International Journal of Research in Engineering, Science and Management
Volume 5, Issue 2, February 2022
https://www.ijresm.com | ISSN (Online): 2581-5792

Power Transformer Differential Protection Based on DWT and EDT

Nitika Shrivastava*

Assistant Professor, Department of Electrical Engineering, Vishwavidyalaya Engineering College Ambikapur, India

***Abstract*: These theoretical outlines differential protection philosophy for power transformer (PT) by utilizing combined discrete wavelet transform (DWT) and Ensemble Methods based on Decision Trees (EDT) methods Discrimination between internal fault and magnetizing inrush condition may be an exceptionally challenging task PT differential protection scheme. Therefore, a discrete wavelet transform is utilized to extract the time and frequency division data simultaneously from the relaying signal (i.e., differential current) and after that, the distinctive highlights like entropy, skewness, and standard deviation are calculated from decomposed signals of the DWT. And after that these highlights of the handing-off flag are utilized to prepare and test the EDT to detect an internal fault. The PT is demonstrated in PSCAD /EMTDC computer program to get the relaying under different working conditions. The proposed calculation is assessed in MATLAB under different working conditions of PT and the tested data is simulated in PSCAD/EMTDC by varying inception and selective under different operating conditions of PT.**

***Keywords*: Power transformer, Differential protection, Transient based protection, Discrete Wavelet Transform, Transformer inrush, MATLAB, PSCAD, SVM.**

1. Introduction

Power transformers are vital links in the chain of components constituting a power system. They are very expensive and are an important component of power system which facilitates the transmission of electric power at higher voltage over long distances. The continuous monitoring of power transformers can provide early warning of electrical failure and could prevent catastrophic losses as well as unscheduled outages of power supply. In view of this, avoiding damage to power transformers is vital; otherwise, continuity of power supply may be seriously disrupted. Furthermore, the repairing or replacing cost of a power transformer may be very high. Therefore, providing proper protection to power transformers is a crucial task. Accordingly, high demands are imposed on power-transformer-protective relays, that is dependability (no missing operation), stability (no false tripping), and speed of operation (short fault clearing). Differential protection scheme is generally used as the primary protection of medium- and large-sized power transformers, in which the value of differential current greater than no-load value indicates an internal fault. Power transformers are devices that require continuous monitoring and fast protection because they are essential to the electrical power systems. About 10% of faults take place into power transformers, in which 70% of these faults are caused by short-circuits in its windings. In case of magnetizing inrush and sympathetic inrush large current flows in the source side. This large current from the source results in large differential current, which in turn causes the relay to operate undesirably. Owing to this reason, conventional differential relays are blocked for few initial cycles of energization which makes the relay operation delayed on switching-in of the transformer on faults. Therefore, discrimination between magnetizing inrush and internal fault condition is the key to improve the security of the differential protection scheme. Traditionally, two types of approaches are used for this purpose, that is, harmonic restraint (HR) and waveform identification (WI) concepts. The HR is based on the fact that the second harmonic (sometimes the fifth) component of the magnetizing inrush current is considerably larger than that in a typical fault current. The literature reveals the extensive use of the HR method. However, the HR-based method fails to prevent false tripping of relays because high second harmonic components during internal faults and low second harmonic components are generated during magnetizing inrush for transformers having modern core material. Therefore, the techniques based on detection of second/fifth harmonic component are not useful to discriminate between the magnetizing inrush and internal fault condition of modern power transformers.

The second method consists of distinguishing magnetizing inrush and over-excitation condition from internal fault condition on the basis of WI concept. The development of advanced digital signal-processing techniques and recently introduced artificial neural network (ANN) provide an opportunity to improve the conventional WI technique and facilitate faster, secured and dependable protection for power transformers. However, a large number of training data samples, slow convergence during training, and a tendency to over-fit data are the limitations of ANN-based schemes.

