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ภาคผนวก ก.
ผลงานที่ได้รับจากโครงการวิจัยที่ได้รับทุนจาก สจล.

1. ผลงานวิจัย/ผลผลิตที่ได้จากการทำวิจัย และมี Impact ต่อสังคม, ประเทศชาติ

1. โครงการวิจัยนี้เป็นการรวมกันของวิทยาการด้านต่างๆ คือ กระบวนการประมวลสัญญาณ ทฤษฎีระบบป้องกัน และ วิศวกรรมไฟฟ้ากำลัง เข้าด้วยกัน ซึ่งจะก่อให้เกิดประโยชน์ร่วมกันของนักวิจัยในสาขาดังกล่าว ทั้งในด้านการแลกเปลี่ยนความรู้ ความคิดเห็น นับเป็นการพัฒนายกระดับงานวิจัยของประเทศ
2. การศึกษาวิเคราะห์ฟอลต์ที่เกิดขึ้นในหม้อแปลงไฟฟ้าที่นำเสนอในโครงการวิจัยนี้ สามารถนำรูปแบบการวิเคราะห์ไปประยุกต์ใช้กับหลักการของระบบป้องกันแบบต่างๆ นับได้ว่าจะเป็นประโยชน์สำหรับวิศวกร นักวิจัย นักศึกษา ตลอดจนผู้สนใจอื่นๆ เพื่อใช้ในการศึกษาวิจัยและพัฒนาต่อไป

2. การนำผลงานวิจัยไปประยุกต์ใช้

1. วิธีวิเคราะห์ฟอลต์ที่เกิดขึ้นบนหม้อแปลงไฟฟ้าแนวใหม่โดยใช้ข้อมูลองค์ประกอบความถี่ต่ำที่ได้จากสัญญาณฟอลต์แบบทรานเซี้ยนต์ ซึ่งช่วยลดช่วงของสัญญาณที่ทำการวิเคราะห์ให้สั้นลง จะส่งผลให้ระบบการวิเคราะห์และตัดสินใจใช้เวลาลดลงตามไปด้วย
2. สามารถนำรูปแบบการวิเคราะห์สัญญาณด้วยการแปลงเวฟเล็ตและการใช้ทฤษฎีการแปลงเวฟเล็ตไปประยุกต์ให้มีประสิทธิภาพเพิ่มมากขึ้นได้โดยการนำปัญญาประดิษฐ์เข้ามาใช้ร่วมด้วย

3. ผลงานตีพิมพ์ในวารสารวิชาการในประเทศ การเสนอผลงานในที่ประชุมวิชาการ หนังสือ การจดสิทธิบัตร หรือผลงานตามที่คาดไว้ในโครงการวิจัย

3.1 การนำเสนอในการประชุมวิชาการระดับนานาชาติ นำเสนอบทความในที่ประชุมวิชาการระดับนานาชาติ รวมทั้งสิ้น 1 บทความ (ภาคผนวก ข)

1. C. Jettanasen and A. Ngaopitakkul, "The spectrum comparison technique of DWT for discriminating between external fault and internal fault in power transformer" *In Proceedings of 17th International Conference on Electrical Engineering (ICEE2011)*, Hongkong, July 2011.

ภาคผนวก ข.

ตัวอย่างบทความประชุมวิชาการระดับนานาชาติที่ได้นำเสนอในที่ประชุมระดับนานาชาติ

1. C. Jettanasen and A. Ngaopitakkul, "The spectrum comparison technique of DWT for discriminating between external fault and internal fault in power transformer" *In Proceedings of 17th International Conference on Electrical Engineering (ICEE2011)*, Hongkong, July 2011.

The spectrum comparison technique of DWT for discriminating between external fault and internal fault in power transformer

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Abstract

This paper proposes a technique for detecting and identifying internal winding fault of three-phase two-winding transformer. A spectrum component obtained from DWT of differential current is analyzed. A ratio between per unit differential current and per unit time is calculated and performed as comparison indicator in order to discriminate between internal fault condition and external fault condition. Various cases based on Thailand electricity transmission and distribution systems are studied to verify the validity of the propsed algorithm. Results show that the proposed technique has good accuracy to detect fault and to identify its position in the considered system.

