

## Discrimination of Inrush and Fault Currents in Protection of Transformer using ANN-DWT Technique

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### Abstract

The main objective of relay is to reduce the occurrence and duration of undesirable outages concerned to the power transformer. This can be achieved by avoiding false tripping and achieving a high operating speed relay. In order to achieve these objectives digital relays are employed which are based on various topologies and concepts, in this paper digital relay based on Discrete Wavelet Transform (DWT) and Artificial Neural Network (ANN) are presented. Often digital relay based on Fourier transform were prone to false tripping as they were unable to distinguish between inrush and internal fault current because inrush current is rich in second harmonic component and second harmonic component may be high enough under internal fault condition also. Even Some power transformers, with new improved core material designs for lower core losses but also older units under some conditions, produce low levels of second harmonics which makes it difficult for relays to operate correctly. Here the wavelet transform is used for signal processing and to extract features from transformer current signals in both time and frequency domain. The current of the transformer is decomposed into a series of detailed coefficients by using DWT. This extracted feature from DWT is used as a training data set for ANN, which will then take the trip signal decision. Four different conditions are analyzed (viz normal current, inrush current, LLL internal fault, and external fault current). Primary current is taken into consideration for DWT analysis in MATLAB. The tested model in MATLAB is then implemented practically by using python programming for DWT and ANN on raspberry pi3 model. Output of ANN algorithm is communicated to circuit breaker for executing "Trip" or "No Trip" signal.

### Keywords

Artificial Neural Network (ANN), Discrete Wavelet Analysis (DWT), Fourier Transforms, MATLAB, Python, Raspberry pi3.

### Introduction

Unwanted outage of power transformer results in discontinuity in power supply for consumers which results in poor performance of whole power system. Protection of large power transformer is a very challenging problem in power systems for uninterrupted power supply. Conventional differential protection scheme for power transformer uses second harmonic restrain principle for discrimination of internal fault and inrush current with the help of FFT (Fast Fourier Transform). Second harmonic restrain principle which is the ratio of second harmonic altitude to fundamental harmonics and this ratio is used for judging whether the current is inrush of internal fault, But well-known Fourier transform suffers some disadvantages which are given below: -

- i. It cannot detect the harmonic which are not integer multiples of the fundamental frequency (50 Hz).
- ii. Fourier Transform accounts for frequency analysis only for a given signal.
- iii. It assumes periodic and stationary signals but Inrush and Fault current are non-periodic and non-stationary.

Above all disadvantages of Fourier transform are mitigated by wavelet analysis. Wavelet transform is used for feature extraction from the current waveform of power transformer (differential current). As Inrush current is neither stationary nor periodic in nature, hence DWT analysis is suitable for feature extraction of the current signals.

### Problem Faced in Differential Relaying

In power transformer, one of the greatest problems is detecting the high magnetizing Inrush Current. Conventional differential relay works on the principle of valuation and measurement of currents at both the terminal of the transformer. Internal faults and inrush current both are reach in second harmonics so harmonic restrain Method unable to distinguish it properly [1]. Deep saturation results in lower levels of second harmonic in the differential currents and can lead to the mal-operation of transformer differential relays due to insufficient harmonic blocking or restraining [6][2].

### Inrush Current

Magnetizing inrush current in transformer is the current which is drawn by a transformer at the time of energizing the transformer. This current is transient in nature and exists for few milliseconds. A typical waveform showing peaky current i.e. inrush current is shown in Fig. 1, having doubling effect on flux waveform at zero switching instant. It is found that after steady state maximum value of flux, the core becomes saturated, the current required