For the new waveform identification based differential protection of power transformer, first differential currents are generated for the different operating conditions of the power transformer. Then this differential current passes through DWT, because it gives both time and frequency resolution. After DWT some of these decomposed details coefficient is used to

*Corresponding author: amangautam2711@gmail.com

calculate the different feature for classification purposes. These features are utilized by SVM to discriminate internal fault from other disturbances. To perform above protection approach it requires PSCAD/EMTDC to simulate the different operating conditions and generate differential currents (relaying signal) and then MATLAB to process these different relaying signal to discriminate internal fault from other disturbances.

2. Differential Current in the Power Transformer

In this section differential current gets achieved by connecting current transformer (CT) in the primary and secondary side of the power transformer. To do that CT ratio should be proper and the star delta connection of CT should be checked properly depending on the connection of power transformer. Figure 1, shows the connection of CTs and the differential current calculation. The current flows in operating coil is the differential current in case of % differential protection.

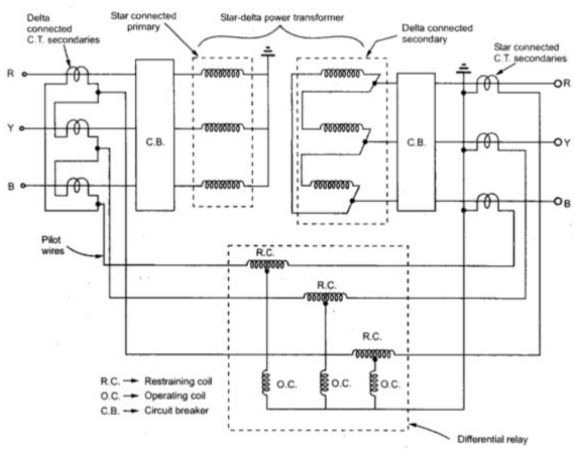

Fig. 1. 3-phase power transformer differential relay configuration

3. Discrete Wavelet Transform

Discrete signal is comprising by using scaling and wavelet function is:

$$x[n] = \frac{1}{\sqrt{M}}\sum_k U_\Omega[l_0,k]\Omega_{l_0,k}[n] + \frac{1}{\sqrt{M}}\sum_{l=l_0}^{\infty}\sum_k U_\beta[\,l,k]\beta_{l,k}[n] \quad (1)$$

Where,
$\Omega_{l_0,k}[n]$ is scaling function
$\beta_{l,k}[n]$ is wavelet function
$U_\Omega[l_0,k]$ is approximate coefficient
$U_\beta[\,l,k]$ is detailed coefficient
l_0 is shifting parameter
k is shifting parameter
Approximate (2) and detailed (3) coefficients are:

$$U_\Omega[l_0,k] = \frac{1}{\sqrt{M}}\sum_k x[n]\Omega_{l_0,k}[n] \quad (2)$$

$$U_\beta[\,l,k] = \frac{1}{\sqrt{M}}\sum_k x[n]\beta_{l,k}[n] \qquad l \geq l_0 \quad (3)$$

In simple way it means that sampled input signal passes through LPF and HPF simultaneously and then it gets down-sampled by two. Output of the HPF is a convolution between input signal and coefficients of HPF and then it gets down-sampled by two. This is called detailed coefficient and it contains upper half of the frequency present in the input signals. And Output of the LPF is also a convolution between input signal and coefficients of LPF and then it gets down-sampled by two. This is called approximate coefficient and it contains lower half of the frequency present in the input signals. And then again output of LPF goes to same kind of LPF and HPF and gets down-sampled by two, and this process goes on until goal will be reached.

Frequency band of detailed and approximate coefficient after m-level of decomposition are:

$$f_{approximate_m} = [0, \quad \frac{f_s}{2^{m+1}}]$$

$$f_{detail_m} = [\frac{f_s}{2^{m+1}}, \quad \frac{f_s}{2^m}]$$

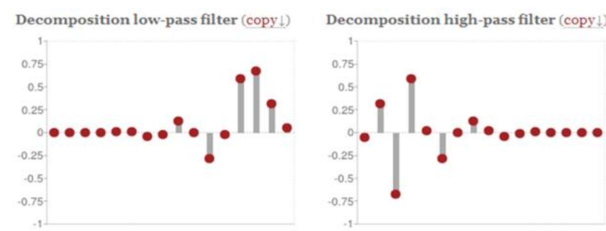

Fig. 2. DWT decomposition LPF and HPF

Figure 2, shows the decomposition LPF and HPF of Daubichies8 (db8) mother wavelet family, where 8 represents the order of the filter.

