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ANFIS based flux-current differential protection scheme for power transformer protection

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ABSTRACT

This paper presents a new approach to differential protection for power transformer by using ANFIS approach. The proposed method was trained and tested with data obtained from PSCAD simulation of a power system under different operating conditions. The simulation results show that this algorithm is very good to recognize the various fault types in power transformers. Using the ANFIS approach, the accuracy and speed of operation of flux-current differential relaying scheme is significantly improved while compared with conventional current differential relaying scheme. The proposed method has an outstanding advantage that it can eliminate the load tap changer error meanwhile in operation and there by sensitivity of the relay is improved.

Introduction

One of the most important and costly equipment in power systems is the power transformer in different sizes, types and connections. The function of a power transformer is to connect as a node to two different or same voltage levels. The reliability of the power system mainly depends upon the protection of power transformer because any unscheduled repair works; especially replacement of faulty transformer is very expensive and time consuming. The current differential protection provides best protection for a power transformer but it may mal operate in case of inrush period and is not capable to detect the internal fault in all conditions [2]. It is well recognized that the current differential relays are affected by many factors such as inrush current, transformer tap and current transformer mismatch. Hence flux-current differential method is preferred for power transformer protection [2].

It is earlier noted that the second harmonic is almost ideal for determining whether a large current is due to initial inrush or due to sudden fault [7]. The conventional technique based on second harmonic restrain has the complexity in distinguishing between internal fault, inrush current and over excitation thereby affecting transformer stability [11].

Therefore alternative improved protection technique based on transient detection is highly desired for accurate and efficient discrimination. Recently fuzzy logic technique [6], [7] has been applied for power transformer protection. In this paper Adaptive Neuro Fuzzy Inference system (ANFIS) is used because this technique provides a method for the fuzzy modeling procedure to learn information about a data set. Moreover, it computes the membership function parameters that best allow the associated fuzzy inference system to track the given input/output data. This learning method works similarly to that of neural networks.

This paper deals with flux-current differential relaying scheme using ANFIS algorithm to recognize the various fault types with respect to transformer protection zone. It enables the power transformer to be robust against recognition of transformer faults and provides a better response and consequently increases the relay's performance in comparison with conventional current differential relaying scheme.

Overview Of Adaptive Neuro Fuzzy Inference System (ANFIS)

The basic idea behind the neuro-adaptive learning techniques is very simple. These techniques provide a method for the fuzzy modeling procedure to learn information about a data set, in order to compute the membership function parameters that best allow the associated fuzzy inference system to track the given input/output data. This learning method works similarly to that of neural networks. The Fuzzy Logic Toolbox function that accomplishes this membership function parameter adjustment is called ANFIS. The ANFIS function can be accessed either from the command line, or through the ANFIS Editor GUI. ANFIS is much more complex than the fuzzy inference systems discussed so far, and is not available for all of the fuzzy inference system options. Specifically, ANFIS only supports Sugeno-type systems, and these must have the following properties:

- Be first or zeroth order Sugeno-type systems.
- Have a single output, obtained using weighted average defuzzification.

All output membership functions must be the same type and either is linear or constant. Have no rule sharing. Different rules cannot share the same output membership function, namely the number of output membership functions must be equal to the number of rules. Have unity weight for each rule.

An error occurs if fuzzy inference system (FIS) structure does not comply with these constraints. Moreover, ANFIS cannot accept all the customization options that basic fuzzy inference allows. That is, membership functions and defuzzification functions, cannot be made by the user, but the user must use functions provided in the toolbox.

The modeling approach used by ANFIS is similar to many system identification techniques. First, hypothesize a parameterized model structure (relating inputs to membership functions to rules to outputs to membership functions, and so

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on). Next, collect input/output data in a form that will be usable by ANFIS for training. Then use ANFIS to train the FIS model to emulate the training data presented to it by modifying the membership function parameters according to a chosen error criterion. In general, this type of modeling works well if the training data presented to ANFIS for training (estimating) membership function parameters is fully representative of the features of the data that the trained FIS is intended to model. This is not always the case, however. In some cases, data is collected using noisy measurements, and the training data cannot be representative of all the features of the data that will be presented to the model. In general, fuzzy sets and neural networks deal efficiently with two very distinct areas of information processing. Fuzzy logic sets are efficient at various aspects of uncertain knowledge representation; While Neural Networks are efficient structures capable of learning from samples. ANFIS are inflected into three basic elements: fuzzification, fuzzy inference and defuzzification. In neural nets, the weights between the input and the first hidden layer as well as the last hidden layer and the output layer determine the input/output behavior. In fuzzy logic, these parameters are found in the fuzzification and defuzzification routines and it can be trained. Calculated degrees of membership in the rule layers are according to IF-THEN rules. In ANFIS the network uses the back propagation gradient descent method and the least-squares method to learn from the data sets, and find a suitable adaptive network fuzzy.

