ANN based Technique for Discrimination between Magnetizing Inrush and Internal Fault Currents in Transformer

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Abstract: ***This paper presents the application of artificial neural network based pattern recognition approach for differential protection of transformer. The power transformer protective relay should block the tripping during magnetizing inrush and rapidly initiate the tripping during short circuit. The ANN based algorithm is designed and trained with experimental data in laboratory using single phase Transformer, which can be extended to Three phase power Transformers, for sinusoidal wave which permits the relay operation only during short circuit conditions and not for inrush current. Solution to Backpropagation Algorithm is given using C programming language. Modeling of ANN using feed forward Backpropagation techniques is introduced. Voltage signals proportional to current is derived through CT's. Data Acquisition is done using ESA interface card at a particular sampling rate using PC.***

Keywords: Artificial neural network, Pattern recognition, Transformer protection, Protective relay, Inrush current

1. Introduction

Transformer is an indispensable part for any power system and hence its protection not only becomes necessary but also the selection of method used for protection. The protection for any internal fault is now universally provided by the differential protection scheme. But this protection sometimes fails for the excitation of the transformer at no – load due to inrush current in the primary circuit, which is generally ten times the normal load current. Hence, to avoid the tripping of the relay during this condition, it is necessary to distinguish between the short circuit current and the inrush current.

Since last 1960's researchers have considerable interest in the area of protection of power apparatus [1]. The main features which have attracted researchers to investigate the feasibility of designing digital relays for power system protection are its speed of operation, dependability, stability, economy, flexibility, and possibility of integrating a digital relay into the hierarchical computer system within the substation and with the grid. Moreover, with the application of Artificial Intelligence in protective devices, the decision making capability of the relays is enhanced.

Early methods were based on desensitizing or delaying the relay to overcome the transients [2]. These methods are unsatisfactory nevertheless, since the transformers were exposed to long unprotected times. Improved security and dependability then was appreciated when the second harmonic content with respect to the fundamental one was introduced as an identification criterion, known as harmonic restraint differential protection [3]. However, some researchers reported the existence of a significant amount of the second harmonic in winding faults [4] [5]. In addition, the new generations of power transformers use low-loss amorphous material in their core, which can produce inrush currents with lower harmonics contents and higher magnitudes [5]. In such cases, some authors have modified the ratio of second harmonic to fundamental restraining criterion by using other ratios defined at a higher frequency [6]. While other researchers proposed hidden Markov's model (HMM) [7], fuzzy-logic-based techniques [4,8], wave shaped recognition technique [1,9], and also artificial neural networks (ANN) [10,11] based learning pattern approach to get better classification accuracy, low computational burden, and fast response of the relay.

Here, the ANN based algorithm is designed and trained with experimental data in laboratory using single phase Transformer for sinusoidal wave which permits the relay operation only during short circuit conditions and not for inrush current. Solution to Backpropagation Algorithm is given using C programming language. ANN incorporates a learning process and hence, the network can be trained for any pattern and could be compared with any input pattern and a judgement could be made whether this input pattern is similar to the trained pattern or not. This method is known as "Pattern Recognition".

In this paper, an ANN based pattern recognition approach for differential transformer protection is presented.

2. Artificial Neural Network (ANN)

A neural network is a powerful data modelling tool that is able to capture and represent complex input / output relationships. The motivation for the development of neural network technology came from the desire to develop an artificial system that could perform "Intelligent" tasks similar to those performed by the human brains. Attention precedes recognition. We look, see, pay attention and then recognition. Neural network theory studies both:

- pre – attentive and attentive

- processing of stimuli

The basic unit of neural networks, the artificial neurons, stimulates the four basic functions of natural neurons. Artificial neurons are much simpler than the biological neurons. The figure 1 shows the basics of an artificial neuron.

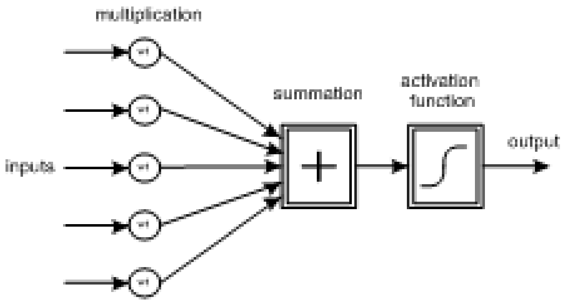

Figure 1: Artificial Neuron

This section gives the formulae used in the model of an artificial neuron: A single neuron may be written mathematically as follows:
y=f (bias + w1*x1 + w2*x2 + w3*x3 +…+ wn*xn)
Where y is output, x1, x2,…xn are the inputs and f(x) is the activation function. And the formula used for this function is called the "sigmoid":

