Inter-Turn Fault Detection in Power transformer Using Wavelets

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Abstract*-Detection and removal of incipient faults in power transformer winding is essential because minor faults may develop and lead to major faults and finally irretrievable damages occur. This research article presenta a new, simple and incipient fault detection technique, which is based on symmetrical component approach. Using this protection technique, it is possible to detect minor turn-to-turn faults in power transformers. This protection technique is being studied via an extensive simulation study using MATLAB/SIMULINK software in three phase power system. The new protection principle is based on the theory of symmetrical components, or more exactly, on the negative sequence currents. To have accurate feature extraction and to improve the sensitivity of proposed technique, wavelet transform (WT) has been employed. In this paper a multi winding transformer of 100 MVA, 138/13.8 KV, Y-Y is simulated using MATLAB software. Different percentages of inter turns of power transformer are short circuited and it is observed that the changes in transformer terminals current is very small. To observe significant changes, negative sequence currents are extracted using symmetrical component approach. The phase angle shift on both sides of the transformer during incipient faults is found to be significant. However, to improve the sensitivity of the proposed technique, wavelet has been employed. Using the wavelet "db3" at level4 the phase angle variations of negative sequence currents during fault incidence period are analyzed. The absolute peak values of detailed1 coefficients on primary and secondary sides are calculated. The ratio of absolute peaks on faulted side to that of non-faulted side is used for feature extraction.

***Keywords*: Incipient fault, Negative sequence current, Phase shift, Wavelet, Detailed coefficient**

I. INTRODUCTION

Power transformer is one of the major elements in power system in the area of reliability issue, since their outage may result in costly and time consuming repair. For each transformer, insulations and windings are the most critical elements technically and economically, so highly sensitive protection should be considered for them. The mail fault that occurs in a transformer is turn-to-turn fault, which may lead to serious damage in windig on transformer including winding deformation, interruption or even the explosion

of the transformer because of overheating of the insulating liquid. Consequently, winding need to be frequently checked to avoid major damages. Diacnosis of incipient faults at an early stage is the key of ensuring reliable electrical power supply to consumers [1]. To prevent permanent damage of the transformers, a routine diagnosis is necessary for detection of inter turn faults. A short circuit of a few turns of the transformer winding will give rise to a heavy fault currentin the short circuited turns, but changes in the transformer terminals current will be very small, because of the high ratio of transformation between the whole winding and the short-circuited turns. For this reason, the traditional differential protection was typically not sensitive enough to detect such winding turn-to-turn faults before they developed into more serious and costly to repair. Alternatively, such faults can be as well detected by sudden pressure relays. However, these relays detect such low-level faults with a significant delay that often allows the fault to evolve into a more serious one.

In order to detect the incipient faults in winding of a power transformer, many methods are suggested. Dissolved gas analysis (DGA) has been recognized as an effective diagnostic technique for power transformer incipient fault detection. Due to variability of gas data it is always not an effective diagnosis technique to detect incipient faults. A study of the records of the power transformer breakdowns, which occurred over a period of years, showed that nearly 70% of the total number of power transformer failures are eventually due to undetected short circuit faults [2-3]. Therefore it is essential to detect the fault at an early stage so that preparations for corrective measures can be plannedin advanced and executed quickly [4]. Internal failures are sometimes catastrophic and almost always result in irreversible internal damage. It is therefore very necessary to closely moniter their online behavior [5].

These incipient faults lead to over-current in windings that results terrible damages such as severe hot-spots, oil heating, winding deformation, damage to the clamping structure, core damage, and even explosion of transformer. Also it causes many adversities in power system (voltage sag, interruption, etc). So the short circuit consideration is one of the most important and challenging aspects of transformer design.There exist a number of ways such as magnetic balance test, Buchholz relay operations, ratio-meter test to detect internal faults in transformers [6]. Magnetic balance tests and Buchholz relays can usually provide indication of winding inter-turn faults in transformers. However their sensitivity in determining such faults at an incipient stage remains questionable. Ratio meter test, which is the standard methodused for determining voltage ratio of the transformer, can also be used in an indirect wayto determine if an inter-turn short circuit exists in the winding of a transformer. However, this test is essentially a bridge method and hence is very sensitive to the accuracy and calibration of the bridge resistors. Increased no-load losses have also been shown to give very good indication of inter-turn faults in case of shorted turns. However the effect of core degradation can influence no-load losses [7].