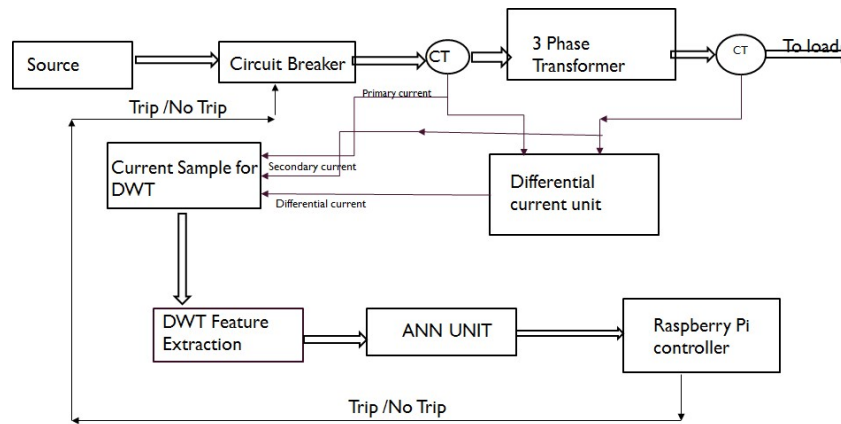


### Use of ANN

To distinguish Inrush current and to give a trip signal while the fault is internal fault a dataset created from coefficients of DWT applied on differential current of transformer in MATLAB. This dataset is used to train the ANN network. This trained ANN model is then used for taking decision whether to give trip signal or not. Use of ANN makes decision making more accurately with higher precision. Introduction of ANN is to avoid fault tripping of circuit breaker.

### Methodology

The main objective of this relay is to provide tripping signal to transformer circuit breaker only for internal fault, and tripping should be avoided in case of inrush current, normal current and for external fault.



**Fig. 3: Conceptual Block Diagram**

The conceptual block diagram shown in Fig. 3, Three phase Transformer is energized by the source having Current Transformers on both sides. Three different current samples are taken, first sample is separately taken as current from primary side of CT, second and third samples are taken as currents from both sides of Transformer CT's. These current samples are used to investigate DWT analysis under different condition such as normal condition, internal fault condition, External fault condition and Inrush condition. All samples of currents are then given to DWT block in the MATLAB so as to get the coefficients of level 5 to achieve the distinguishing factors in inrush current and internal fault current. Based on the above block diagram simulation work is carried out, for which simulation block of DWT is used directly from Simulink library of MATLAB-2013 version. The choice of mother wavelet plays a significant role in time and frequency analysis. It also depends on a particular application. This block takes frame-based types of inputs. For this purpose, buffer block is used to make input available to DWT in the form of frames. In first part discrete wavelet analysis is done to understand the difference between normal current, internal fault current, external fault current and inrush current.

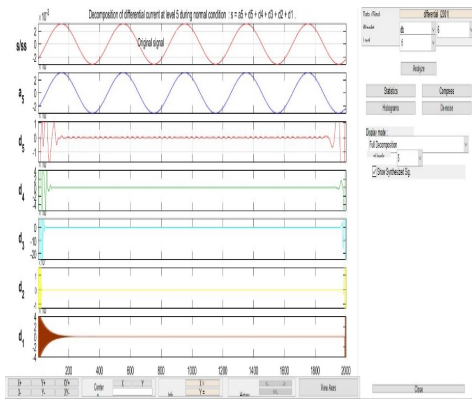
### Explanation of Simulation Model

The simulation model was built based on Conceptual block diagram. Model is Comprising 3-phase generator which is supplying power to 3-phase 600 KVA transformer with 3-phase load and circuit breaker is connected on primary side of transformer. Two Current Transformers of ratios 1000/1 are used on both primary and secondary side. The simulation using db6 mother wavelet for DWT analysis is done. Four different conditions are considered for analyzing : 1.Normal condition/ healthy condition 2.Internal fault current condition 3.External fault condition 4.Inrush Condition