F(x) = 1/ (1+ exp (-x))

2.1 Back Propagation Learning

Neural networks are typically organized in layers. Layers can be made up of number of interconnected nodes which contain an activation function. Parameters are presented to the network via the input layer, which communicate to one or more hidden layers where the actual processing is done via a system of weighted connections. The hidden layers then link to an output layer where the answer is output as shown in the graphic below (Fig. 2):

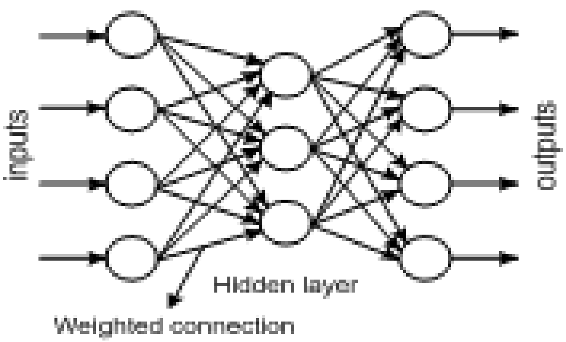

Figure 2: Answer is Output

The fully connected neural network in this paper has the following structure:

Input Layers: One with 78 units or nodes
Hidden layer: One with 10 units or nodes
Output Layer: One with 1 unit or node

This neural network has been trained by "Back propagation" algorithm. In Back propagation the network learns a predefined set of input – output examples pairs by using a two phase propagate adopt cycle. After an input pattern has been applied as a stimulus to the first layer of network unit, it is propagated through each upper layer until an output is generated. This output pattern is then compared with the desired output pattern and an error signal is computed for each output unit.

The error signals are then transmitted backward from the output layer to each node in the intermediate layer that contributes directly to the output. However, each unit in the intermediate layer receives only portion of the total error signal, based roughly on the relative contribution the unit made to the original output. This process repeats layer by layer, unit each node in the network has received an error signal that describes its relative contribution to the total error. Based on the error signal, connection weights are then updated by each unit to cause the network to converge towards a state that allows all the training patterns to be encoded.

The Back propagation algorithm (BPA), also called as the generalized Delta rule, provides a way to calculate the gradient of the error function efficiently using chain rule of differentiation. Although there are different kinds of learning rules used by neural networks, this paper is concerned with the delta rule. With the delta rule, as with other types of back propagation, 'learning' is a supervised process that occurs with each cycle or 'epoch' (i.e. each time the network is presented with a new input pattern) through a forward activation flow of outputs, and the backward error propagation of weight adjustments.

Within each hidden layer node is a sigmoidal activation function which is differentiable and therefore continuous everywhere. Sigmoidal function polarizes network activity and helps stabilize it.
$Y_j = 1 / (1 + \exp(-S_i))$

Back propagation performs a gradient descent within the solution's vector space towards a 'Global Minimum' along the steepest vector of the error space. The global minimum is the theoretical solution with the lowest possible error. The error itself is a hyper paraboloid but is seldom smooth. The flow chart for Backpropagation learning is given below.

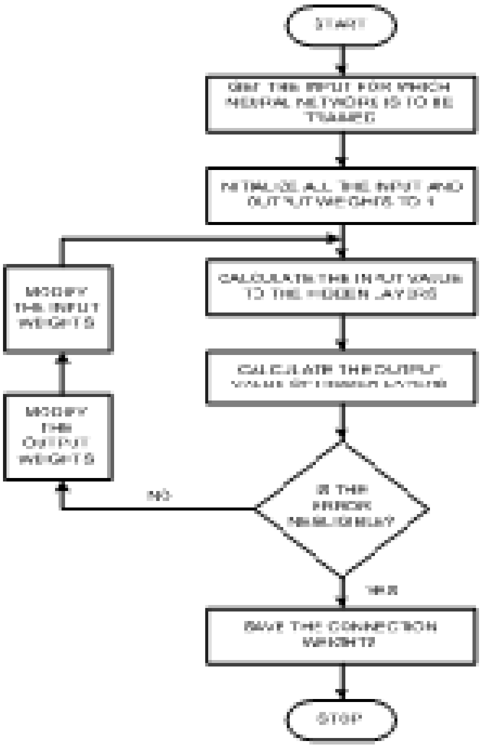

Figure 3: Flowchart for back propagation learning

3. Data Acquisition System

Today most scientists and engineers are using personal computers for laboratory research, industrial control, test and measurement. The components of typical PC based DAS are:

1) The personal computer
2) Transducers
3) Signal conditioning
4) Data Acquisition Hardware
5) Software

The PC used in the DAS determines the overall processing speed. Data Acquisition Hardware consists of the DAS card like the model ESA2174 ADI card. Data acquisition board specifications include the number of channels, sampling rate, resolution, range, accompanying noise and non linearity, all of which affect the quality of the digitized signal. The flow chart for training and backpropagation is shown below (Fig. 4):

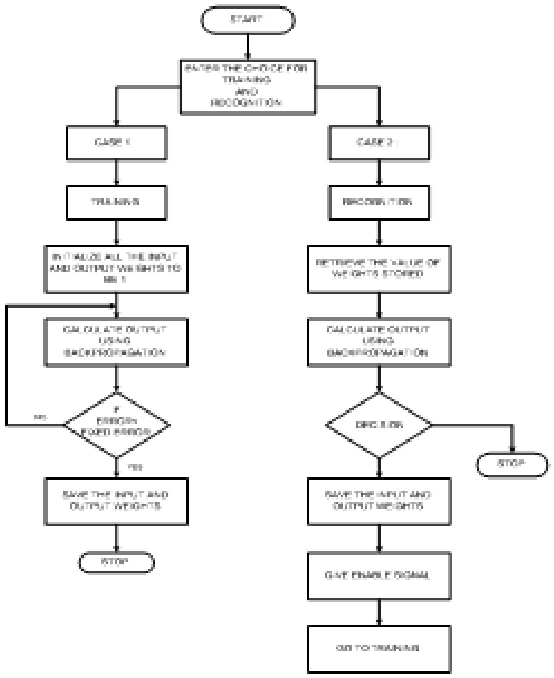

Figure 4: Flowchart for training and back propogation

4. Magnetizing current in transformer

When the transformer is energized initially there is no induced emf, the condition is similar to switching of an inductive circuit. The resistance being low, large inrush of magnetizing current takes place. The magnitude of current inrush can be several times that of load current. The magnitude of inrush current depends on circuit conditions and voltage at the instant of switching. The maximum peak values equal to 8 to 10 times the rated current can occur.

Maximum inrush current can occur if transformer is energized when the voltage wave is passing through zero. At this instant, the current flux should be maximum in highly inductive circuit and in next half wave the flux should change its direction to attain the maximum value. If there is residual flux in transformer, the flux may be in the same or opposite direction. Accordingly the magnetizing current will be less or more, it will saturate the core and increase the magnetizing component further.

Factors influencing the magnitude and duration of magnetizing current inrush are:

1. Size of transformer: as size of transformer increases, the inrush current also increases.
2. Type of magnetic material in the core: if the core is made up of material having good permeability then the inrush current automatically decreases.
3. Residual flux of transformer before switching in: presence of residual flux also increases the magnetizing current.
4. Instant of switching: if the transformer is switched on at the instant when the voltage wave is passing through zero value, then the magnetizing inrush current at that inrush will be maximum.

5. Implementation:

In this paper, the differential protection for single phase transformer for an internal short circuit using artificial neural network is realized. The complete experimental setup is as shown in the figure 5. The said scheme is possible to extend for a three phase transformer.

