Coefficient Comparison Technique of Discrete Wavelet Transform for Discriminating between External Short Circuit and Internal Winding Fault in Power Transformer

C. Pothisarn, C. Jettanasen, J. Klomjit, and A. Ngaopitakkul, *Member, IAENG*

Abstract—**This paper proposes a technique for detecting and identifying internal winding fault of three-phase two-winding transformer which variations of coefficients of high frequency component obtained from DWT of differential current are analyzed. The maximum coefficient details of DWT are performed as comparison indicator in order to discriminate between internal fault and external short circuit. Various cases based on Thailand electricity transmission and distribution systems are studied to verify the validity of the proposed algorithm. Results show that the proposed technique has good accuracy to detect fault and to identify its position in the considered system.**

Index Terms—**Wavelet Transform, Power Transform, External short circuit, Internal winding fault**

I. Introduction

To guarantee safety and stability of power grid operating, a precise protection scheme is required. In the literature for fault detection, several decision algorithms have been developed to be employed in the protective relay [1-5]. They (most of them) have different solutions and techniques [1-10]. In [1], high frequency component of transformer terminal current technique is proposed for detecting internal faults in power transformers. A digital technique that uses positive- and negative-sequence models of the power system in a fault-detection algorithm is presented in [2]. An application of a finite impulse response ANN (FIRANN) as differential protection for a three-phase power transformer is proposed in [3]. In [4], this paper describes a new approach for transformer differential protection that ensures security for external faults, inrush, and over-excitation conditions and provides dependability for internal faults. The development of a wavelet–based scheme, for distinguishing between transformer inrush currents and power system fault currents is presented in [5]. A technique for discriminating fault currents from inrush currents is presented in [6]. The performance of the technique is checked from simulation of a 132/11 kV transformer, connected to a 132 kV power system. A new relaying fuzzy logic algorithm to enhance the fault detection sensitivities of conventional techniques is proposed in [7]. The relaying algorithm consists of flux-differential current derivative curve, harmonic restraint, and percentage differential characteristic curve. In [8], a new algorithm based on processing differential current harmonics is proposed for digital differential protection of power transformers. This algorithm has been developed by considering different behaviors of second harmonic components of the differential currents under fault and inrush current conditions. In [9], an Equivalent Instantaneous Inductance (EII)-based scheme is proposed to distinguish the inrush current from internal faults in power transformers, which is derived from the inherent difference of the magnetic permeability, due to the saturation and un-saturation, in the transformer iron core between the inrush current and an internal fault. In [10], this paper describes a new approach for transformer differential protection that ensures security for external faults, inrush and over-excitation conditions and provides dependability for internal faults. As a result, most research works are interested in only the effects from magnetizing inrush current and the discrimination between magnetizing inrush current and internal faults [5-10], and etc.

In addition, the traditional method of signal analysis is based on Fourier transforms However, Fourier transform was not suited to fault transient analysis, because the desired information may be not only located in the frequency domain but also in the time domain. Besides, wavelet transform can be used in signal analysis. This mathematical technique is not intended to replace Fourier transform technique in analysing steady state signals, it is just an alternative tool for analysing non-stationary or non-steady state signals.

In previous research works [11], in order to discriminate between external fault and internal fault in power transformer, the comparisons of the coefficients of discrete wavelet transform (DWT) have been performed. The proposed decision algorithm can give more satisfactory results for separation between internal fault and external fault but case studies were verified with power transformer which is connected with wye-wye. In a fact, power transformer which is connected with delta-wye is widely employed more than power transformer which is connected

Manuscript received December 28, 2011.
C. Pothisarn, C. Jettanasen, J. Klomjit, and A. Ngaopitakkul are with Department of Electrical Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand (e-mail: knatthap@kmitl.ac.th).

with wye-wye in power system so decision algorithm should prove to be more complicated to analyze.