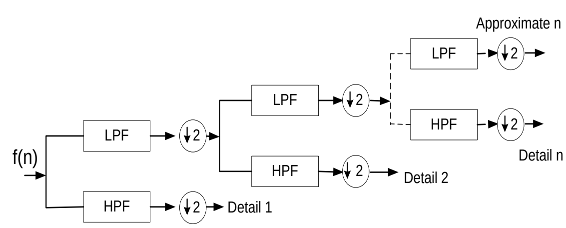

Fig. 3. DWT decomposition filtering block diagram

After the decomposition of sampled signals, these approximate and details coefficient are used to generate different features like entropy, r.ms., skewness, average and standard deviation etc. for the SVMs. So that the fault detection accuracy would be improved.

4. Random Forest

Random forest is a good example of ensemble machine learning method.

- Random forest technique combines various decision trees to produce a more generalized model.
- Random forests are utilized to produce de-correlated decision trees.
- Random forest creates random subsets of the features.

Smaller trees are built using these subsets, creating tree diversity.

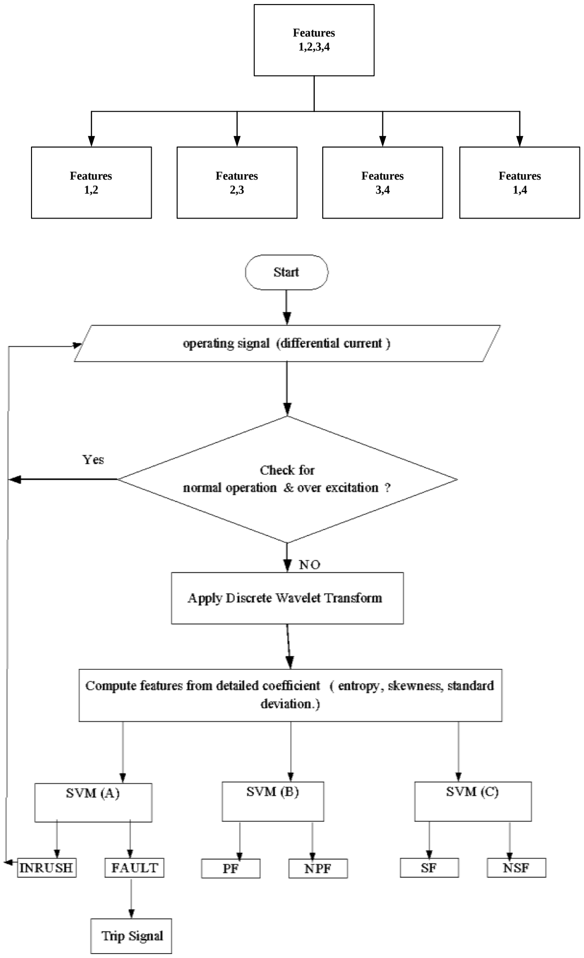

Fig. 4. DWT and SVM based PT protection algorithm

5. Modelling, Simulation and Results

Power transformer protection are performed in this thesis. To achieve that first a power system is modelled in the PSCAD/EMTDC where a source, power transformer, transmission line and load is connected. Where ratings of source is 400kV 50Hz, power transformer is 315 MVA 400kV/220kV 50Hz, transmission line is 220kv 100km and the load is 285 MW, 137MVAR. The operation of Power Transformer can be categorized into five categories which is normal operating condition, internal fault, external fault, over excitation, magnetizing inrush/ Sympathetic inrush. For these operating conditions differential current is being generated in the PSCAD/EMTDC software. In case of inrush three things are considered first is the residual flux, second is the switching angle and last is the loading conditions. In this case switching angle is varied from 0° to 330° in the interval of 30° and residual flux is varied from 10% to 80% of rated flux in the interval of 10%. When generating internal fault current two things are considered, first is fault percentage of winding, and fault inception angle (time of fault). And this differential current is sampled at 10 kHz. The different operating conditions model and the differential current waveform are shown in the following figures.