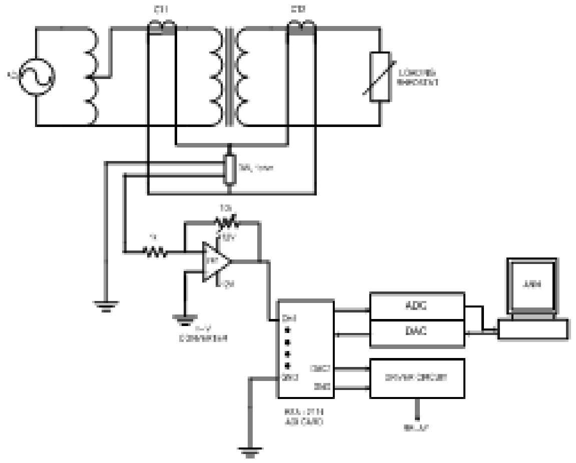

Figure 5: Experimental Setup

<u>Driver circuit:</u>

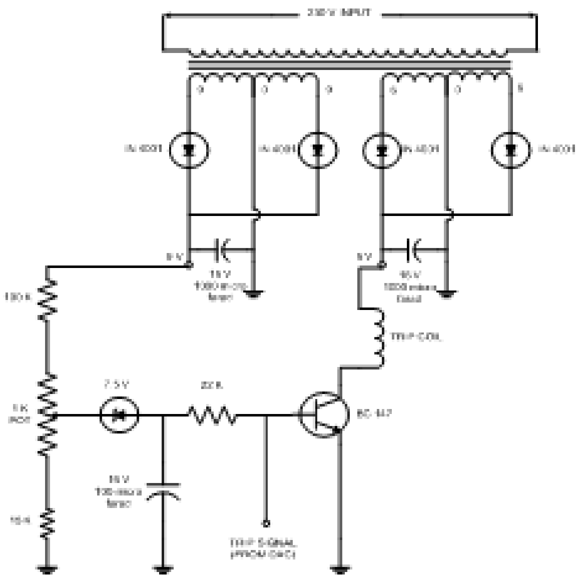

Figure 6: Driver Circuit

Here the current flowing through the differential circuit is converted into voltage form (using I – V converter). Then this is supplied to the channel 1 of junction box and hence to the Data Acquisition Card (ESA 2174). This converts the analog input signal to digital output using an inbuilt A – D converter and simultaneously samples down the data using a C program and then saves it in a data file. This data file is then fed in an already trained ANN network program, which detects the pattern of sample data. If it is a sine wave, then it checks whether its r.m.s. value is greater than the preset level of the short circuit value. And if this value exceeds the stipulated value, then trip circuit of a relay is energized by the pulse given via DAC output of the ADC card. Following this operation, the relay trips the transformer.

If the sampled data corresponds to normal load current or an inrush current pattern, no trip operation takes place, and hence this scheme also incorporates avoiding unnecessary tripping of transformers due to magnetizing inrush current. Hence, the problems associated with energizing of a transformer at no – load is also eliminated.

<u>Hardware Scheme</u>:

Data Acquisition Card: Model- ESA 2174 ADI – CARD

Absolute maximum rating:
1) Maximum positive input voltage: +16.5 V
2) Maximum negative input voltage: -16.5 V

Analog input:
1) number of input channels: 16 single ended, 8 differential
2) analog resolution: 12 bits,1 in 4096
3) input type: unipolar, bipolar

Data Acquisition:
1) Sampling rate (Single channel): 100 K samples/sec (Typical)

Analog Output:
1) Number of DAC's: 2
2) Type of DAC: 12 bit multiplying
3) Output Voltage range: 0-10V, +10V (software selectable)
4) Current drive capability: ±5mA

Timer Capability:
1) Number of channels: 3
2) Resolution: 16 bits
3) Base clock: 1.7897725 MHz (0.55873 µs)
4) Compatibility: TTL Compatible

Interface specifications:

1) 25 Pin D – Type Male Connector: for ADC and DAC signals
2) 50 Pin Berg Connector: for DIO signals

Hardware specifications:

Transformer-
Single phase, 50 Hz, 230/115 V, 1 KVA, core type

C.T. –
10A/1A, 5A/1A
Burden- 1 VA

Op – amp –
LM 741; Power consumption: 50mW;
Slew rate: 0.5V/µs; Biasing Voltage: ±12 V
Relay –
230V, 5 Amps; Trip coil: 6V

Driver Circuit -
IC – BC147; Resistance - 1K, 1.5K, 33K; Capacitor - 100µF, 16 V; Transformer – 9-6-0-6-9, 200mA; Diode – IN 4001; Preset – 4.7 K; Capacitor - 100µF, 20 V

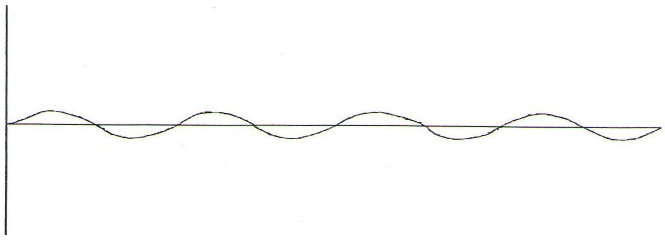

Figure 7: Pattern Of Sinusoidal Wave Used For Network Training:

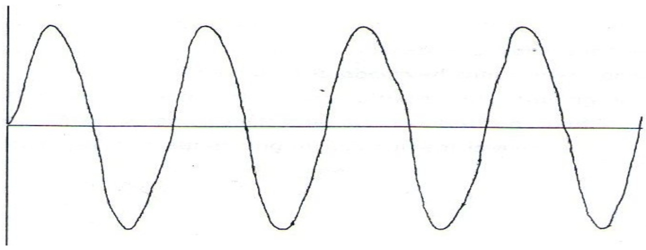

Figure 8: Pattern Of Short Circuit Current For Which Tripping Occurs:

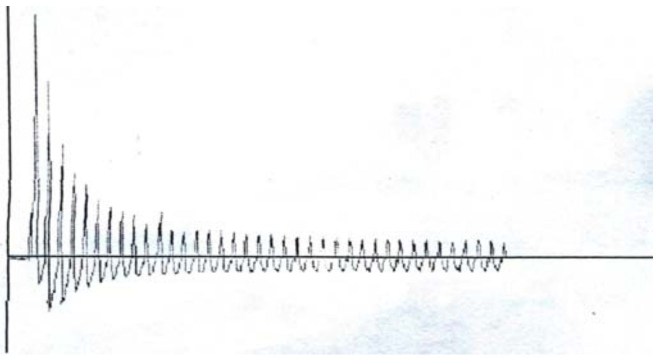

Figure 9: Pattern Of Magnetizing Inrush Current

The final output weights obtained after pattern recognition technique are given below:

4.581 4.581 4.581 4.581 4.581 4.581 4.581 4.581 4.581 4.581

6. Conclusion

Extensive C programming for Back propagation Algorithm is verified for the chosen model of 78 Neurons input representing current samples. Final weights obtained after pattern recognition techniques is mentioned here. With this Differential protection scheme associated with Artificial Neural Networks, desired operation of relay for the short circuit condition is achieved. It is observed that under normal load condition the scheme does not initiate any tripping signal as desired. Also when transformer is excited on no load, the mal-operation due to magnetization inrush current is avoided.

References

[1] M. Tripathy, R. P. Maheshwari, and H. K. Verma, "Advances in transformer protection: a review," Electric Power Components and Systems, vol. 33, no. 11, pp. 1203–1209, 2005.

[2] P. Arboleya, G. Díaz, J. Gómez-Aleixandre, and C. González-Morán, "A solution to the dilemma inrush/fault in transformer differential relaying using MRA and wavelets," Electric Power Components and Systems, vol. 34, no. 3, pp. 285–301, 2006.

[3] Ouahdi Dris, F. M. Elmareimi and R. Fouad, "Transformer differential protection scheme with internal faults detection algorithm using second harmonic restrain and fifth harmonic blocking logic,"

[4] M. C. Shin, C. W. Park, and J. H. Kim, "Fuzzy logic-based relaying for large power transformer protection," IEEE Transactions on Power Delivery, vol. 18, no. 3, pp. 718–724, 2003.

[5] Iswadi HR and Redy Mardiana, "Differential power transformer protection technique using the wavelet packet transform approach," Proceedings of International conference on Electrical engineering and Informatics, Indonesia, June 17-19, 2007

[6] S. Ala, M. Tripathy, and A. K. Singh, "Identification of internal faults in power transformer using symmetrical components and Park's plots," in Proceedings of IEEE International Conference on Power Systems, IIT, Kharagpur, India, December 2009.

[7] X. Ma and J. Shi, "New method for discrimination between fault and magnetizing inrush current using HMM," Electric Power Systems Research, vol. 56, no. 1, pp. 43–49, 2000.

[8] A. A. Aziz, A. A. Ali and A. H. Abbas, "Power transformer protection by using Fuzzy logic,"Electrical and Electronic Engineering, vol 5, no. 1, 2009

[9] J. Ma, Z. Wang, Q. Yang, and Y. Liu, "Identifying transformer inrush current based on normalized grille curve," IEEE Transactions on Power Delivery, vol. 26, no. 2, pp. 588–595, 2011.

[10] L. G. Perez, A. J. Flechsig, J. L. Meador, and Z. Obradovic, "Training an artificial neural network to discriminate between magnetizing inrush and internal faults," IEEE Transactions on Power Delivery, vol. 9, no. 1, pp. 434–441, 1994.

[11] Venkatesan and M. S. Kumar, "Power transformer differential protection with neural network based on symmetrical components," International journal of communications and engineering, vol. 06, no. 6, issue 01, March 2012.

Author's Profile

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Vinay Barhate received the M.Tech degree in Integrated Power Systems from VRCE/VNIT, Nagpur having passed B.E. Electrical (Electronics and Power) from Govt. College of Engineering, Amravati, under Nagpur University. Joined as Lecturer in Ramdeobaba College of Engineering and Management, Nagpur in 1985 and served their on various posts as Assistant Professor, head of Department and now Dean, International Cell at the same Institute.