Overview of Transformer Differential Protection Schemes

Differential relaying usually involves the detection of an imbalance in current flow into and out of a protected area. Differential relays are used for protection of a transformer, a length of circuit, a winding of a generator, a section of bus bar, etc. The differential protection scheme of transformer employs a biased differential relay.

The differential relays can be classified as:

- Circulating current differential protection
- Opposed voltage differential protection
- Biased or percentage differential protection

A. Current Differential Protection Scheme

In conventional circulating current differential protection the currents entering and leaving the equipment to be protected are compared. If these currents are not equal, it means that a third branch has been created and the current equal to the difference of the two currents being compared flows through this third branch, which signifies a fault. The current proportional to this fault current is made to pass through the relay, which senses the fault current leading to its operation. This conventional technique is refined further and used as biased differential relays which are most commonly used for the differential protection of large power transformers.

The biased differential relay has two coils. One coil is known as restraining coil or bias coil, which restrains the operation of the relay. Another coil, the operating coil, produces the operating torque for the relay. When the operating torque exceeds the restraining torque, the relay operates.

But in this conventional scheme there is a possibility for mal operation of relay. This is because of the presence of harmonics the internal and magnetizing inrush current are not distinguished correctly at all times. Hence to overcome this difficulty Flux-current differential scheme is formulated.

B. Flux- Current Differential Protection Scheme

Flux-current differential protection scheme clearly discriminates the internal fault from the magnetizing inrush current. It also detects internal fault under inrush and over-excitation conditions. The algorithm needs only three to four samples of the currents and voltages. A relay with the flux-based algorithm is much faster than a harmonic restrain relay. It is based on the principle of the derivative of flux –current with respect to differential current. ($d\Phi_d/di_d$).

The flux-current relationship is highly non-linear due to the saturation and the remnant flux in the core. Since the remnant flux depends on the previous conditions the flux-current relationship also depends on the previous conditions. So care must be taken to estimate the flux in the core as accurately as possible to develop Flux- current differential protection scheme.

The algorithm needs only one cycle of the first and second harmonic primary currents and first harmonic secondary current of the power transformer.

Proposed differential protection scheme for power transformer using ANFIS

In this paper ANFIS model has been developed for the conventional current differential protection scheme and then for the flux current differential protection scheme. The overall block diagrams of both these cases are shown in Figure 1 and Figure 2 respectively.

Figure 1 shows the schematic block diagram of the ANFIS based current differential protection scheme. The inputs are obtained by preprocessing primary and secondary current signals.

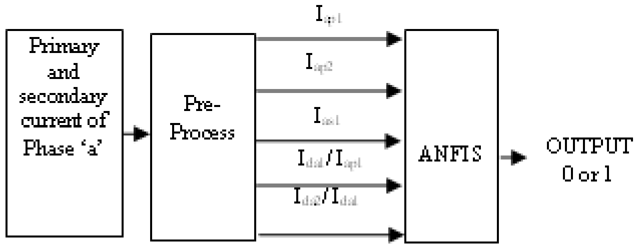
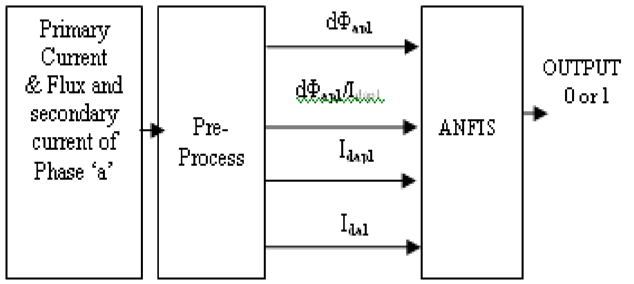


Fig.1.Block diagram of the ANFIS based current differential protection scheme

These inputs are required at the input layer of ANFIS structure. The output layer consists of only one neuron, which has value 0 or 1. Output 1 indicates tripping, otherwise no-tripping.