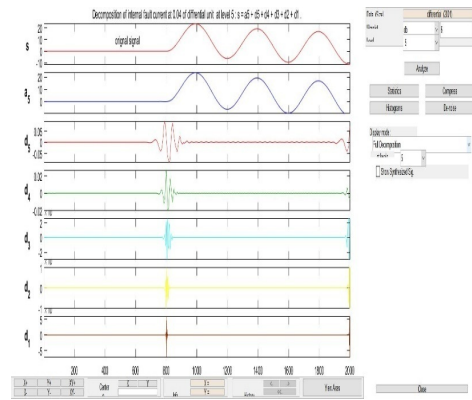
### Results of Simulation Model

The results of DWT taken from differential current is only shown here for the sake of brevity. But while deciding tripping logic, DWT analysis of all the current samples are considered i.e. current sample from primary side, current sample from secondary side and current sample from differential current side. It is found that tripping logic works more efficiently with current samples taken from differential side.

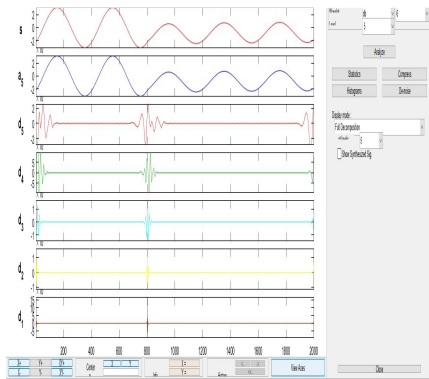
**Wavelet Decomposition of Differential Current**



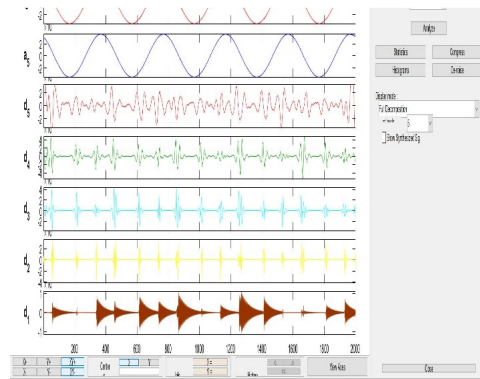
**Fig.4: Normal Condition Sample’s Wavelet Decomposition of Differential Current up to Level 5 with db6 Mother Wavelet**



**Fig.5: Internal Fault Condition Sample’s Wavelet Decomposition of Differential Current up to Level 5 with db6 Mother Wavelet**



**Fig. 6: External Fault Condition Sample’s Wavelet Decomposition of Differential Current up to level 5 with db6 Mother Wavelet**



**Fig.7: Inrush Condition Sample’s Wavelet Decomposition of Differential Current up to Level 5 with db6 Mother Wavelet**

During normal condition no disturbance is observed except at initial time as shown in fig 4. And under fault condition DWT analysis show a spike in all coefficients at the time of fault Internal and external fault conditions as shown in Fig.5 and Fig.6 respectively. The DWT Analysis is taken up to level five in which it is observed that all the level coefficients are heavily distorted in case of inrush condition as shown in figure 7. Cd5 coefficient is taken for further work i.e. for creating dataset for training ANN model which will decide trip or no trip signal to circuit breaker.

**Results of ANN Block**

Training set which is given for ANN block is shown in figure8. Array of plot and 3-D visualization of cd5 for inrush current and for differential current is shown fig 9 & 10, which is the main factor for deciding the trip signal or no trip signal by the said ANN block. cd5 is considered for defining feature to ANN to make its classification or recognition.