Keywords

Power Transformer, external fault, internal fault, discrete wavelet transform

1. 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 [1-10]. Most of them have different solutions and techniques. An application of a finite impulse response ANN (FIRANN) as differential protection for a three-phase power transformer is proposed in [1]. In [2], the 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. A new relaying fuzzy logic algorithm to enhance the fault detection sensitivities of conventional techniques is proposed in [3]. The relaying algorithm consists of flux-differential current derivative curve, harmonic restraint, and percentage differential characteristic curve. In [4], 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 behavior of second harmonic components of the differential currents under fault and inrush current conditions. In [5], the 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 [1-8], and etc.

In addition, wavelet transform has been reported in the literature [6]. The idea of application of wavelet transform to fault diagnosis is not new, and there is a number of research papers related to this idea [9-11]. The advantage of the wavelet transform is that the band of analysis can be fine adjusted so that high frequency components and low frequency components are detected precisely. Results from the wavelet transform are shown both in time domain and in frequency domain. In previous research works [9], an analysis of the spectrum of the transient current signal is performed in order to determine whether the current is a fault or a magnetizing inrush current. The approximated signal of DWT is then employed in the algorithm for a decision unit in the protection scheme.

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 wavelet transform 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.

2. Wavelet transform

The wavelet transform is a tool that cuts up data or functions or operators into different frequency components, and then studies each component with a resolution matched to its scale. The advantage of the transform is that the band of analysis can be fine adjusted so that high frequency components and low frequency components are detected precisely. Results from the wavelet transform are shown both in time domain and in frequency domain. The wavelet transform, which has a change in the analysis scaled by the factor of two, is called discrete wavelet transform (DWT) as shown in Equation 1.

$$DWT(m,n) = \frac{1}{\sqrt{2^m}} \sum_k f(k) \psi\left[\frac{n - k2^m}{2^m}\right]. \quad (1)$$

where,

$$\psi\left[\frac{n-k2^m}{2^m}\right]$$ = mother wavelet

3. Power System Simulation using EMTP

For a computational model of a two-winding three-phase transformer, which has primary and secondary windings in each phase, BCTRAN is a well-known subroutine on ATP/EMTP. To study internal faults of the transformer, Bastard et al proposed modification of the BCTRAN subroutine.

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 [12] 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.

After transformer model had been modified, the ATP/EMTP program was employed to simulate the transients of fault signals, at a sampling rate of 200 kHz. A 50 MVA, 115/23 kV two-winding three-phase transformer was employed in simulations with all parameters and configuration provided by a manufacturer [12-13]. The scheme under investigations is a part of Thailand electricity transmission and distribution system as depicted in Figure 1 [13-14]. To implement the transformer model, simulations were performed with various changes of system parameters as follows:

- The angles on phase A voltage waveform for the instants of fault inception were 0°-330° (each step is 30°).
- Two types for internal faults at the transformer windings (both primary and secondary), winding to ground faults and interturn faults, were investigated.
- For the winding to ground faults, the fault positions were designated on any phases of the transformer windings at the length of 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90%.
- For the interturn faults, the position of point a on the transformer winding, as shown in Fig. 1, was varied at the length of 10%, 20%, 30%, 40%, 50%, 60%, 70% and 80%.
- Fault resistance was 5 Ω.

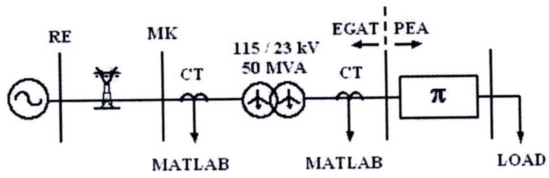


Figure 1. The system used in simulations studies [13].

For simulations of external faults 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 faults were 30° and 210°.
- 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.

4. Decision Algorithm and Result

From the simulated signals, DWT is applied to the quarter cycle of current waveforms after the fault inception. In addition, fault signals generated by ATP/EMTP are employed to decompose high frequency components from the simulated current signals using mother wavelet daubechies4 (db4) [14-15]. Examples of the approximated signal of the extracted waveform using DWT for the differential currents from scale1 to scale 5 are illustrated in Figures 2-4.

