. It is notable that not only the internal TTFs can be detected by the proposed technique but also other types of internal faults are diagnosable by this technique. For example, the Earth faults near the star point are detectable whenever the star connected winding is grounded solidly. Such faults are similar to TTFs near the star point, and then they are detectable by the proposed technique, as well.**

The presented technique can discriminate the external faults from the internal ones, too. When an external fault occurs, transformer winding is shorted entirely. Therefore, the corresponding SCs measure the equal reduced linkage fluxes overall the faulty phase, and accordingly the ΣΔE on the faulty phase cannot be activated, as it should be. As a brief review, the ΣΔE can detect any event that creates a distortion in the flux symmetricity along each core leg. It senses only the flux uniformity along the core legs and reacts whenever this regularity is distorted.

The proposed technique can be used for all power transformers with different rating voltages and powers. Moreover, type of windings connections cannot impact the performance of the proposed technique, while it is demonstrated on the basis of the flux homogeneity in the healthy transformer core.

Keywords*— *Transformer, internal fault, search coil location.

1. Introduction

Power transformers are one of the most important and expensive apparatus in the power systems and short circuits are an unavoidable event in power transformers that can be happened. Turn-to-turn faults (TTFs) are the most common events inside transformers. A brief review on the records of the modern transformer breakdowns shows that around 70–80% of the failures are caused by TTFs.

Early stages of TTF may often have negligible effects on the transformer performance; however, such faults may rapidly lead to more serious permanent forms such as phase-to-phase or phase-to-ground faults.

1. Metallic contact coming about because of mechanical powers because of outer short out.
2. Severe protection weakening therefore of unnecessary over-burdening.
3. Insulating oil corruption because of defilement by dampness.
4. Applying an enormous drive voltage because of an exchanging/helping overvoltage.

The most common protective device for power transformers is differential relay. Though it can protect the power transformer against the severe TTFs, it is unable to detect the minor ones because the terminal currents are not affected significantly by them. Though a TTF will give rise to a heavy fault current in the short-circuited loop, the terminal currents will be very small, because of the high ratio of transformation between the whole winding and the short-circuited turns.

Since the current-based relays use the terminal waveforms, their performance and setting are dependent on some variables, including:

1. Magnetizing current.
2. Current transformer (CTs) turns ratio error.
3. CT saturation in heavy external fault
4. Tap changer (TC) operation.

Which all of above items reduce the protection sensitivity to detect the internal faults. Therefore operate-restrain characteristics must be considered to activate differential relays. Indeed these characteristics reduce the sensitivity, and the relay performance will be limited by it, while TTF occurs. Indeed, the minor TTFs (that are located in the restrain region above –mentioned characteristics) cannot be detected by differential relays.

Energizing inrush current is another phenomenon that affects the differential relays security and causes a mal-operation.

The inrush current, though generally resembling an in zone fault current, differs greatly when the waveforms are compared. The difference in the waveforms can be used to distinguish between the conditions. The inrush current contains all harmonic orders but in practice only the second harmonic is used as an attractive basis for a stabilizing bias against inrush effects. To distinguish the inrush current from faulty current, the differential current is passed through filter that extract the second harmonic; this component is then applied to produce a restraining quantity sufficient to overcome the operating tendency due to the whole of inrush current flows in the operating circuit.

In addition, to modify the differential relay performance, some algorithms presented to block or restrain relay such as:

1. Harmonic restraint.
2. Wave-shape recognition.
3. Signal processing methods such as wavelet transform.

The over fluxing phenomenon as another trouble for differential relays arises principally from the following system condition.

1. High system voltage
2. Low system frequency
3. Geomagnetic disturbance.

Which the letter results in low frequency earth currents circulating through a transmission system, since momentary system disturbance can cause transient over fluxing that is not dangerous, time delayed tripping is required. The normal protection is an inverse definite minimum time (IDMT) or definite time characteristics, initiated if a defined V/F threshold is exceeded. Some relays provide a fifth harmonic detection feature, which can be used to detect such a condition as levels of this harmonic rise under over fluxing conditions. Though various current and or voltage based algorithms had been presented to modify the differential Relay performance for TTF detection, there are some problem yet, as below:

1. They are insensitive to detect minor TTFs.
2. The most of them have mal-operation in the face of inrush current, over fluxing, CT saturation or TC operation.
3. Some of them cannot operate properly when the related transformer feeds an unbalanced load or while the transformer is fed by an unbalanced voltage source.
4. They cannot operate accurately due to instrument transformers errors (because they use instrument transformer to obtain the necessary data).
5. Most of them cannot specify the faulty phase and /or TTF region on the faulty winding.