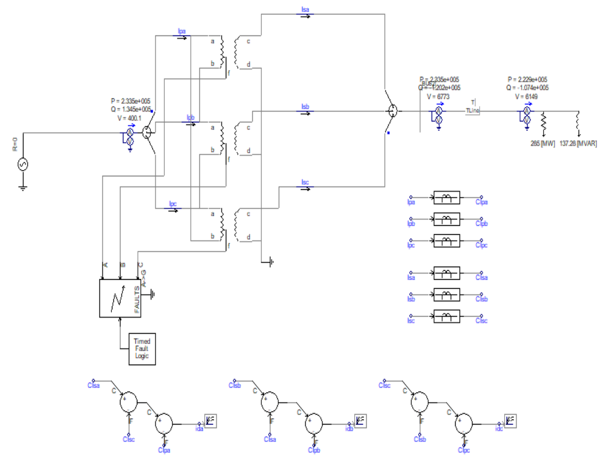

Fig. 5. Power transformer internal fault model with CTs

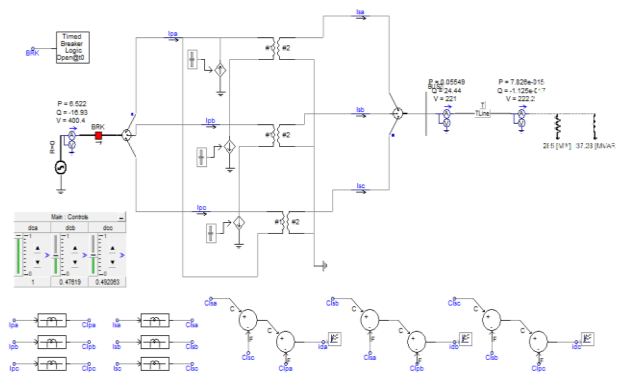

Fig. 6. Power transformer magnetizing inrush model with residual flux and CTs

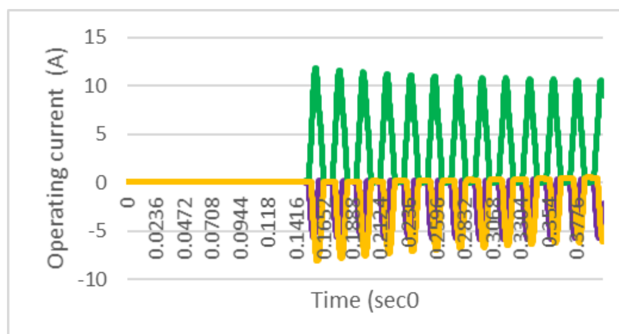

Fig. 7. Differential current during magnetizing inrush condition

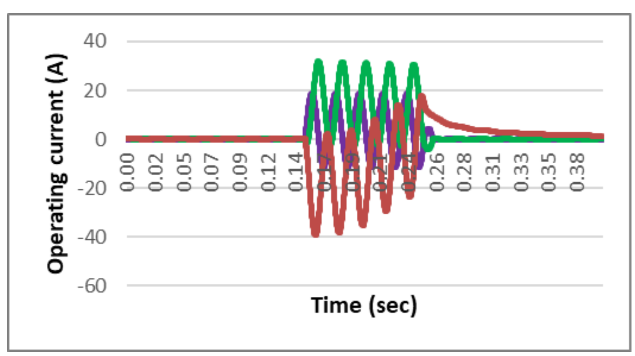

Fig. 8. Differential current during internal fault condition

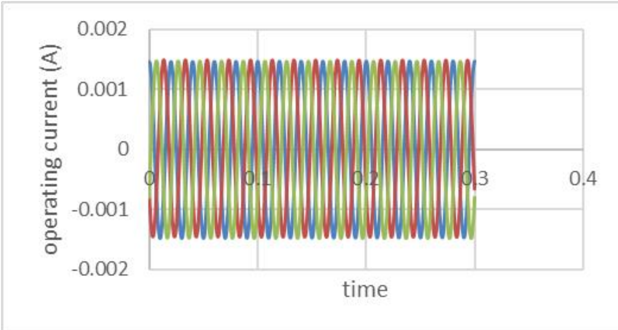

Fig. 9. Differential current during normal operating condition

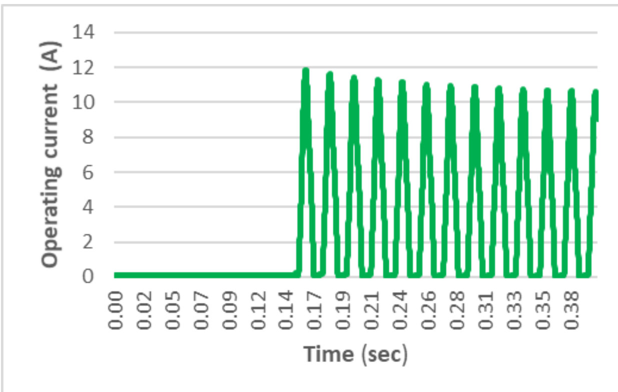

Fig. 10. Single phase differential current during magnetizing inrush condition

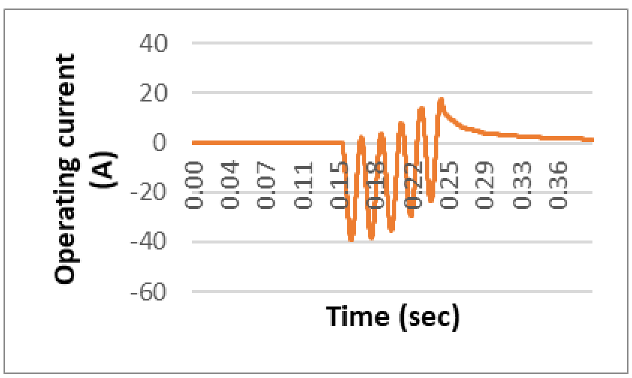

Fig. 11. Single phase differential current during internal fault condition

After modelling of power transformer in PSCAD these differential currents are used in the MATLAB for DWT and EDT based transformer protection. This