Therefore, this paper is interested in the decision algorithm for detecting and discriminating between internal fault and external fault for power transformer. A decision algorithm is based on DWT as an alternative or improvement to the existing protective relaying functions. The construction of the decision algorithm is detailed and implemented with various case studies based on Thailand electricity transmission and distribution systems.

II. Simulation

To study internal faults of the transformer, Bastard et al [12] proposed modification of the BCTRAN subroutine. Normally, the BCTRAN uses a matrix of inductances with a size of 6x6 to represent a transformer, but with the internal fault conditions, the matrix is adjusted to be a size of 7x7 for winding to ground faults. However, the effects of high frequency components which may occur during the faults are not included in such a model. In this paper, the combination between the transformer models proposed by Bastard et al [12] and the high frequency model including capacitances of the transformer recommended by IEEE working group [13] is used for simulations of internal faults the transformer windings.

The process for simulating internal faults based on the BCTRAN routine of EMTP can be summarized as follows:

1st step: Compute matrices [R] and [L] with a size of 6x6 to represent a power transformer from manufacture test data [14] without considering the internal faults.

2nd step: Modify matrix of [R] and [L] to be a size of 7x7 for winding to ground faults and of 8x8 for interturn faults.

3rd step: The inter-winding capacitances and earth capacitances of the HV and LV windings can be simulated by adding lumped capacitances connected to the terminals of the transformer.

The scheme under investigations is a part of Thailand electricity transmission and distribution system as depicted in Figure 1. A 50 MVA, 115/23 kV three-phase two-winding transformer was employed in simulations with all parameters and configuration provided by a manufacturer [14].

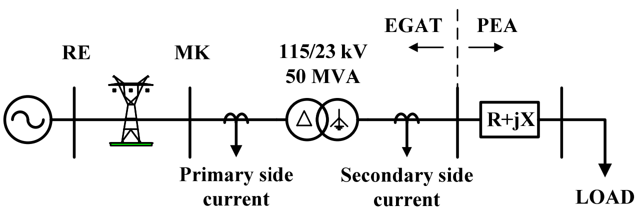


Figure 1. The system used in simulations studies [15].

It can be seen that the transformer which is a step down transformer is connected between two subtransmission sections. To implement the transformer model, simulations were performed with various changes in system parameters as follows:

- The angles on phase A voltage waveform for the instants of fault inception were 0^{o}-330^{o} (each step is 30°).
- For the internal winding faults, the fault positions as shown in Figure 3, were designated on any phases of the transformer windings (both primary and secondary) at the length of 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90% measured from the line end of the windings.

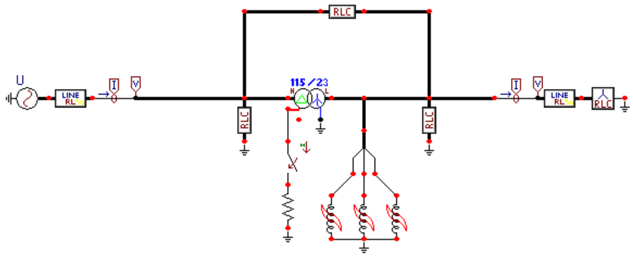


Figure 2. Internal fault model implemented in ATP/EMTP

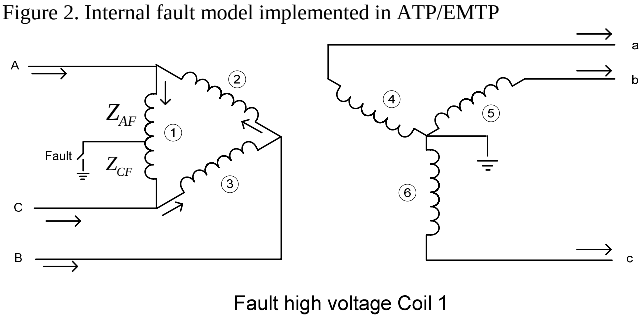


Figure 3. The modification on ATP/EMTP model for a three-phase transformer with winding to ground faults.