Data set for ANN Training											
	SUM	MEAN	RMS	MEDIAN	DEVIATION	VARIANCE	MAX	MIN	classification	target	
	-2.66827	-0.08338	0.67441	-0.00025	0.67994	0.46232	1.77266	-3.14841	normal	0	
full load	NORMAL	171.878	5.37118	90.9578	-0.00025	92.2519	8510.42	447.847	-252.525	internal	1
	internal	-2.56	-0.08	0.67469	-1.20E-05	0.68065	0.46329	1.77266	-3.14841	external	0
	external	221.591	6.92473	165.759	1.0647	168.264	28312.7	478.347	-362.883	inrush	0
1/2 load	inrush	-2.67039	-0.08345	0.67403	-0.00026	0.67955	0.46179	1.76842	-3.14855	normal	0
	NORMAL	139.019	4.34433	86.0291	-0.00026	87.2941	7620.27	413.583	-256.003	internal	1
	internal	-2.57535	-0.08048	0.67419	7.00E-07	0.68008	0.46251	1.76842	-3.14855	external	0
1/4 load	external	221.591	6.92473	165.759	1.0647	168.264	28312.7	478.347	-362.883	inrush	0
	inrush	-2.67037	-0.08345	0.67354	-0.00026	0.67905	0.46111	1.7654	-3.14727	normal	0
	NORMAL	122.784	3.83639	83.6557	-0.00026	84.9049	7208.84	396.663	-257.732	internal	1
1/4 load	internal	-2.58249	-0.0807	0.67366	-2.39E-06	0.67951	0.46174	1.7654	-3.14727	external	0
	external	221.591	6.92473	165.759	1.0647	168.264	28312.7	478.347	-362.883	inrush	0
	inrush	-2.67007	-0.08344	0.67322	-0.00027	0.67872	0.46066	1.76365	-3.14627	normal	0

Fig. 8: Data Set for ANN Training

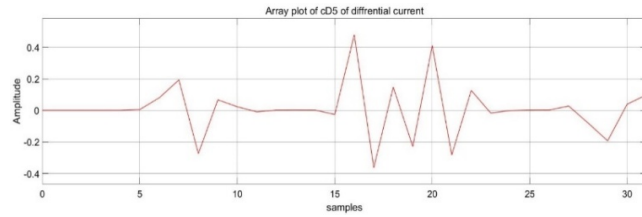


Fig. 9: Array Plot of cD5 of Differential Current

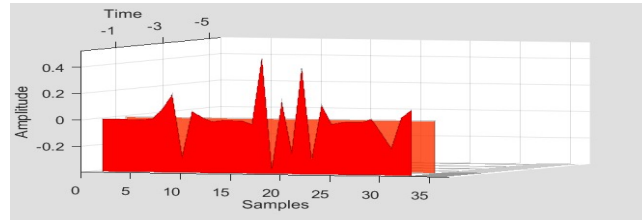


Fig. 10: 3D Visualization of cD5 of Differential Current

**Conclusion from Simulation Result**

No Trip signal to CB during inrush current as shown in Fig.11. and Output of ANN shows the value which is close to zero as shown in Fig.12. While during internal fault, it gives trip signal to circuit breaker as shown in Fig.13. and ANN output for internal fault current shows value which is almost 1 as shown in Fig.14.

