Inter Turn Fault Detection in Power transformer using DWT

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Abstract*-Detection and removal of inter turn short circuits in a power transformer winding is essential because minor faults may develop into more serious faults and finally lead to irretrievable damages to the transformer windings. This research work explores a new, simple and robust inter turn 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 particular protection technique is validated using an extensive simulation study using MATLAB/SIMULINK software. In this work, a multi-turn Y-Y connected transformer of 100 MVA, 138/13.8 KV, is simulated using MATLAB software. Different percentages of inter turns of power transformer are short-circuited and the terminals current is found to be significantly low. To observe significant changes in the corresponding currents, negative sequence currents are extracted using symmetrical component approach. The phase angle shift on primary and secondary sides of the transformer during inter turn short circuits are measured. Discrete Wavelet Transform (DWT) is employed in order to improve the sensitivity of the proposed technique. 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 to feature extraction.*

Keywords**:** *Incipient fault, negative sequence current, phase shift, wavelet, detailed coefficient*

1. INTRODUCTION

Power transformer is one of the vital elements of an integrated electrical power system in the area of reliability issue since its failure may result in costly and time consuming repair. For each transformer, insulations and windings are the most important elements technically and economically. So, highly sensitive protection is needed for them. The main fault that occurs in a transformer is turn-to-turn fault, which may lead to severe damage in winding on transformer including winding deformation, explosion of the transformer because of overheating of the insulating liquid. Consequently, winding need to be frequently checked to avoid major damages. Diagnosis of inter turn 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 high fault current in 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 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 detected by sudden pressure relays. However, these relays detect such low-level faults with a significant delay that often allows the fault to develop into a more serious one.

In order to detect the incipient faults in winding of a power transformer, many methods are proposed in the literature. 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 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 planned in advance [4]. Internal failures are sometimes disastrous and almost always result in irreparable internal damage. It is, therefore very essential to closely monitor their online behavior [5].

These incipient faults lead to over-current in windings that results in awful damages such as severe hotspots, 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 uncertain. Ratio meter test, which is the regular method used for determining voltage ratio of the transformer, can also be used in an oblique way to determine if an inter-turn short-circuit exists in the winding of a transformer. However, this test is basically 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 work a multi-turn 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 2 a brief introduction to the DWT is presented. Section 3depicts the power system under study. In section 4 power transformer simulation and results are presented. Feature extraction is explained in section 5. Flow chart of the proposed algorithm is presented in section 6. The final section concludes the paper.

2. 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 are effective for power system transient analysis and feature extraction. The principle involves in choosing a particular 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 a 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.

Different kinds of wavelet families are derived. Db3 is simply chosen since it gives more accurate solution and minimum reconstruction error. Wavelet Transform (WT) is an efficient means of analyzing transient currents and voltages.

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

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

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

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.

3. POWER SYSTEM UNDER STUDY

The power system consists of a source, transmission line, a transformer and loading arrangements over it as shown in Fig. 1

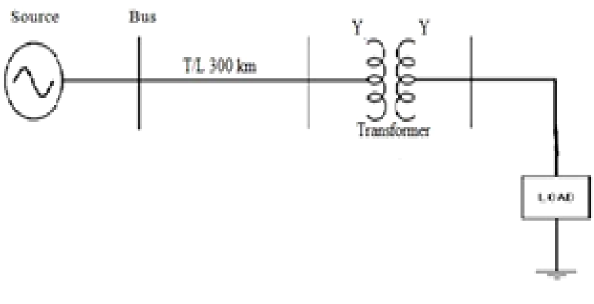

Fig. 1. One line diagram of power system model.

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.