For simulations of external short circuit occurring at the transmission lines at both sides of the transformer, case studies were varied as follows:

- The angles on phase A voltage waveform for the instants of fault inception were 0^{o}-150^{o} (each step is 30°).
- Types of faults were single line to ground, double lines to ground, line to line and three-phase faults (AG, BG, CG, ABG, BCG, CAG, AB, BC, CA, ABC).
- The fault locations on the transmission lines were at the length of 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90%.
- Fault resistance was 5 Ω.

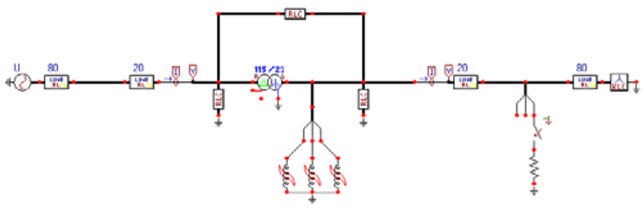


Figure 4. Components of a proposed simulation model in case of external short circuit.

The primary and secondary current waveforms, then, can be simulated using ATP/EMTP, and these waveforms are interfaced to MATLAB/Simulink for a construction of fault diagnosis process. The fault signal in each phase is obtained from primary and secondary current of transformer as illustrated in Figure 5 to Figure 8. These obtained figures correspond to two zones protection. Figure 5 is obtained when internal winding fault occurred at high voltage winding while Figure 7 is obtained when external fault occurred at high voltage winding.

ISBN: 978-988-19251-9-0
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

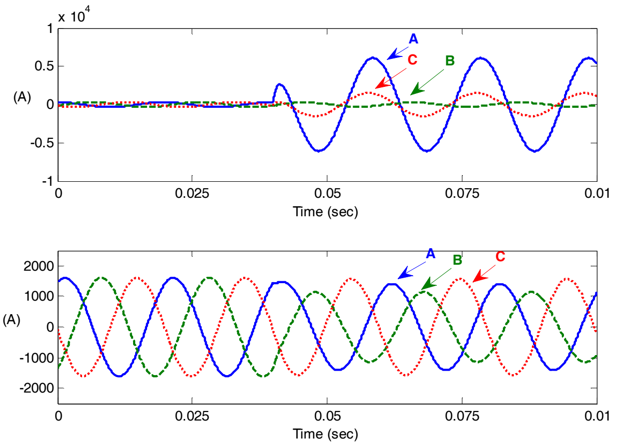


Figure 5. Primary and secondary currents for a case of internal fault at 20% of length of the high voltage winding.

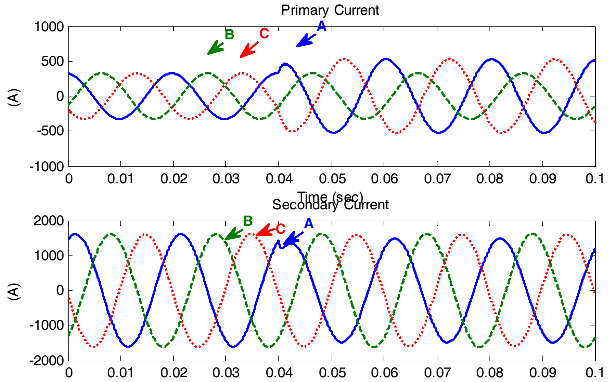


Figure 6. Primary and secondary currents for a case of internal fault at 20% of length of the low voltage winding.