The leakage flux-based (LFB) technique, which is described in this paper for online TTF detection, can also be used to identify the faulty phase and faulty region in transformer winding as an offline repairing method. The LFB technique can detect TTFs by measuring the leakage flux in various points along the core legs. And compare them to assess the flux distribution symmetricity overall the legs the LFB technique uses some search coil (SCs), which each one is made by a few turns of tiny wire wrapped around core, with specific intervals to measure the flux in different places. In normal and healthy condition (NHC), the core flux passing each transformer leg induces equal voltages in the all corresponding SCs (installed on the corresponding leg). TTF occurrence in each transformer winding decreases the core flux in the faulty region and reversely increases the leakage flux in that region i.e. the flux distribution along the faulty leg will be disturbed, and accordingly unequal voltages will be induce in the related SCs. Comparing the output voltage of the opposite SCs on any phase reveals the flux linkage asymmetrically as an essential effect of the TTF occurrence. Since the installed SCs in regular places cannot detect TTFs in the middle points (MTTFs) of the phases, a modification is applied on the mentioned technique by using two additional irregular installed SCs. In this paper LFB protection technique is described, simulated and implemented on a real distribution transformer. In addition, the effect of magnetizing inrush current and over-fluxing phenomenon is shown, experimentally. Since the TC operation cannot change the flux symmetricity along the core leg, the performance the proposed technique.

2. Construction and Operating principle

The proposed method is based on the magnetic flux continuity law that means the magnetic fluxes are continues and enclosed lines, which do not originate nor terminate at a point. Moreover, flux is determined by the induced or applied voltage, and some turns are shorted; linkage flux in to them tends to reduce. In that time the linkage flux changes to leakage flux and closes its path with air or oil.

Linkage flux in the power transformer passes through both the primary and secondary windings. This sinusoidal flux (Φ link) induces voltage (E ind) in any winding according to faradays law as (eq. 1), which N is the number of turns of the related winding.

$$E_{ind} = N * d\phi_{core}/dt \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where N is the number of turns of related winding.

Moreover, the smaller than normal flux that goes through the non-attractive locales is known as the flux leakage. This flux induces the voltage in essential and auxiliary windings shown in fig.1.

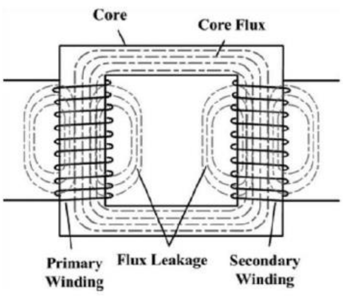

Fig.1

During TTF condition, flux going through the flawed turns tends to change its own way from the center to the external, that is, the center flux diminishes and relatively the flux leakage increments. Appropriately, the unbalanced flux lines go through the flawed center leg, particularly in the fault region. In addition, assymetric flux will bring about the flux leakage being brought up in the flawed district. The previously mentioned assymetric flux is discernible by means of embeddings a couple of SCs on the transformer legs, at standard interims. Unpredictable appropriation of the center flux along the defective leg instigates diverse voltages in the SCs, which are utilized as the primary criteria to:

1. Determine the faulty phase and the fault location in that phase during the test and repairing process.
2. Monitor and protect the transformer in online conditions.

The linkage flux-based (LFB) technique is for online TTF detection, can also be used to identify the faulty phase and faulty region in transformer winding as an offline repairing method. The LFB technique can detect TTFs by measuring the linkage flux in various points along the core legs, and compare them to assess the flux distribution symmetricity overall the legs. The LFB technique uses some search coils (SCs), which each one is made by a few turns of tiny wire wrapped around the core, with specific intervals to measure the flux in different places. In normal and healthy condition (NHC), the core flux passing each transformer leg induces equal voltages in the all corresponding SCs (installed on the corresponding leg). TTF occurrence in each transformer winding decreases the core flux in the faulty region and reversely increases the leakage flux in that region, i.e. the flux distribution along the faulty leg will be disturbed, and accordingly unequal voltages will be induced in the related SCs. Comparing the output voltage of the opposite SCs on any phase reveals the flux linkage asymmetrically as an essential effect of TTF occurrence.

Since the installed SCs in the regular places cannot detect TTFs in the middle points (MTTFs) of the phases, a modification is applied on the mentioned technique by using two additional irregular installed SCs.