differential current first decomposed into different frequency band using db8 mother wavelet. The reconstructed decomposed signals for internal fault and inrush are shown in the following figures.

From those DWT frequency band only fourth level decomposed signal is used to calculate entropy, skewness and standard deviation, these are called feature. This feature goes to the kernel based radial basis function non-linear mapping EDT classifier for classification purposes and the final internal fault detection accuracy achieved by this algorithm is 100% on one cycle data of total 178 testing samples. Apart from the internal fault detection there exist two EDT that identifies in which side of the transformer winding's fault has occurred, table 1 and table 2 shows their classification accuracy.

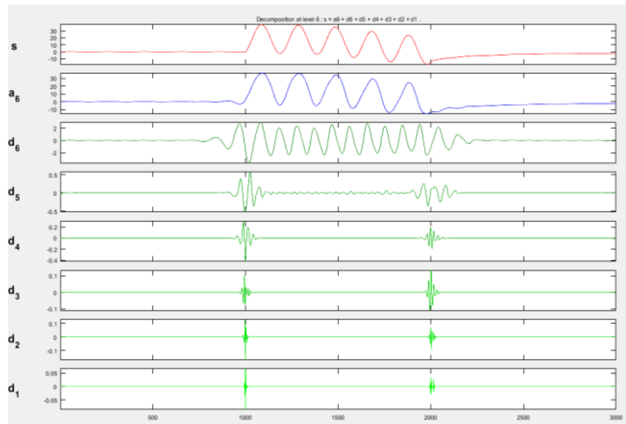
Fig. 12. Different details and approximate signals of internal fault current