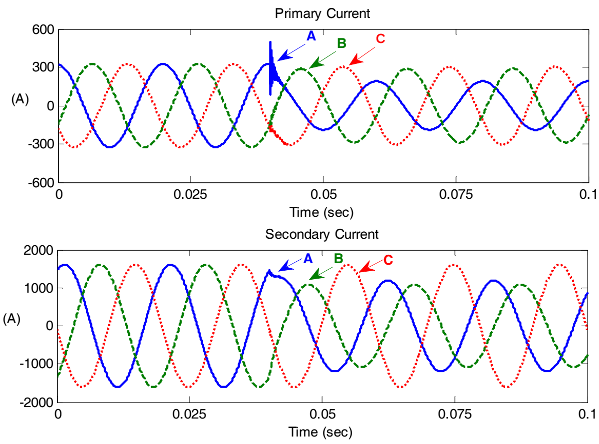


Figure 7. Primary and secondary currents for a case of external fault at 20% of length of the transmission line high voltage side.

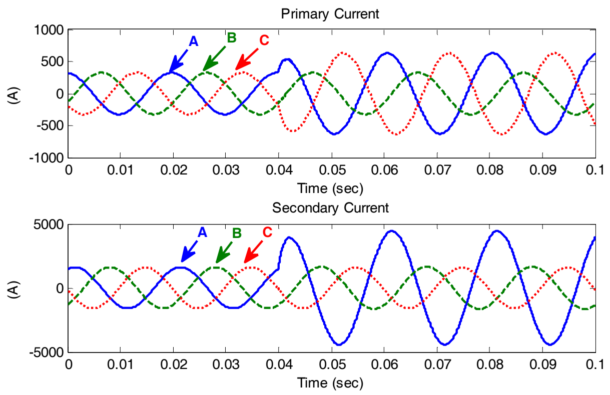


Figure 9. Primary and secondary currents for a case of external fault at 20% of length of the transmission line low voltage side.

III. Decision Algorithm and Result

With fault signals obtained from the simulations, the differential currents, which are a deduction between the primary current and the secondary current in all three phases as well as the zero sequence, are calculated, and the resulted current signals are extracted using the DWT. The mother wavelet daubechies4 (db4) is employed to decompose high frequency components from signals. From the differential current of all three phases, coefficients from each scale of DWT are considered and employed in the fault detection with several trial and error processes as shown in Figure 9.

From Figure 9, the coefficients of the signals obtained from the DWT are squared. The comparison of the coefficients from each scale is investigated. The result is clearly seen that when fault occurs, the coefficients of high frequency components have a sudden change compared with those before an occurrence of the faults as illustrated in Figures 10-12. This sudden change is used as an index for the occurrence of faults.

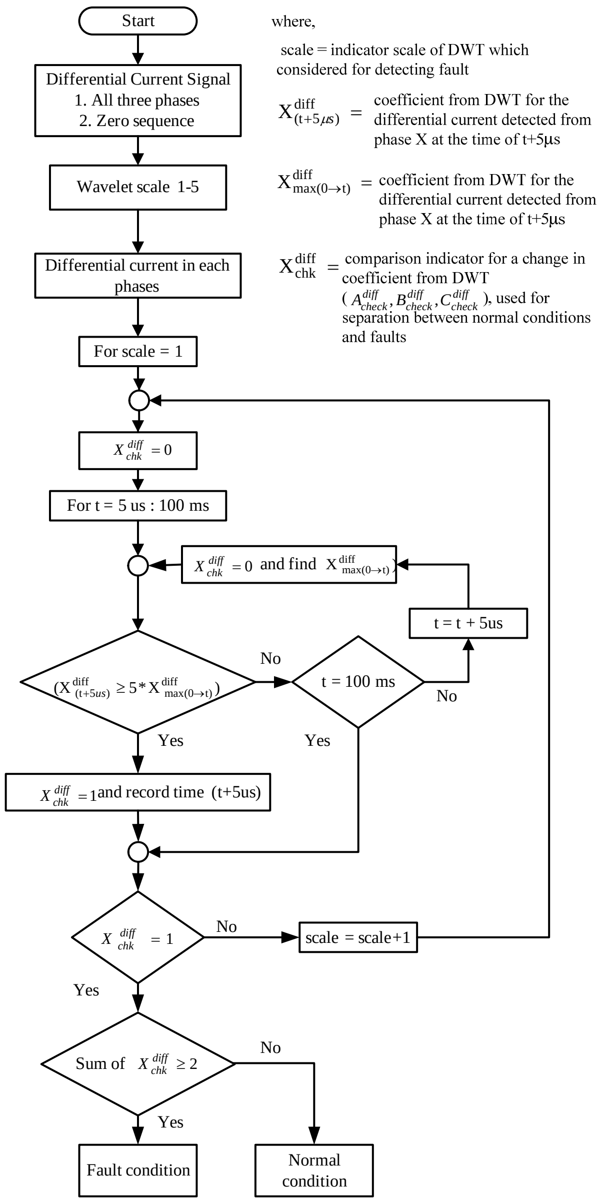
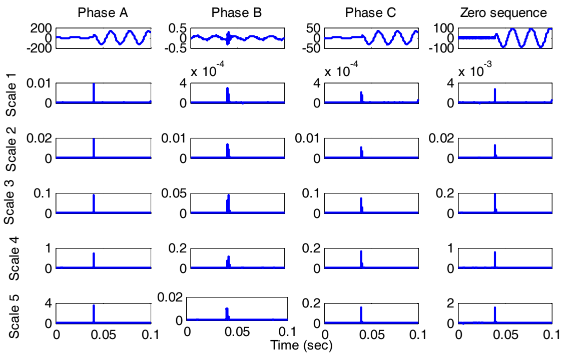