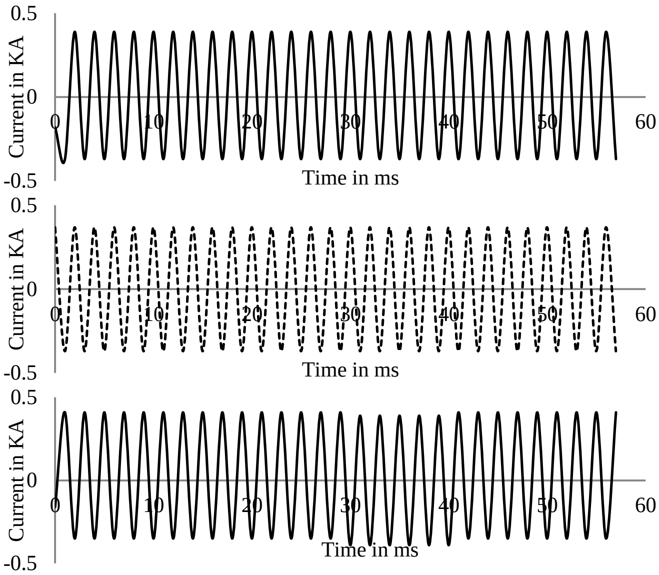

Fig. 2. Three Phase currents on primary side when 1% of turns are shorted in phase C.

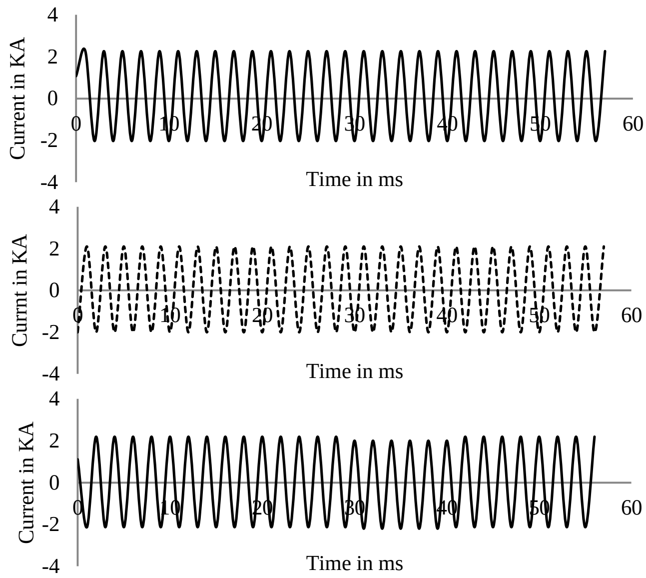

Fig. 3. Three Phase currents on secondary side when 1% of turns are shorted in phase C.

In a similar manner different percentages of the transformer turns are short circuited and the measurements of the terminals currents are given in Tables 1 and 2.

Table 1. Percentage changes in the transformer terminals current in secondary, phase C for different percentages of shorted turns.

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 2. Percentage changes in the transformer terminals currents in primary, phase C for different number of shorted turns.

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. The phase angle variations of negative sequence currents on both sides of the power transformer during different percentages of shorted turns are measured and the phase variations during 1% and 3% shorted turns are shown in Fig. 4. & Fig. 5.

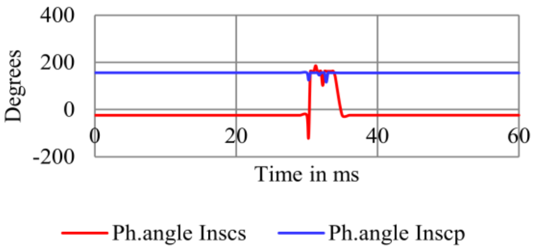

Fig. 4. Phase shift between Inscs to Inscp when 3% turns are shorted

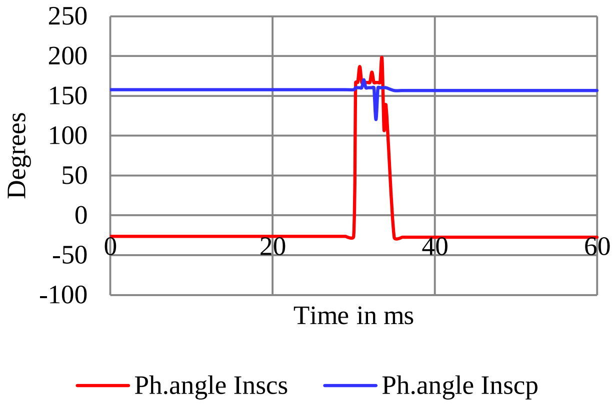

Fig. 5. Phase shift between Inscs to Inscp when 1% turns are shorted

The phase shift during different percentages of shorted turns on primary and secondary sides of power transformer is shown in the Table 3.