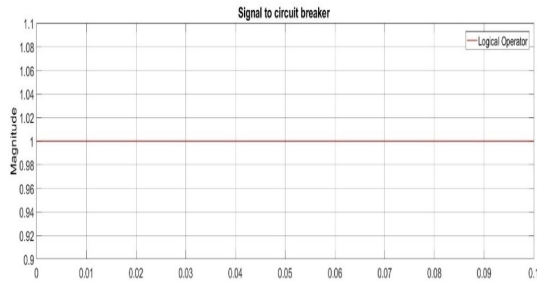


Fig. 11: Signal to Circuit Breaker During Inrush Condition

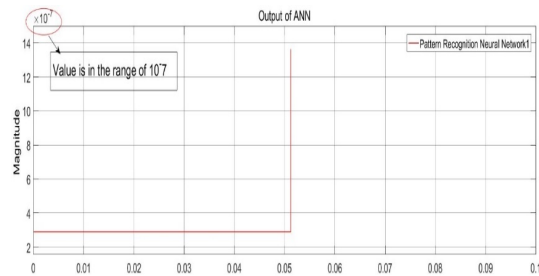


Fig. 12: Out of ANN Block during Inrush Condition

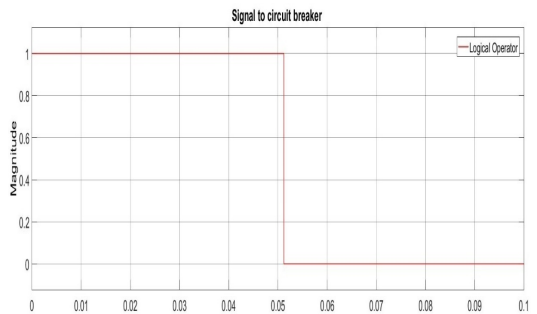


Fig. 13: Signal to Circuit Breaker during Internal Fault Condition

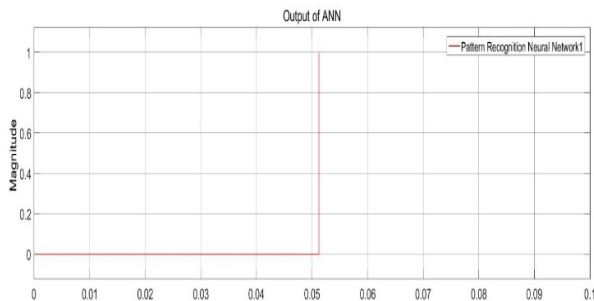


Fig. 14: Out of ANN Block during Internal Fault Condition



The simulation results concludes that Output of ANN for inrush current is close to zero and gives “No Trip” signal to circuit breaker. While during internal fault , the ANN output value is almost “1” and this gives “Trip” signal to circuit breaker.

**Hardware Implementation**

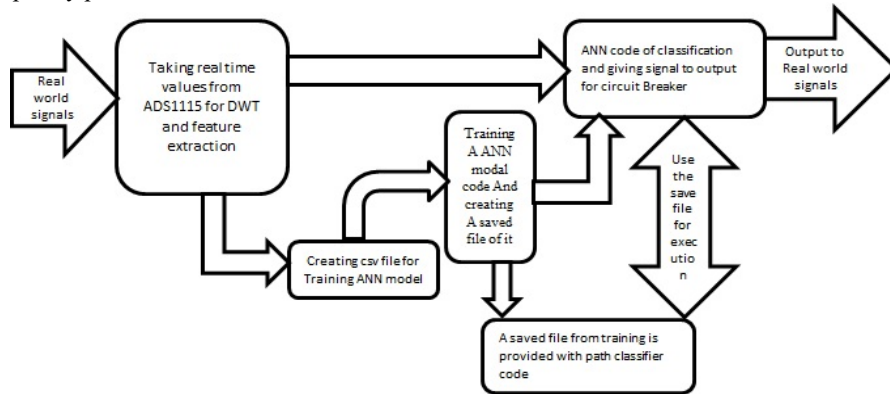
Having concluded the simulation work, a hardware implementation is developed by using Raspberry pi as a controller, and a state of art current transducer LEM HXS 10 – NP/SP3 is used to take the current samples. For feature extraction, cD5 array is used to define features by which ANN algorithm can recognize and decide whether to give trip or no trip signal to circuit breaker which is communicated through GPIO pins of Raspberry pi 3. Logic behind coding is used in following three ways :

- i. To read analog values from ADS1115, its DWT and creating real time data for training
- ii. Pre-processing of data, making it suitable for training network in ANN and code for training ANN
- iii. Predicting values of input signals and giving it to Raspberry pi GPIO pin

A framework has been developed in python programming to take real-time values to create dataset in CSV file and then that data is used to train ANN model which can then predict whether to trip or not depending on its real-time input given to it.

Real time signal is given to first code which converts Analog value to digital values by using ADS1115 and then DWT is performed to extract cD5 level. Then applying statistical function on extracted cD5 level values for ANN training and features are saved in CSV in the form of dataset by using pandas’ library of python.