Figure 9. Flowchart for detecting the fault condition

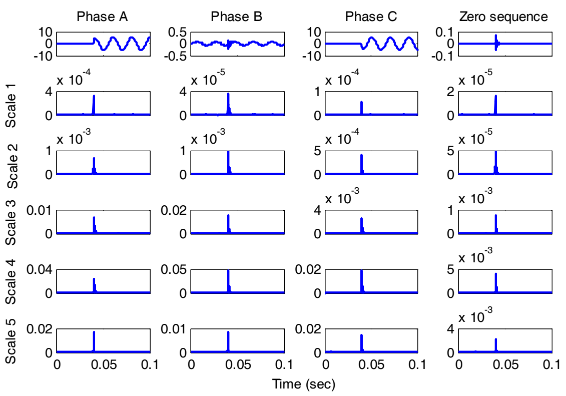
From Figure 10 and Figure 11, it is clearly seen that the coefficients of high frequency components, when fault occurs, have a sudden change compared with those before

ISBN: 978-988-19251-9-0
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

an occurrence of the faults but the coefficient in each scale of the DWT does not obviously change as shown in Figure 12.

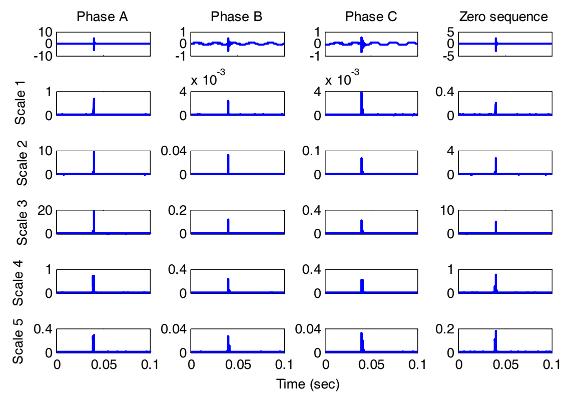


(a) High Voltage Winding

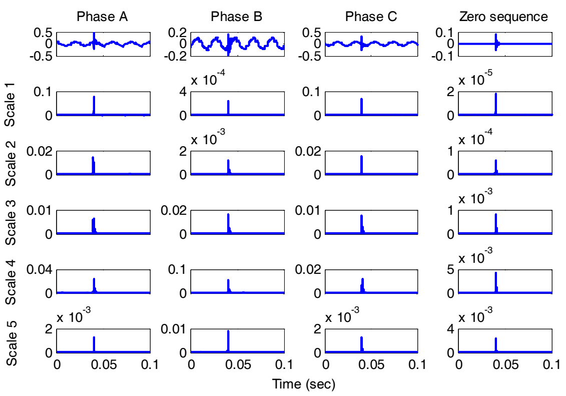


(b) Low Voltage Winding

Figure 10. DWT of differential currents from scale 1 to scale 5 in case of internal winding fault.