In case of internal fault condition, the differential current waveforms obtained for winding to ground fault are shown in Figure 2 whereas cases of interturn fault are shown in Figure 3. Figure 4(a) illustrates an example of an extraction using DWT for the differential currents current from scale1 to scale 5 for a case of external fault at high voltage side while case of external fault at low voltage side is shown in Figure 4(b). The similarity between the internal and the external fault signals waveforms as shown in Figures 2-4 can be obviously seen so that the spectrum comparison technique of DWT is considered.

A ratio between per unit differential current and per unit time is calculated and performed as comparison indicator in order to discriminate between the internal fault condition and the external fault condition. The ratio is calculated as follow:

$$X_{chk}^{diff} = \frac{\left(X_{\max}^{diff} - X_{\min}^{diff}\right) / I_{rated}}{\left(t_{\max}^{diff\_x} - t_{\min}^{diff\_x}\right) / T} \qquad (1)$$

where,

$X_{\max}^{diff}$ = the maximum coefficient from the approximated of DWT for differential signal

$X_{\min}^{diff}$ = the minimum coefficient from the approximated differential signal of DWT

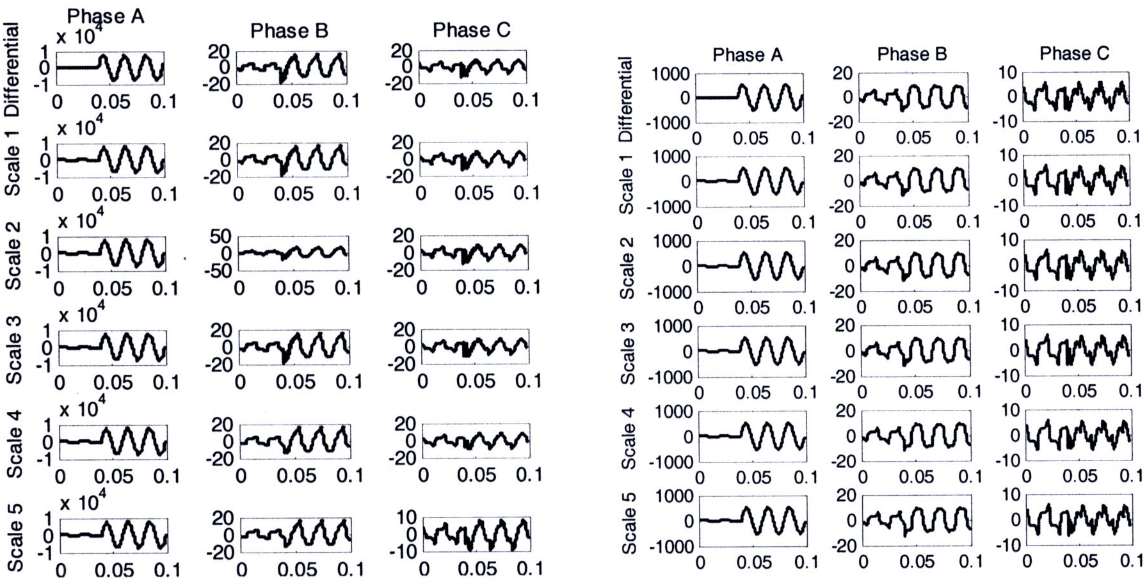
$t_{\max}^{diff\_x}$ = the time at which the maximum coefficient of the approximated differential signal occurs

$t_{\min}^{diff\_x}$ = the time at which the minimum coefficient of the approximated differential signal occurs

X_{chk}^{diff} = comparison indicator for separation between internal fault condition and external fault condition