3. Transformer Specifications

3A.Table for Specification of Transformer

Sr. No.	Parameter	Specification
1	Height of Core	225 mm
2	Width of Core	270 mm
3	Width of limb	50 mm
4	Height of yoke	50 mm
5	HV turns	786
6	LV turns	456
7	Depth of model	50 mm

4. Simulation and Simulation Results

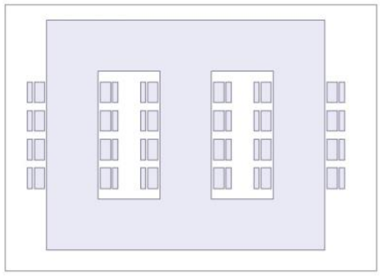

Fig.2

Above Fig.2 shows that 2D model of transformer to be fabricated, simulated in Ansoft Maxwell software to analyze the flux distribution, during normal as well as in faulty condition.

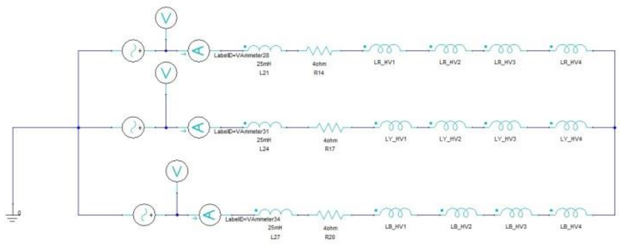

Fig.3

Fig.3 show that electrical network of transformer to be simulated with respective voltmeters and ammeters to observe voltage and current in respective phases.

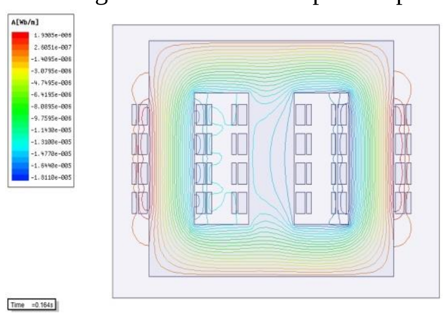

Fig.4

After simulating 2D model fig.4 shows that flux distribution at normal condition i.e. there is no any fault present, so the flux distribution is normal.

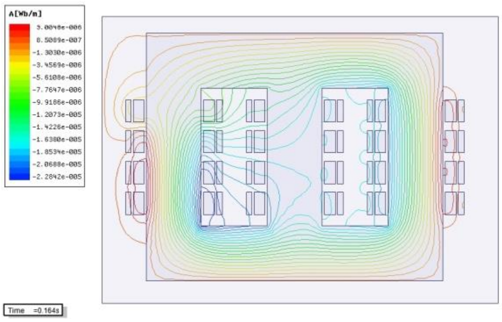

Fig.5

After simulating 2D model of transformer, during fault condition flux distribution is shown in fig.5. Having disturbance in the flux at both LV winding and HV winding. Core area flux is also disturbed compare to fig. 4.

5. Hardware Setup

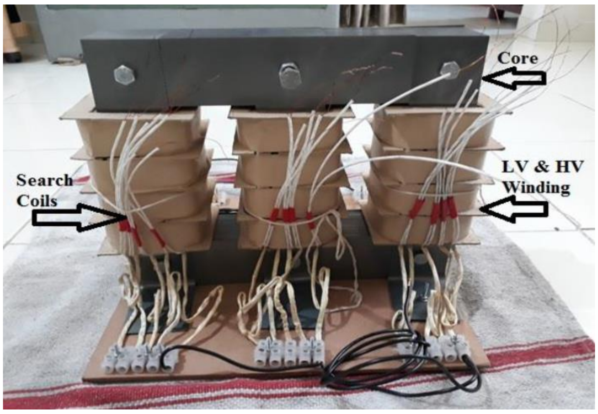

Fig.6

Fig.6 shows that actual setup of transformer designed with search coils having on each limb of core to identify the voltage during normal and during fault condition to identify the location of fault and also sense the fault as early as possible.

6. Result

6A.Vvoltage variation across each search coil during fault

Search coil number	Normal condition (voltage across search coils)	When fault occurs in Winding Part 111(Y-Phase)	When fault occurs in Winding Part 112(Y-Phase)	When fault occurs in Winding Part 113(Y-Phase)	When fault occurs in Winding Part 114(Y-Phase)
Search coil 111	3.8 V	**0.91 V**	0.65 V	0.88 V	1.0 V
Search coil 112	3.8 V	0.96 V	**0.58 V**	0.84 V	1.0 V
Search coil 113	3.8 V	1.0 V	0.67 V	**0.81 V**	0.9 V
Search coil 114	3.8 V	1.1 V	0.69 V	0.85 V	**0.8 V**

7. Conclusion

This paper presents flux based method to diagnose and identify the location of turn-turn faults in transformer, using search coil. Placed on transformer limbs to observe flux leakage during normal and in fault condition, also this method is more sensitive compare to other protection methods of transformer. It is stable during transformer energizing process, and also it is stable in over-fluxing condition of transformer. It can be introduced as a successful online technique to protect expensive power transformer.

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