(a) High Voltage Winding



(b) Low Voltage Winding

Figure 11. DWT of differential currents from scale 1 to scale 5 in case of external short circuit.

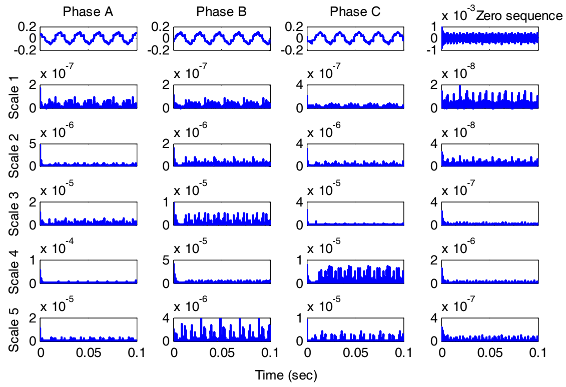


Figure 12. DWT of differential currents from scale 1 to scale 5 in case of Normal Condition.

After applying the fault detection algorithm, DWT are applied to the quarter cycle of current waveforms after the fault inception. The coefficients of scale 1 obtained using the DWT are used for discriminating between external short circuit and internal winding fault as shown in Figure 13.

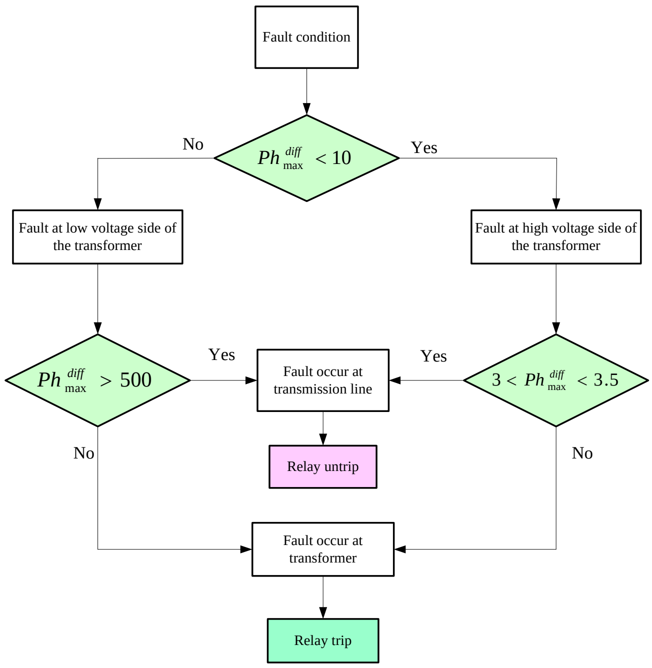


Figure 13. Flowchart for discriminating among inrush current, external fault and internal fault

where,

$$I^{diff}_{XZ,\max(post)} = \frac{X^{diff}_{\max(post)}}{Z^{diff}_{\max(post)}}$$

$X^{diff}_{\max(post)}$ = maximum value of coefficient from DWT of differential current for phase X at the time of ¼ cycles after detecting faults

$Z^{diff}_{\max(post)}$ = maximum value of coefficient from DWT of zero sequence current at the time of ¼ cycles after detecting faults

$Ph^{diff}_{\max}$ = maximum value of comparison indicators ($I^{diff}_{AZ,\max(post)}, I^{diff}_{BZ,\max(post)}, I^{diff}_{CZ,\max(post)}$) used in classifying the fault condition

ISBN: 978-988-19251-9-0
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

For classifying the fault condition, the coefficient from scale1 of DWT for differential current and zero sequence current waveforms is used in the decision algorithm. The results are shown as Tables 1-4.