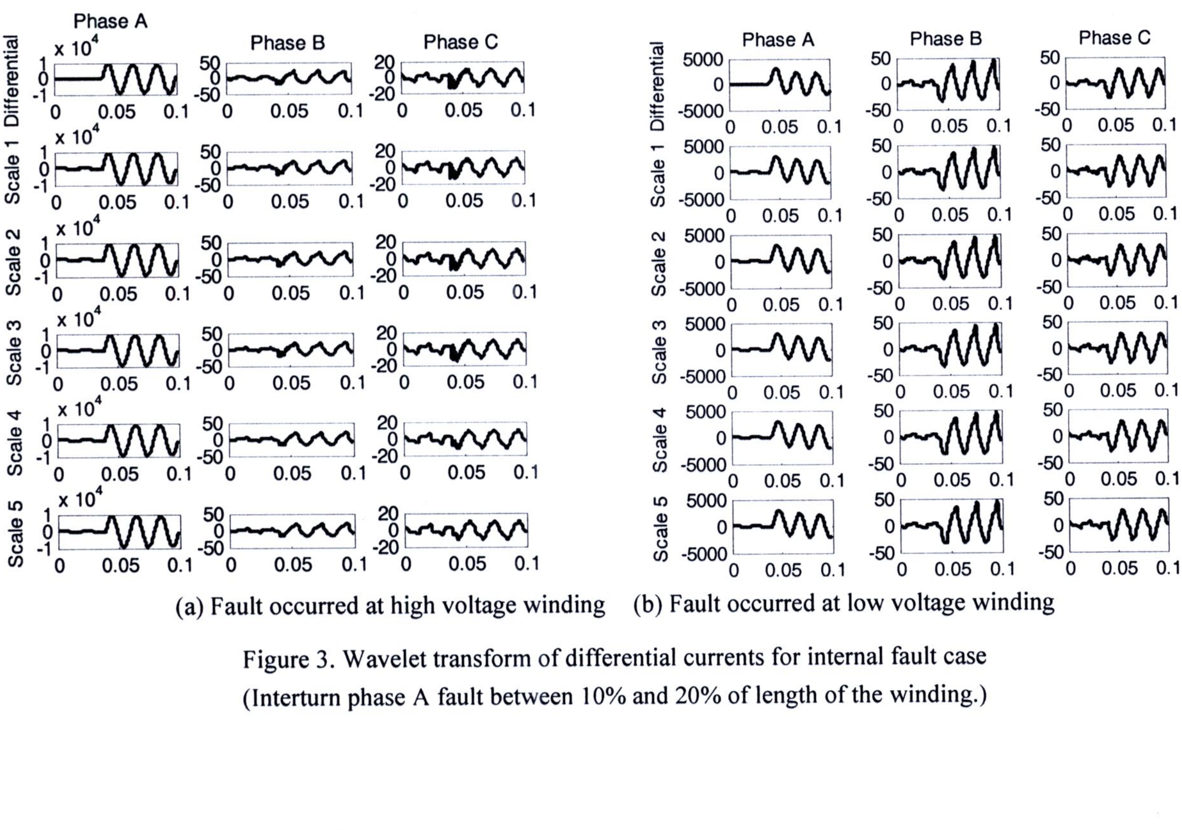
I_{rated} = rated current of the power transformer

T = the period of the power frequency of the system



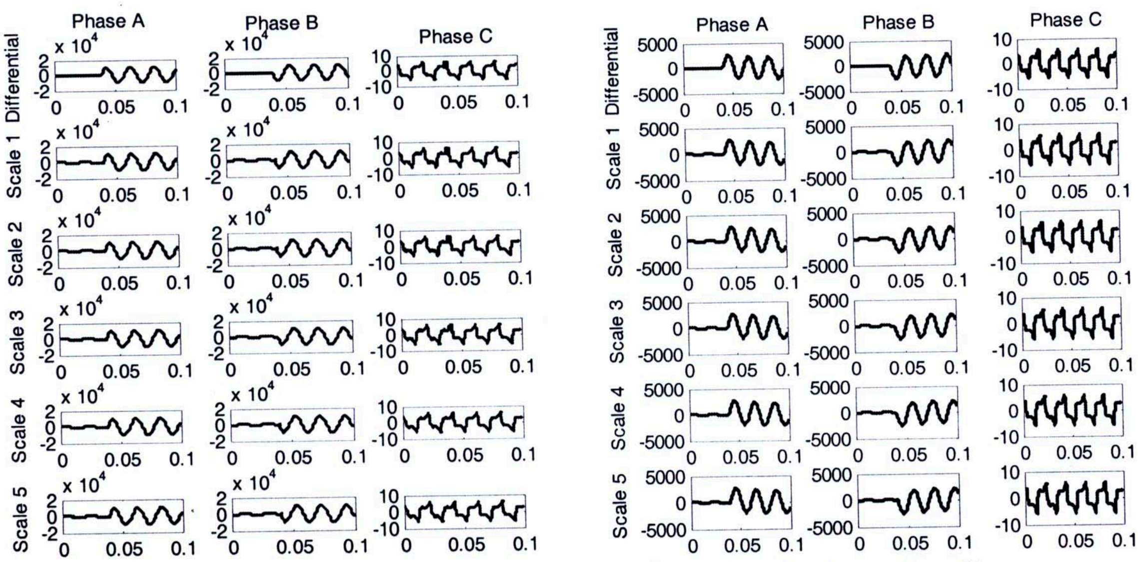
(a) Fault occurred at high voltage winding (b) Fault occurred at low voltage winding