In this research article a multi winding transformer of 100 MVA, 138/13.8 KV, Y-Y is simulated using MATLAB/SIMULINK software. Different percentages of inter turns of power transformer are short circuited and it is observed that the changes in transformer terminals current is very small. To observe significant changes, negative sequence currents are extracted using symmetrical component approach. The phase angle shift on both sides of the transformer during incipient faults is found to be significant. However, to improve the sensitivity of the proposed technique, wavelet transform has been employed. Using the wavelet "db3" at level4 the phase angle variations of negative sequence currents during fault incidence period are analyzed. The absolute peak values of detailed1 coefficients on primary and secondary sides are calculated. The ratio of absolute peaks on faulted side to that on non-faulted side is used for feature extraction. If this ratio exceeds a pre defined threshold, an incipient fault is assumed.

The organization of the paper is as follows: In section II a brief introduction to the wavelet transform is presented. Section III depicts the power system under study. In section IV power transformer simulation and results are presented. Feature extraction is explained in section V. Flow chart of the proposed algorithm is presented in section VI. The final section concludes the paper.

II. WAVELET TRANSFORMS

As power system disturbances are subjected to transient and non-periodic components, the traditional Fourier transform fails to describe the sudden change that exists in any transient process. A wavelet based signal processing techniques an effective tool for power system transient analysis and feature extraction. The principle involves in choosing a wavelet which is dilated and translated to vary the frequency of oscillation and time location, superimposed on to the non-stationary signal. These dilating and translating mechanisms are desirable for analyzing the waveforms containing non-stationary events. By continuously dilating the wavelet, the instant of fault occurrence is known on the time scale.

If a pure frequency signal is given, Fourier based methods will isolate a peak at that particular frequency. But if a signal is built of two pure oscillations occurring in two adjacent intervals, two peaks are obtained without localization in time. This immediately points out the need for a time frequency representation of a signal which would give local information in time and frequency [8]. The most interesting property of wavelet transforms is that individual wavelet functions are localized in space. This localization feature, along with wavelets localization of frequency, makes many functions and operators using wavelets 'sparse' when transformed into the wavelet domain. This sparseness, in turn, results in a number of applications such as data compression, detecting features in images, and removing noise from time series [9].

In order to isolate signal discontinuities, one would like to have some short basis functions. At the same time, in order to obtain detailed frequency analysis, one would like to have some very long basis functions. A way to achieve this is to have short high-frequency basis functions and long low-frequency ones. This is exactly what is obtained with wavelet transforms. They have an infinite set of possible basis functions. Thus wavelet analysis provides immediate access to information that can be obscured by other time-frequency methods such as Fourier analysis. Selection of wavelet is very important. In this paper, Db3 wavelet is used for its property of orthogonality. In this work it is used for the analysis of phase varying negative sequence currents.

Wavelet Transform is defined as a sequence of a function {h (n)}(low pass filter) and {g (n)}(high pass filter). The scaling function φ (t) and wavelet ψ (t) are defined by the following equations.

$$\varphi(t) = \sqrt{2}\sum h(n)\, \varphi(2t-n) \quad (1)$$

$$\psi(t) = \sqrt{2}\sum g(n)\, \varphi(2t-n) \quad (2)$$

Where $g(n) = (-1)^n h(1-n)$

A sequence of {h (n)} defines a Wavelet Transform. There are many types of wavelets such as Haar, Daubachies, and Symlet etc. The selection of mother wavelet is based on the type of application.

III. POWER SYSTEM UNDER STUDY

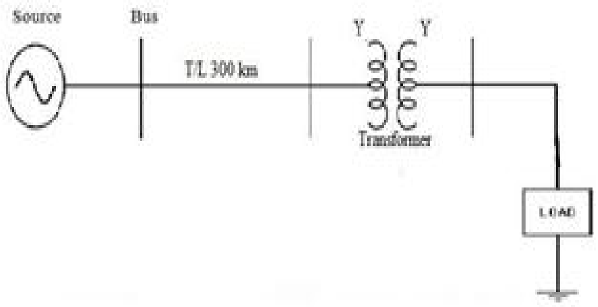
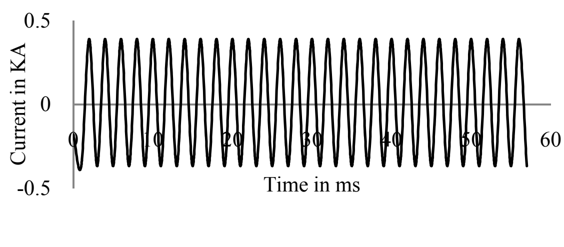


Fig. 1. One line diagram of power system model.