The primary and secondary of three phase current signals are sampled and then magnitudes of harmonics of current signals have been obtained by FFT algorithm. The current magnitudes are inputs of differential protection. It consists of three FNN units; each of them is specified to one phase. Also a logical unit is embedded into this structure to provide the accurate tripping commands based on the output of previous three units. The inputs of these units are 1^{st} harmonic primary current and secondary current, 2^{nd} harmonics of primary and secondary current , ratio of 1^{st} harmonic component of the differential current to primary current and ratio of 2^{nd} harmonic component of the differential current to primary current.

Figure 2 shows the block diagram of the proposed ANFIS based flux-current differential protection scheme. The inputs are obtained by preprocessing primary current signals, primary flux and secondary current signals. These inputs are required at the input layer of ANFIS structure. The output layer consists of only one neuron, which has value 0 or 1. Output 1 indicates tripping, otherwise no-tripping.



The first primary and secondary three phase current and primary flux signals are sampled and then magnitudes of harmonics of currents and primary flux have been obtained by FFT algorithm. These magnitudes are inputs of flux-current differential protection. It consists of three FNN units; each of them is specified to one phase also a logical unit is embedded in to this structure to provide the accurate tripping commands current based on the output of previous three units. The inputs of these units are primary flux 1st harmonic differential value, ratio of 1st harmonic flux differential to 1st harmonic differential, 1st harmonic current differential and 1st harmonic current differential between primary and secondary consists of primary and secondary current.

The salient feature of the new method is elimination of load tap changer error of the three phase transformer and thereby sensitivity of the relay is improved over the conventional algorithm and time taken for training and testing is greatly reduced.

A. Test system modeling and simulation

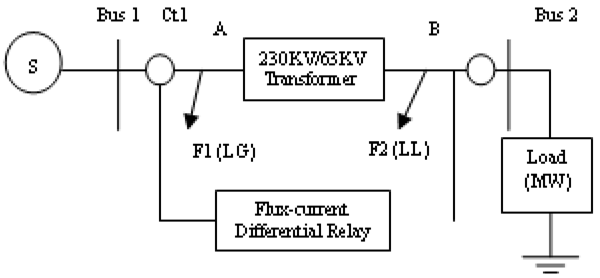


Fig. 3.Test power system model

In this paper, for the study of a three phase 230/63 KV, delta to star connected power transformer which is included in the power system, having a 50 km transmission line is considered. The power system model is shown in Figure 3. In the test system, the transformer has tap changer in primary winding in the range of ± 9 % of rated value is varied with the step of 1.5. To prove the reliability of the proposed scheme the primary winding tap settings, voltage inception angle and load are varied for steady state, inrush and internal fault conditions which are modeled and simulated by using PSCAD 4.1 version software.

The training and testing process is implemented by using MATLAB 7.0 version.

The system configuration is given below:

Pentium-IV

CPU-3.00 GHZ (operating speed)

RAM-504 MB

Development of data for training and testing by preprocessing

The data to be given as inputs to ANFIS are obtained by preprocessing the simulated waveforms(three phase primary current, flux and secondary current) for various operating condition(steady state, inrush and internal fault conditions). These samples were processed by 2nd order low pass anti aliasing filters and are resampled at 250 microseconds.

The magnitudes and angles of harmonics of voltage, current and flux has been obtained by full cycle Fast Fourier Transform (FFT) filter from primary and secondary current and flux samples. The preprocessing algorithm is shown in Figure 4.

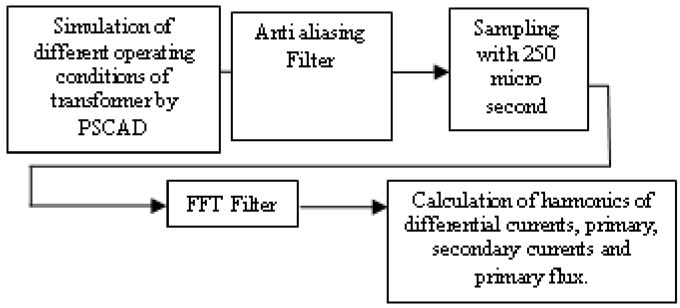


Fig. 4.Preprocessing method

Development of ANFIS architecture

The architecture of adaptive network fuzzy has been used. In general, fuzzy sets and neural networks deal efficiently with two very distinct areas of information processing. Fuzzy logic sets are efficient at various aspects of uncertain knowledge representation; While Neural Networks are efficient structures capable of learning from samples. ANFIS are divided into three basic elements: fuzzification, fuzzy inference and defuzzification. In neural nets, the weights between the input and the first hidden layer as well as the last hidden layer and the output layer determine the input/output behavior. In fuzzy logic, these parameters are found in the fuzzification and defuzzification routines and it can be trained. Calculated degrees of membership in the rule layers are according to IF-THEN rules. The network uses the back propagation gradient descent method and the least-squares method to learn from the data sets, and find a suitable adaptive network fuzzy.