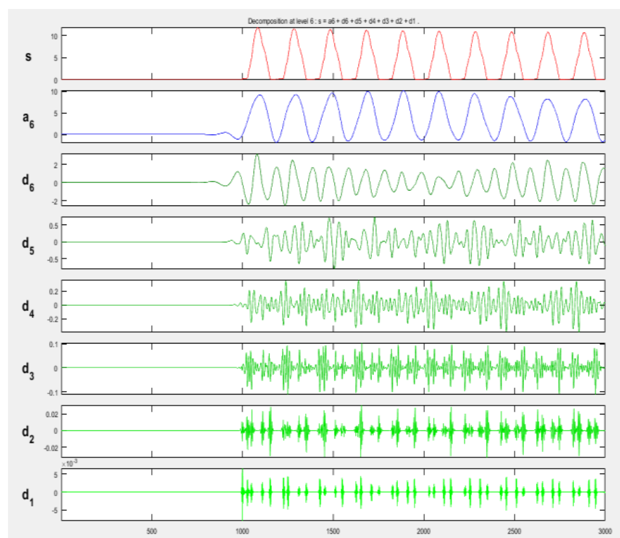
Fig. 13. Different details and approximate signals of inrush current

Table 1
Fault detection accuracy table

Fault and Inrush	Training Sample	Testing Sample	False Detection	Accuracy
Internal fault	440	136	0	
Inrush	150	42	0	
Total samples	590	178	0	99.43%

Table 2
Fault detection accuracy table for primary winding

Fault Unit and Inrush	Training Sample	Testing Sample	False Detection	Accuracy
Primary winding fault	240	72	05	
Secondary winding fault	200	64	02	94.85%
Total samples	440	136	07	

In this paper 590 training samples, 178 testing samples, and 668 total samples were generated. Training data is used to create a differential power transformer protection model and the testing samples is used to find the accuracy of that created differential protection model. To do that it took only one cycle data at the occurrence time of fault and inrush. The following algorithm is performed in this paper:

$$\text{Fault detection accuracy} = \frac{\text{total current signal} - \text{false identification}}{\text{total current signal}} \times 100$$

$$= \frac{178 - 1}{178} \times 100 = 99.43\%$$

$$\frac{\text{Primary}}{\text{Secondary winding accuracy}} = \frac{\text{total current signal} - \text{false identification}}{\text{total current signal}} \times 100$$

$$= \frac{136 - 7}{136} \times 100 = 94.85\%$$

6. Conclusion

The proposed protection based on combined wavelet and EDT algorithm provides a differential protection for Power Transformer. Which provides much more security than the other existing ANN and conventional dual slope percentage differential-based protection. Here DWT extracted the very good features from differential current that further leads to the EDT based classifier and this algorithm achieved an accuracy of 100% to detect the internal fault from magnetizing inrush current. To achieve that much accuracy, it only took one cycle data from differential current for the processing which leads to the fast power transformer protection.

In the future to enhance the speed of operation the data require for the processing would be reduce and search for the new features so that EDT classify most accurately. And this proposed algorithm can be implemented in real time.

References

[1] Abbas, M. F., & Zhiyuan, L. (Oct. 2016). Inrush current discrimination in power transformer differential protection using wavelet packet transform based technique. IEEE PES Asia-Pacific Power and Energy Engineering Conference.

[2] Aktaibi, A., & Rahman, M. A. (Aug. 2014). An Experimental Implementation of the dq -Axis Wavelet Packet Transform Hybrid Technique for Three-Phase Power Transformer Protection. IEEE Transactions on Industry Applications, 50(4), 2919 - 2927.

[3] Ashrafian, A., & Mirsalim, M. (June 2017). Application of a Recursive Phasor Estimation Method for Adaptive Fault Component Based Differential Protection of Power Transformers. IEEE Transactions on Industrial Informatics, 13(3), 1381 - 1392.

[4] Barbosa, D., & Netto, U. C. (April 2011). Power Transformer Differential Protection Based on Clarke's Transform and Fuzzy Systems. IEEE Transactions on Power Delivery, 26(2), 1212 - 1220.