1V. POWER TRANSFORMER SIMULATION AND RESULTS

A power transformer of 100 MVA, 13.8/138 KV multi-winding transformer with 100 turns on the secondary is simulated using MATLAB/SIMULINK software and the changes in the transformer terminals current in phase C are observed due to internal turn-to-turn fault, when 1%, 3%, 5%, 10%, 15%, and 25% of the turns are shorted on the secondary winding. Fig. 2. and Fig. 3. show the variation of transformer terminals current.



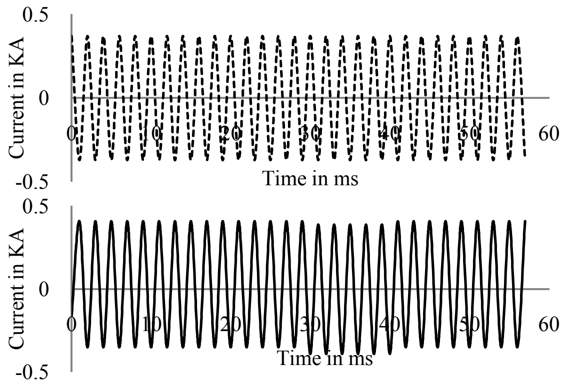


Fig. 2. Three Phase currents on primary side when 1% of turns are shorted in phase C.

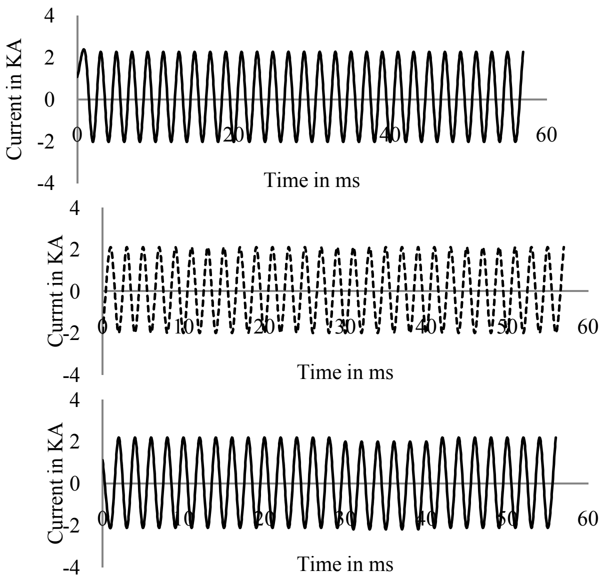


Fig. 3. Three Phase currents on secondary side when 1% of turns are shorted in phase C.

Table I shows percentage changes in the transformer terminals current in secondary, phase C for different percentages of shorted turns.

TABLE I

Sl. no	% of shorted turns in secondary of phase C	Magnitude of steady state current	Magnitude of fault current	% change
1	1	2.15	2.2	2.27
2	3	2.13	2.2	3.286
3	5	2.06	2.13	3.39
4	10	1.92	2	4.16
5	15	2.21	2.284	3.34
6	25	2.41	2.53	4.97

Table II shows percentage changes in the transformer terminals currents in primary, phase C for different number of shorted turns.

TABLE II

Sl. No.	% of shorted turns	Terminals current during steady state	Fault current	% change
1	1	0.41	0.415	1.21
2	3	o.34	0.364	1.62
3	5	0.38	0.384	1.05
4	10	0.36	0.367	1.944
5	15	0.37	0.377	2.652
6	25	0.375	0.392	4.53

The percentage changes in the transformer terminals currents are very small during incipient faults. So a new protection principle based on the theory of symmetrical components or more exactly, on the negative-sequence currents is proposed. The negative sequence currents are extracted using MATLAB/SIMULINK. The phase angle variations of negative sequence currents on both sides of the power transformer when 1% shorted turns are shown in Fig. 4.