Table 1 Results of classifying for internal winding faults as shown in Figure 10(a)

Differential Current					Result	
$I^{diff}_{AZ,\max(post)}$	$I^{diff}_{BZ,\max(post)}$	$I^{diff}_{CZ,\max(post)}$	$Z^{diff}_{\max(post)}$	$Ph_{\max}$	Condition	Relay
3.6e-3	2.88e-4	2.10e-4	2.60e-3	3.69	Internal	Trip

Table 2 Results of classifying for internal winding faults as shown in Figure 10(b)

Differential Current					Result	
$I^{diff}_{AZ,\max(post)}$	$I^{diff}_{BZ,\max(post)}$	$I^{diff}_{CZ,\max(post)}$	$Z^{diff}_{\max(post)}$	$Ph_{\max}$	Condition	Relay
3.23e-4	3.54e-5	5.29e-5	1.63e-5	19.81	Internal	Trip

Table 3 Results of classifying for external faults as shown in Figure 11(a)

Differential Current					Result	
$I^{diff}_{AZ,\max(post)}$	$I^{diff}_{BZ,\max(post)}$	$I^{diff}_{CZ,\max(post)}$	$Z^{diff}_{\max(post)}$	$Ph_{\max}$	Condition	Relay
6.74e-1	2.30e-3	3.80e-3	2.02e-1	3.33	External	Un-Trip

Table 4 Results of classifying for external faults as shown in Figure 11(b)

Differential Current					Result	
$I^{diff}_{AZ,\max(post)}$	$I^{diff}_{BZ,\max(post)}$	$I^{diff}_{CZ,\max(post)}$	$Z^{diff}_{\max(post)}$	$Ph_{\max}$	Condition	Relay
7.68e-2	2.29e-4	6.89e-2	1.76e-5	4359	External	Un-Trip

After the decision algorithm process, the algorithm was employed in order to classify fault condition. Case studies were varied so that the algorithm capability can be verified. The considered system is shown in Figure 1. The total number of the case studies was 510. The results obtained from the algorithm proposed in this paper are shown in Table 5.

Table 5 Summary of results from all simulations

Fault types	Internal faults		External faults		Normal condition
	HV side	LV side	HV side	LV side	
Number of cases studies	162	162	90	90	6
Detection accuracy	98.15%	100%	87.77%	100%	100%

IV. Conclusion

This paper proposed a technique for detecting and discriminating between external fault and internal fault. The simulations, analysis and diagnosis were performed using ATP/EMTP and MATLAB/Simulink. The current waveforms obtained from ATP/EMTP were extracted to several scales with the DWT, and the coefficients of the first scale from the DWT were investigated. The division between the maximum coefficient of different current phase (A, B, C) and zero sequence different current, was performed as comparison indicators in order to discriminate between external fault and internal fault. The results obtained from the algorithm proposed in this paper can detect and indicate the fault condition with the accuracy higher than 87% as presented in Table 5.

Acknowledgements

The authors wish to gratefully acknowledge financial support for this research sponsored by the faculty of engineering, King Mongkut's Institute of Technology Ladkrabang (KMITL), Thailand.

References

[1] Z. Bo, G.Weller, T. Lomas, "A New Technique for Transformer Protection Based on Transient Detection," *IEEE Trans. Power Delivery*, Vol.15, pp. 870–875, 2000.

[2] T. S. Sidhu, H. S. Gill, M. S. Sachdev, "A Numerical Technique Based on Symmetrical Components for Protecting Three-Winding Transformers," *Electric Power Systems Research*, Vol.54, pp. 19–28, 2000.