ANFIS architeuture of flux-current differential relaying scheme

Number of nodes: 524

Number of linear parameters: 1458

Number of non linear parameters: 30

Total number of parameters: 1488

Number of training data pairs: 324

Number of checking data pairs: 0

Number of fuzzy rules: 243

Fuzzy Inference System

Name: 'sug 51'; Type: 'sugeno'

And Method: 'prod'; Or method: 'probor'

Imp method: 'min'; Agg method: 'max'

Defuzz method: 'wtaver'

Input: [1x5 struct]; Output: [1x1 struct];

Rule: [1x15 struct]

Training And Testing

The data set for steady state, magnetizing inrush state and different fault types [LL, LG] was generated by using PSCAD simulation for the test power system model shown in Fig.1.

Out of the data set generated from simulated signals nearly 20% of the data set patterns were used for testing and about 80% of the data set patterns are used for training. For training and testing, Matlab 7.0 software has been used.

For different conditions of fault type, fault inception time, transformer tap were changed to investigate the effects of the factors on the performance of both conventional current differential relaying scheme and flux-current differential relaying scheme.

ANFIS uses the least squares method and the back propagation gradient descent method to learn from the data sets, and find a suitable adaptive network fuzzy. All the rules are derived from the training of the fuzzy-neuro model based on the prior data-base. Once trained, the ANFIS performance was tested using test patterns that were different from the training patterns.

Simulation results and analysis

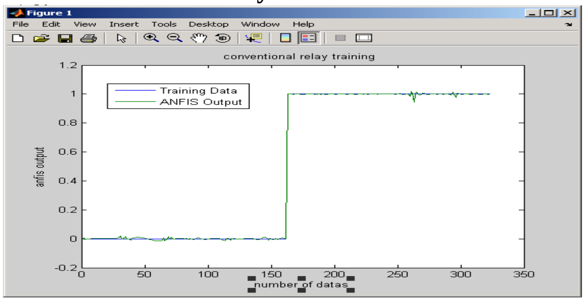


Fig.5.ANFIS Training and Testing for current differential relaying Scheme

Figure.5 depicts the performance of ANFIS based current differential relaying scheme. It is inferred that there is a slight variation in between the training data and ANFIS output. Similarly ANFIS output is slightly deviated from the testing data. The simulation time taken for testing the state of transformer is nearly 40 seconds for one epoch.

Table II describes the proper action of flux-current differential relaying scheme for various operating conditions like with & without inrush and also with internal fault & without internal fault.

Table III gives the performance comparison of ANFIS based conventional current differential relaying scheme and ANFIS based flux-current differential relaying scheme for different conditions of the transformer including LG&LL fault types. It shows that there is improvement in sensitivity and speed of operation in the proposed flux-current relaying scheme. Table III lists the main difference between that two relay protection schemes.

From the results it is inferred that comparing to ANFIS based conventional current differential protection scheme, ANFIS based flux-current differential protection scheme gives better accuracy and also simulation time taken is drastically reduced.(i.e. from about 40 seconds to less than 1 second)

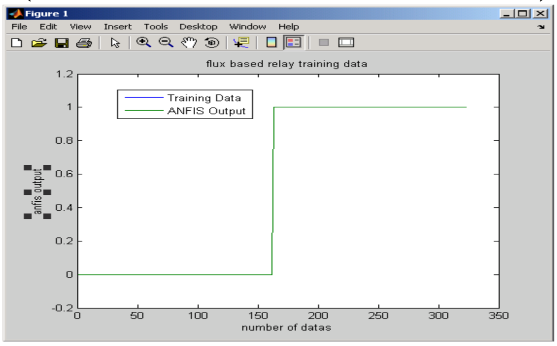


Fig.6.ANFIS Training and Testing for Flux-current differential relaying scheme

Figure.6 depicts the performance of ANFIS based Flux-current differential relaying scheme, It is clear that the training data & ANFIS output and testing data & ANFIS output perfectly match in this case. Also the simulation time taken for testing the state of transformer is less than a second for one epoch.