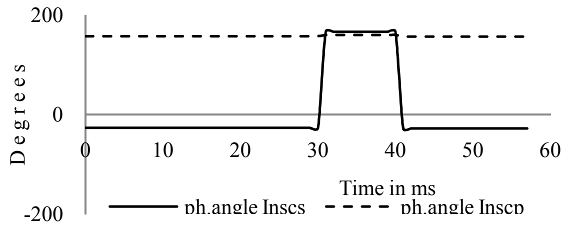


Fig. 4. Phase shift between Inscs to Inscp when 1% turns are shorted

Theoretically, the phase angle between two phasors of negative sequence currents has to be 0 degrees during internal short circuit. But in reality there are some other arbitrary phase angle shift caused by the quite high current in the shorted turns as shown in figures. The phase shift during different percentages of shorted turns on primary and secondary sides of power transformer is shown in the Table III.

Table III

Sl. No.	% of shorted turns	Phase angle of Inscs	Phase angle of Inscp	Phase shift
1	1	166.84	160.27	6.57
2	3	162.33	156.11	6.21
3	5	156.64	151.12	5.51
4	10	160.63	152.40	7.80
5	15	159.11	152.83	6.28
6	25	160.19	154.63	5.55

The phase shift between negative sequence currents is also not significant. So to improve the sensitivity of the proposed scheme wavelet transform has been employed. Unlike DFT, WT not only analyzes the signal in frequency bands, but also provides non- uniform division of the frequency domain, i.e. WT uses a short window at high frequencies and long window at low frequencies. This helps to analyze the signal in both frequencies and time domains effectively. In this research work the negative sequence currents of varying phase shift are analyzed by using Db3 wavelet at level4. Figure5.

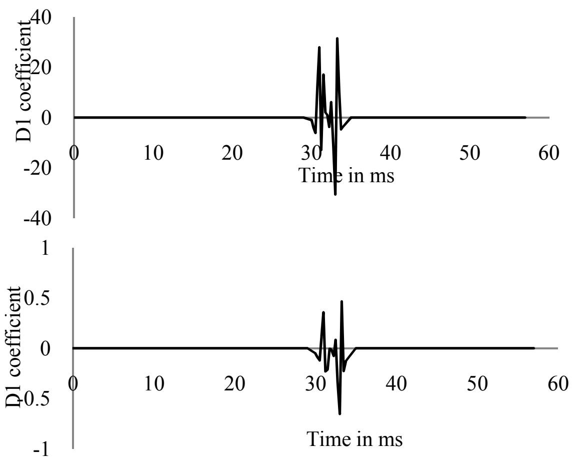


Fig. 5. d1 coefficient of phase varying signals when 1% turns are shorted.

V. FEATURE EXTRACTION

The phase shift occurred during different percentages of faulted turns is considered as the key issue for the inter turn fault detection. To improve the sensitivity of the proposed scheme, wavelet has been employed. Wavelet is applied to phase varying negative sequence current signals, and their features are well identified in both time and frequency domains. In this research work Db3 wavelet at level4 is applied and detailed1 coefficients are extracted on both sides of the power transformer. The ratio of absolute peak on faulted side to that of non faulted side is calculated. Based on number of simulation studies a threshold is set. If this ratio exceeds the settled threshold, an incipient fault is assumed. The ratio of absolute peaks of d1 coefficients on faulted side (secondary) to that on non-faulted side (primary) at different percentages of shorted turns is calculated and the results are given in Table IV.

Table IV

Sl. No.	% of shorted turns	Absolute peak of d1 coefficient on secondary	Absolute peak of d1 coefficient on primary	Ratio
1	1	31.4178	0.65169	48.20
2	3	50.7503	0.8982	57.02
3	5	27.0606	0.5426	49.87
4	10	50.1187	0.9268	54.07
5	15	49.8699	0.9626	51.8
6	25	48.1615	0.9805	49.14

It is observed that the ratio is minimum when 1% of the turns are shorted. So this value is set as threshold value. If the ratio exceeds the settled threshold, an incipient fault is assumed. In the following section the novel algorithm for detection of incipient faults in a power transformer using Multiresolution Analysis of the transient negative sequence currents associated with the fault is proposed.