[3] A. L. Orille-Fernandez, N. K. I. Ghonaim, J. A. Valencia, "A FIRANN as a Differential Relay for Three-Phase Power Transformer Protection," *IEEE Trans. on Power Delivery*, Vol. 16, pp. 215–218, 2001.

[4] A. Guzman, S. Zocholl, G. Benmouyal, H. J. Altuve, "A Current-Based Solution for Transformer Differential Protection II. Relay Description and Evaluation," IEEE Trans. on Power Delivery, Vol. 17, pp. 886–893, 2002.

[5] O. A. S. Youssef, "Discrimination Between Faults and Magnetizing Inrush Currents in Transformers Based on Wavelet Transforms," *Electric Power Systems Research*, Vol. 63, pp. 87–94, 2002.

[6] H. Zhang, P. Liu, O. P. Malik, "A New Scheme for Inrush Identification in Transformer Protection," *Electric Power Systems Research*, Vol. 63, pp. 81–86, 2002.

[7] Myong-Chul Shin; Chul-Won Park; Jong-Hyung Kim, "Fuzzy Logic-Based Relaying for Large Power Transformer Protection," *IEEE Trans. on Power Delivery*, Vol. 18, pp. 718–724, 2003.

[8] M. E. Hamedani Golshan, M. Saghaian-nejad, A. Saha, H. Samet, "A New Method for Recognizing Internal Faults from Inrush Current Conditions in Digital Differential Protection of Power Transformers," *Electric Power Systems Research*, Vol. 71, pp. 61–71, 2004.

[9] G. Baoming, A.T. De'Almeida, Q. Zheng, X. Wang, "An Equivalent Instantaneous Inductance-based Technique for Discrimination Between Inrush Current and Internal Faults in Power Transformers," *IEEE Trans. on Power Delivery*, Vol. 20, pp. 2473–2482, 2005.

[10] A. Guzman, H. Altuve, D. Tziouvaras, "Power Transformer Protection Improvements with Numerical Relays," *CIGRE Study Committee B5—Protection and Automation*, 2005.

[11] A. Ngaopitakkul, A.Kunakorn and I.Ngamroo, "Discrimination between External Short Circuits and Internal Faults in Transformer Windings using Discrete Wavelet Transforms," *IEEE Industries Application Society Annual Conference 40th*, pp. 448-452, 2005.

[12] P. Bastard, P. Bertrand and M. Meunier, "A transformer model for winding fault studies," *IEEE Trans. on Power Delivery*, Vol. 9, pp. 690-699, 1994.

[13] IEEE working group 15.08.09, *Modeling and analysis of system transients using digital programs*, (IEEE PES special publication)
[14] ABB Thailand, Test report no. 56039.
[15] *Switching and Transmission Line Diagram* Electricity Generation Authorisation Thailand, 2002.

BIOGRAPHIES

Chaichan Pothisarn graduated with B.Eng in electrical engineering from Prince of Songkla University, Songkhla, Thailand in 1994 and M.Eng in electrical engineering from King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand in 2003. He is currently an assistant professor in Electrical Engineering Department at KMITL. His research interests are in power systems analysis and renewable energy.

Chaiyan Jettanasen received his B.Eng. and M.Eng. from Institut National des Sciences Appliquées (INSA) de Lyon in 2005 and Ph.D. from Ecole Centrale de Lyon, France in 2008. His research interest is EMC in power electronic systems. He is currently a lecturer in Electrical Engineering Department at KMITL.

Jittiphong Klomjit graduated with B.Eng in electrical engineering from King Mongkut's Institute of Technology Laddrabang, Bangkok, Thailand in 2011. He is currently a M.Eng. candidate at the school of electrical engineering, King Mongkut's Institute of Technology Ladkrabang. His research interest is in power transformer.

Atthapol Ngaopitakkul is currently an assistant professor at the department of electrical engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand. His research interest is on transmission systems and Protection Relay.

ISBN: 978-988-19251-9-0
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)