Figure 2. Wavelet transform of differential currents for internal fault case
(Winding phase A to ground fault at 10% of length of the winding)



(a) Fault occurred at high voltage winding (b) Fault occurred at low voltage winding

Figure 3. Wavelet transform of differential currents for internal fault case
(Interturn phase A fault between 10% and 20% of length of the winding.)



(a) Fault occurred at high voltage side (b) Fault occurred at low voltage side

Figure 4. Wavelet transform of differential currents for external fault case
(Line A to Line B fault at 10% of length of the transmission line)

A numerator of the ratio is the difference between the maximum differential current and the minimum differential current in term of per unit with a base value selected at a transformer rated current. A denominator of the ratio is the difference between the time when $t_{\max}^{diff\_x}$ occurs and the time when $t_{\min}^{diff\_x}$ occurs, with a base value selected at a quarter cycle of power frequency (in this case, power frequency = 50 Hz). The ratio is calculated for all three phases, and from the trial and error process, the index for the separation between the internal fault condition and the external fault condition is defined. The most appropriate algorithm for the decision algorithm from the case studies of the system under the investigations can be concluded as follows:

if [($Z_{chk}^{diff} \geq 50$) and ($100 \leq A_{chk}^{diff} + B_{chk}^{diff} + C_{chk}^{diff} \leq 200$)]
then internal fault at high voltage winding
else if [($Z_{chk}^{diff} \geq 50$) and ($A_{chk}^{diff} + B_{chk}^{diff} + C_{chk}^{diff} > 200$)]
then external fault at high voltage side
else if [($Z_{chk}^{diff} \leq 1$) and ($A_{chk}^{diff} + B_{chk}^{diff} + C_{chk}^{diff} > 200$)]
then external fault at high voltage side
else if [($Z_{chk}^{diff} \leq 0.1$) and ($50 < A_{chk}^{diff} + B_{chk}^{diff} + C_{chk}^{diff} < 100$)]
then external fault at low voltage side
else if [($1 \leq Z_{chk}^{diff} \leq 50$) and ($5 < A_{chk}^{diff} + B_{chk}^{diff} + C_{chk}^{diff} < 50$)]
then internal fault at low voltage winding
end

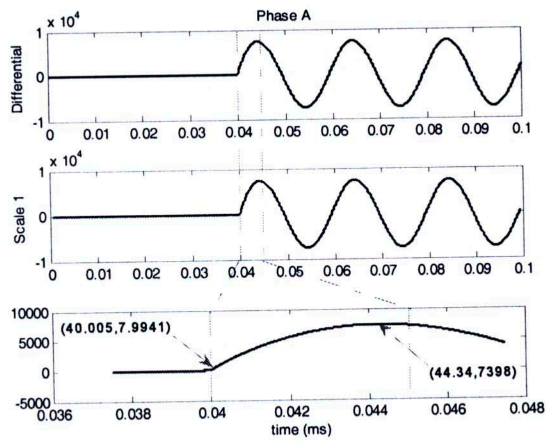


Figure 5. Responses to the internal fault condition.