VI. PROPOSED ALGORITHM

1. Three phase currents are measured.
2. Observe all the phase currents whether is there any deviation from steady state value. If there is no deviation then, go for negative sequence currents measurement.
3. Obtain negative sequence currents by using symmetrical component approach on primary and secondary sides.
4. Find the faulted phase by observing relative variation in the magnitudes of negative sequence currents on primary and secondary sides.
5. Apply multi resolution analysis to obtain detailed1 coefficients on both sides.
6. Obtain absolute peaks of d1 coefficients on primary and secondary.
7. Find the ratio of absolute peaks on faulted side (say secondary) to non-faulted (say primary).
8. Find whether the ratio exceeds a predefined threshold.
9. If it exceeds the pre defined threshold value then an incipient fault is detected.

The flowchart for the proposed algorithm is given in Fig. 6.

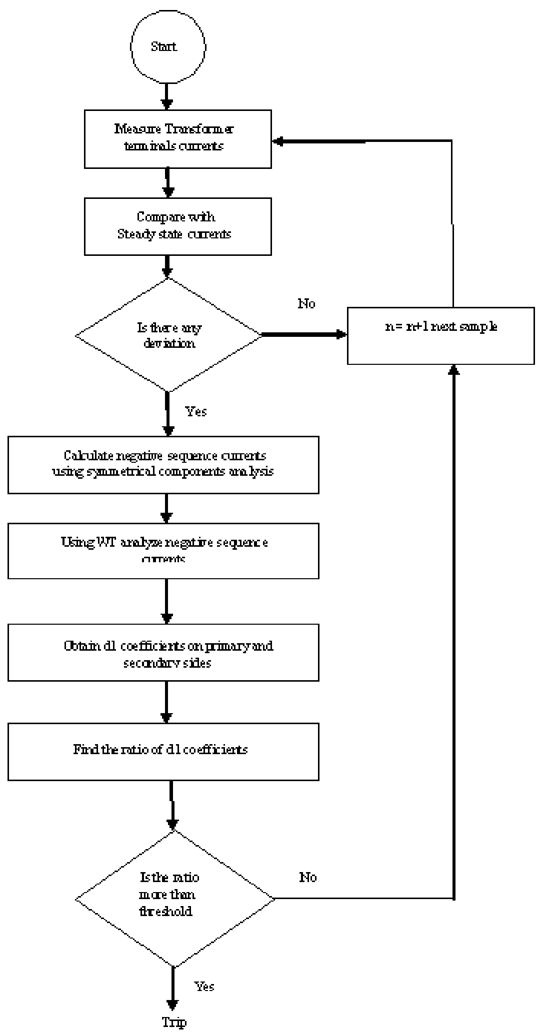


Fig. 6 Flow chart of the proposed algorithm

VII. CONCLUSION

An entirely new method is presented for incipient fault detection in power transformers. A negative sequence current based sensitive detection method using wavelets has been presented in this paper. The terminals current whose change is very minute when a minor fault occurs, is analyzed by the wavelet transform method. The proposed method conquers the limitations of the traditional power transformer protection schemes in detecting low-level inter-turn faults. Hence, it is found to be a very good compliment to the existing power transformer fault detection methods. The proposed method is a non-invasive method and no additional measurements are required to implement the technique, since it only needs the terminal current data. Also, no information concerning the transformer is needed for the application of the technique. Simulation is performed by applying the MATLAB tools. The simulation results obtained demonstrate the success of the proposed algorithm.

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NOMENCLATURE

NSC: Negative Sequence Current.
Ph.angle Inscs: Phase angle variation of negative sequence current on secondary side.
Ph.angleInscp: phase angle variation of negative sequence current on primary side.
DWT: Discrete Fourier Transform
WT: Wavelet Transform
Db3: Daubechies3
D1: detailed1 coefficient

APPENDIX

Three phase voltage source
Voltage: 138KV
Frequency :50Hz
Three phase transformer block parameters
Nominal Power: 100MVA
Voltage:138/13.8 KV
Transmission line parameters
Resistance per unit length: 0.02ohms/km
Inductance per unit length :0.506*10^2 H/km
Capacitance per unit length :1*10^-12 F/km
Line length: 300 km

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