Table 3. Phase shifts during different % of shorted turns

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. Figures 6 and 7 show the d1 coefficients obtained using multiresolution analysis.

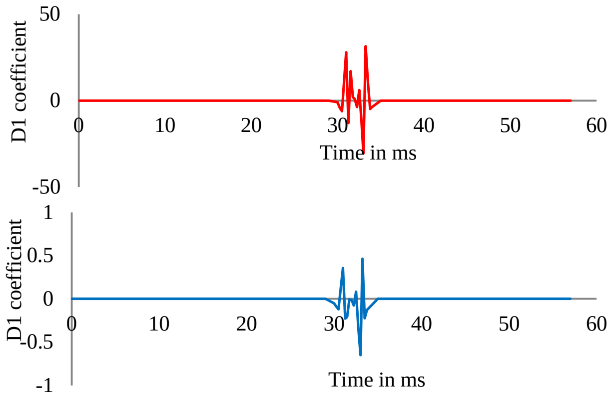

Fig. 6. d1 coefficient of phase varying signals when 1% turns are shorted.

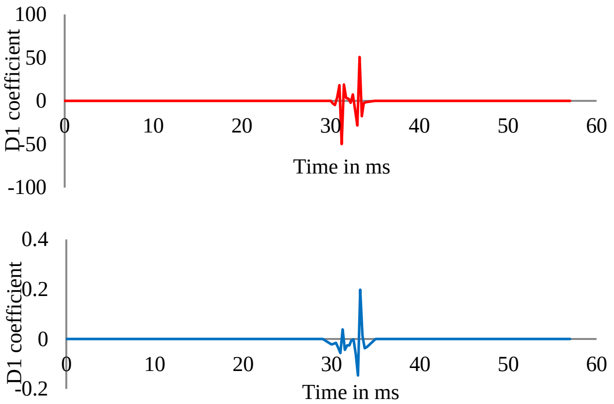

Fig. 7. d1 coefficient of phase varying signals when 3% turns are shorted

5. 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 4.

Table 4. Ratio of detailed coefficients

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 Multi resolution Analysis of the transient negative sequence currents associated with the fault is proposed.

6. 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.

If it exceeds the pre defined threshold value then an incipient fault is detected.

8. 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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REFERENCES

[1] S. W. Fei, X. B. Zhang, "Fault diagnosis of power transformer based on support vector machine with genetic algorithm," Expert systems with Applications 36 (2009) 11352-11357.

[2] W. Bartly, "Analysis of transformer failures," *in proc. International Association of Engineering Insurers 36th Annual Conference*, Stockholm, Sweden, 2003.

[3] S. A. Stigant and C. Franlin, The J and P Transformer Book: A Practical Technology of the power Transformer, 10th ed., Newyork: Wiley, 1973.

[4] V. Behjat, A. Vahedi, S. Setayeshmehr, H. Borsi, and E. Gockenbach, "Identification of the most sensitive frequency response measurement technique for diagnosis of interturn faults in power transformers," *IOP Publishing (Measurement Science and Technology), Meas. Sci. Technol. 21 (2010) 075106 (14pp)*, pp. 1-14, 2010.

[5] W. H. Tang, K. Spurgeon, Q. H. Wu, and Z. J. Richardson, An evidential reasoning approach to transformer Condition assessments, IEEE Trans. Power Delivery, vol. 19, no.4, pp. 1696-1703, Oct. 2004.

[6] M. R. Barzegaran, M. Marzaie, Detecting the position of winding Short Circuit Faults in Transformer Using High frequency Analysis, EURO journels: pp. 644-648, Vol. 23, No. 4, 2008.

[7] Subhasis Nandi, A Noval Frequency Domain Based Technique to Detect Transformer Inter-turn Faults, IEEE Trans. Power Del, Vol. 24 pp. 569-584, Feb 2008.

[8] Proceedings of IEEE, Special issue on wavelets, Vol. 84, April 1996.

[9] Raghuveer M. Rao and Ajit. S. Bopardikar, Wavelet transforms, Pearson Education Asia, 1999.

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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