Also in flux –current differential scheme the salient feature is the elimination of load tap changer error of the three phase transformer. And so, the sensitivity of the relay is improved over the conventional current differential relay. Moreover in ANFIS model there is minimization of error and drastic reduction in simulation time taken while flux-current differential relaying algorithm is used. So from the simulation results it is concluded that the performance of ANFIS based flux-current differential protection scheme is better than ANFIS based conventional current differential protection scheme by all means.

Conclusion

This paper presents an ANFIS based flux-current differential relaying scheme for power transformer protection and shows a vastly improved performance over ANFIS based conventional current differential relaying scheme. The obtained results show that flux-current differential relay works with proper action for all conditions of the power transformer. It can operate with proper sensitivity and even without tap changing effect by using an ANFIS. The result also indicates that the ANFIS based flux-current differential relaying scheme provides faster operation than ANFIS based conventional current differential relaying scheme. The simulation results obtained shows that the new proposed method provides more accurate (in terms of sum squared error) and high speed response (in terms of simulation time taken for convergence) for various operating conditions of power transformer. Thus ANFIS based flux-current differential relaying scheme for power transformer protection shows promising security, ability to not trip when it should not, dependability(ability to trip when it should) and speed of operation (short fault clearing time).

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Biographies

M.Geethanjali obtained her BE degree in Electrical engineering in 1989 and Master's degree in Power Systems Engineering in 1991 from Thiagarajar college of Engineering, Madurai. She has been awarded PhD degree in Power system protection in 2008. She has been in teaching for the past 20 years. She is presently working as an Assistant Professor in Electrical and Electronics Engineering at Thiagarajar College of Engineering, Madurai-625 015, India. Her field of interest is Power system protection and control.

G.Sundari is working as a Project Fellow in Electrical and Electronics Engineering at Thiagarajar College of Engineering, Madurai-625 015, India. Her field of interest is Digital power system protection.

Table I. Test power system data

Transformer reactance(p.u)	j 0.13
Line impedance (ohm/km)	0.35+j1
Generator impedance (ohm)	40
Power system condition	Fault LG, LL at points A, and B. Inrush: in different voltage angle.
Tap changer	± 9% of rated voltage with the step of 1.5
Voltage angle	0 to 90º with the step of 10º
Load (MW)	20,30 & 50

Table II Pscad simulation results of Flux-current differential protection scheme

Tap Setting in % of Rated Voltage	INRUSH WITH OUT FAULT		INTERNAL FAULT IN F1 (LG)		INTERNAL FAULT IN F2 (LL)	
	Voltage Inception angle	Relay output	With Inrush	With out Inrush	With Inrush	With out Inrush
0	20	No Trip	Trip	Trip	Trip	Trip
1.5	30	No Trip	Trip	Trip	Trip	Trip
3	15	No Trip	Trip	Trip	Trip	Trip
4.5	45	No Trip	Trip	Trip	Trip	Trip
6	25	No Trip	Trip	Trip	Trip	Trip
7.5	30	No Trip	Trip	Trip	Trip	Trip
9	35	No Trip	Trip	Trip	Trip	Trip
-1.5	40	No Trip	Trip	Trip	Trip	Trip
-3	45	No Trip	Trip	Trip	Trip	Trip
-4.5	50	No Trip	Trip	Trip	Trip	Trip
-6	55	No Trip	Trip	Trip	Trip	Trip
-7.5	60	No Trip	Trip	Trip	Trip	Trip
-9	75	No Trip	Trip	Trip	Trip	Trip

Table III Performance comparison of ANFIS based flux-current differential relay and ANFIS based current differential relay

Parameters / State of transformer	Time taken to train and test the state of transformer in seconds for one epoch		Average accuracy of testing the state of transformer	
	ANFIS based current differential relaying scheme	ANFIS based Flux-current differential Relaying scheme	ANFIS based current differential relaying scheme	ANFIS based Flux-current differential Relaying scheme
Steady state	38	1	99.9298	99.8464
Magnetizing inrush	39	1	99.9385	99.8380
Line to ground fault (a-g)	40	1	99.8672	99.8771
Line to ground fault (b-g)	40	1	99.7223	99.8772
Line to ground fault (c-g)	40	1	99.3678	99.8774
Line to line fault (a-b)	40	1	99.8721	99.8782
Line to line fault (b-c)	40	1	99.8572	99.8783
Line to line fault (c-a)	40	1	99.8617	99.8785