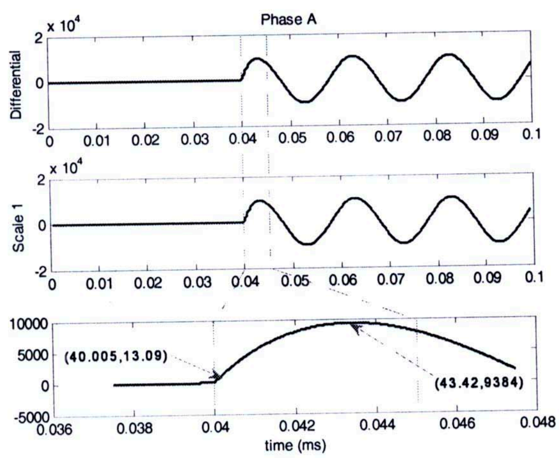


Figure 6. Responses to the external fault condition.

Table 1 Result of identifying for case of winding to ground fault

Coefficient of DWT	High voltage winding			Low voltage winding		
	A	B	C	A	B	C
$X_{\max}^{diff}$	7398	-3.4181	2.9981	517.2047	-2.9337	3.1736
$X_{\min}^{diff}$	7.9941	-19.3668	-13.0789	1.3385	-11.7363	-5.7248
$t_{\max}^{diff\_x}$	44.34	40.32	40.32	44.52	40.005	40.005
$t_{\min}^{diff\_x}$	40.005	40.15	40.15	40.005	40.24	43.67
X_{chk}^{diff}	135.8415	7.4754	7.5355	9.1041	2.9847	0.1935
Sum of Ratio	150.8524			12.2822		
Result	Tripped			Tripped		

Table 2 Result of identifying for case of interturn fault

Coefficient of DWT	High voltage winding			Low voltage winding		
	A	B	C	A	B	C
$X_{\max}^{diff}$	9204	-3.5771	2.6769	2580.1	-2.977	3.1172
$X_{\min}^{diff}$	8.0698	-19.4902	-14.0205	1.4192	-33.6105	-28.8653
$t_{\max}^{diff\_x}$	44.58	40.11	40.11	45.005	40.005	40.005
$t_{\min}^{diff\_x}$	40.005	40.62	44.13	40.005	44.95	44.20
X_{chk}^{diff}	160.1682	2.4862	0.331	41.0945	0.4936	0.6075
Sum of Ratio	162.9854			42.1956		
Result	Tripped			Tripped		

Table 3 Result of identifying for case of external fault

Coefficient of DWT	High voltage winding			Low voltage winding		
	A	B	C	A	B	C
$X_{\max}^{diff}$	9384	-14.7625	5.9716	2552	-4.0516	5.6688
$X_{\min}^{diff}$	13.0905	-9383	-2.6341	2.3804	-2548	-2.4921
$t_{\max}^{diff\_x}$	43.42	40.005	41.58	45.005	40.005	41.75
$t_{\min}^{diff\_x}$	40.005	43.41	44.97	40.005	45.005	44.98
X_{chk}^{diff}	218.6485	219.2308	0.2023	40.6345	40.5423	0.2013
Sum of Ratio	438.0816			81.3782		
Result	UnTripped			UnTripped		

TABLE 4 Summary of results from all simulations

Fault types	Winding to ground faults		Interturn faults		External faults
	HV side	LV side	HV side	LV side	
Number of cases studies	324	324	1296	1296	360
Detection accuracy	100%	94.44%	100%	83.33%	99.44%

The proportion of the spectral differential current signal, calculated between maximum and minimum value in a quarter cycle period of an analysis data, and the time deviation are shown in Figure 5 and Figure 6. Results illustrated from Tables 1 to 3 are obtained from one case of each type of faults as shown in Figures 2-4. When all conditions as stated in the section 4 are applied, the total number of case studies is 628 for winding to ground faults, 2592 for interturn faults, and 360 for external faults. The accuracy of the proposed decision algorithm for all case studies is shown in Table 4.

4. CONCLUSION

A technique using discrete wavelet transform in order to discriminate between internal fault condition and external fault condition has been proposed. Daubechies4 (db4) is employed as mother wavelet in order to decompose low frequency components from fault signals. A ratio between per unit differential current and per unit time is calculated and performed as comparison indicator. Various case studies have been done including the variation of fault inception angles and fault types. It is shown that the proposed technique can detect and indicate the internal and external faults with the accuracy higher than 83.33% as presented in Table 4. In addition, the proposed technique uses data of the differential current with a time of a quarter cycle for the analysis, which is less than that employed in a conventional protection scheme.

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