[5] Bejmert, D. (February 2015). Analysis of potential use of the SVM technique for transformer protection. IEEE Power Systems Computation Conference.

[6] Dashti, H., & Pasand, M. S. (April 2014). Power Transformer Protection Using a Multiregion Adaptive Differential Relay. IEEE Transactions on Power Delivery, 29(2), 777 - 785.

[7] Deshmukh, M. S., & Barhate, V. T. (June 2017). Microcontroller based differential relay using fuzzy logic for transformer protection. International Conference on Intelligent Computing and Control Systems.

[8] Elsamahy, M., & Babiy, M. (Oct. 2012). An intelligent approach using SVM to enhance turn-to-turn fault detection in power transformers. IEEE Electrical Power and Energy Conference.

[9] Gaouda, A. M., & Salama, M. M. (July 2010). DSP Wavelet-Based Tool for Monitoring Transformer Inrush Currents and Internal Faults. IEEE Transactions on Power Delivery, 25(3), 1258 - 1267.

[10] Medeiros, R. P., & Costa, F. B. (December 2015). Power Transformer Differential Protection Using the Boundary Discrete Wavelet Transform. IEEE Transactions on Power Delivery, 31(5), 2083-2095.

[11] Murugan, S. K., & Simon, S. P. (July 2016). Power transformer protection using chirplet transform. IET Generation, Transmission & Distribution, 10(10), 2520 - 2530.

[12] Orille-Fernandez, A. L., & Ghonaim, N. K. (Apr 2001). A FIRANN as a differential relay for three phase power transformer protection. IEEE Transactions on Power Delivery, 16(2), 215 - 218.

[13] Poornima, S., & Ravindra, K. (Oct. 2016). Comparison of CWT & DWT based algorithms in combination with ANN for protection of power transformer. International Conference on Signal Processing, Communication, Power and Embedded System.

[14] Saleh, S. A., & Rahman, M. A. (Aug. 2005). Real-time testing of a WPT-based protection algorithm for three-phase power transformers. IEEE Transactions on Industry Applications, 41(4), 1125 - 1132.

[15] Segatto, E. C., & Coury, D. V. (Aug. 2006). A differential relay for power transformers using intelligent tools. IEEE Transactions on Power Systems, 21(3), 1154 - 1162.

[16] Sevov, L., & Khan, U. (June 2017). Enhancing Power Transformer Differential Protection to Improve Security and Dependability. IEEE Transactions on Industry Applications, 53(3), 2642 - 2649.

[17] Shah, A. M., & Bhalja, B. R. (April 2013). Discrimination Between Internal Faults and Other Disturbances in Transformer Using the Support Vector Machine-Based Protection Scheme. IEEE Transactions on Power Delivery, 28(3), 1508 - 1515.

[18] Shah, A. M., & Bhalja, B. R. (Dec. 2016). Power transformer differential protection using S-transform and Support Vector Machine. National Power Systems Conference (NPSC).

[19] Shin, M. C., & Park, C. W. (July 2003). Fuzzy logic-based relaying for large power transformer protection. IEEE Transactions on Power Delivery, 18(3), 718 - 724.

[20] Tripathy, M., & Maheshwari, R. P. (Jan. 2010). Power Transformer Differential Protection Based on Optimal Probabilistic Neural Network. IEEE Transactions on Power Delivery, 25(1), 102 - 112.

[21] Tripathy, M., & Maheshwari, R. P. (Sept. 2007). Probabilistic neural-network-based protection of power transformer. IET Electric Power Applications, 1(5), 793 - 798.

[22] Vazquez, E., & Mijares, I. I. (Jan. 2008). Transformer Differential Protection Using Principal Component Analysis. IEEE Transactions on Power Delivery, 23(1), 67 - 72.

[23] Yin, J., & Zhu, Y. (Oct. 2011). Power transformer fault diagnosis based on support vector machine with cross validation and genetic algorithm. International Conference on Advanced Power System Automation and Protection.