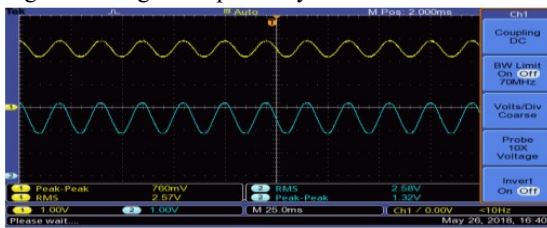
Saved CSV file is used by ANN training program and creates saved file by providing a path which is used by third code to recognize whether a given real time condition should trip the circuit breaker or not. The whole idea of this project code is explained and is shown graphically in Fig.15, which shows the flow of data from real world to raspberry pi3 and back to real world.



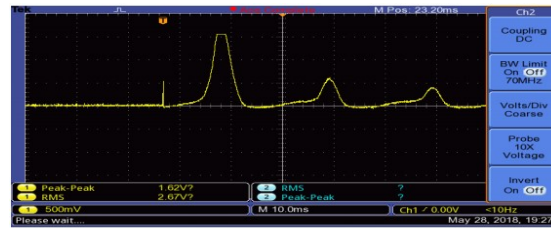
**Fig. 15: Flow Diagram for Hardware Implementation Using ANN and DWT**

The current transducer LEM HXS 10 – NP/SP3 is used to take the current samples from real world which are output of Primary and secondary currents of given Transformer.

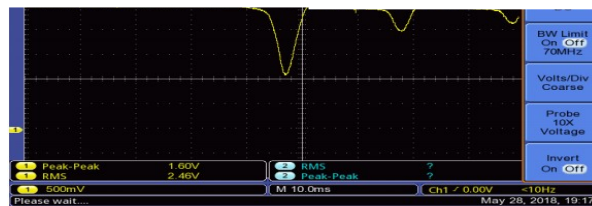
The output of Current Transducer (CTs) for normal , Positive Inrush and Negative inrush are shown in Fig.16, Fig.17 and Fig.18 respectively.



**Fig.16 :Output Sample of CTs during Normal**



**Fig.17 : Output Sample of CTs during Positive**



**Fig.18 : Output Sample of CTs during Negative**

As all real time signals are Analog in nature and Raspberry pi accepts data in digital formats only hence one Analog to digital converter IC like ADS1115 which is 16 bits IC is used whose maximum sampling rate is 860 samples/cycle. Connection of ADS1115 is not explained here, but it has 4 channels for Analog input out of which three channels are used for current inputs. It was necessary to install python library for ADS 1115 IC from Adafruit website to use python code to control it. Consequently it can efficiently read Analog values into digital format which is suitable for raspberry pi, that too into array format which is best suited for a Discrete wavelet Transform. To execute wavelet, transform in python pywavelets library was imported. Once the wavelet analysis was done then all the coefficients of cD5 is taken for statistical feature extraction into an array like structure which consist of sum, median, deviation, standard, deviation, minimum value and maximum value. These values are first stored into a list and then that list is stored in to a python dictionary. With the help of pandas' library in python it is possible to write that dictionary into a CSV file. One care was taken that, saved CSV file should be in same folder where ANN training program code is stored. The created CSV file sent to ANN algorithm for its training and then it creates a new file by saver object which is then used by third program to take decision whether to give TRIP signal or No TRIP signal to GPIO of raspberry pi3 through which it communicates with the Relays at outer world.

### Conclusion

The proposed simulation work with ANN block is working exactly as it was desired to trip circuit breaker only on occurrence of internal fault. In hardware part the second code, which is developed for training ANN model is working properly, as it was able to achieve the accuracy up to 85% to 95% and loss is also minimized up to a satisfactory level in practical environment. The Third Code, which is developed program for prediction or recognition is working satisfactorily and it is observed that while recognizing whether to give "Trip" signal or "No Trip" signal to GPIO pins of raspberry pi3, it gives trip signal where it was intended to give trip signal

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