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A Review of various Techniques for the Improvement of Differential Protection in Power Transformers

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ABSTRACT

Differential protection, was one of the first protection system used in power transformers, to get rid of the problem of Magnetizing inrush current which causes mal-operation of the relays. This mal-operation of differential relay can affect stability and reliability of the overall power system. In this paper, an attempt is made to cover all the developed techniques to discriminate between Magnetizing Inrush and Internal Fault currents for the protection of power transformers. This paper presents a sequence with conventional methods like second harmonic restraint and fifth harmonic blocking under differential protection scheme and proceeds to the Discrete Fourier transform, wavelet transform, and to the most recent techniques using Artificial Neural Networks, Fuzzy logic, Fuzzy- Neuro techniques, Wavelet-Neural Network techniques for the discrimination between Magnetizing Inrush and Internal Fault currents. The set of references of all concerned papers and a summary of the work presented by researchers is included in this paper. It also includes the results of these techniques as provided in the respective references.

KEYWORDS

PowerTransformer protection, Differential Protection Scheme, harmonic restraint, Magnetizing Inrush current, Artificial neural network, wavelet transform, fuzzy logic, Fuzzy – Neuro, Wavelet - Neural Network

INTRODUCTION

Power transformers are the basic part of the power systems and it requires special attention when it comes to save false tripping of Differential Protection Relay, which was already applied towards the end of 19th century and was one of the first protection systems ever used. Since minimization of frequency and duration of unwanted outages is very desirable, hence its protection not only becomes necessary but also the selection of method used for protection. This includes the requirements of dependability associated with no mal-operations, security associated with no false tripping, and operating speed associated with short fault clearing time.

The main problem in differential protection of power transformer exists in the accurate and quick discrimination of inrush current from internal fault current. Inrush current, which occurs during the energizing the transformer, results in 8 to 10 times full load current and therefore can cause mal-operation of the relays. It affects the reliability and stability of the power system.

False tripping due to magnetizing inrush current makes transformer protection a challenge to researchers. Many researchers have done the calculation and analysis of inrush current by considering different transformer parameters.

M. Jamali et al [1] investigated the effects of some parameters on the characteristics of inrush current in MATLAB Simulink. Their results showed that by increasing the switching angle at a positive remanent flux or source resistance will decrease the amplitude of magnetizing inrush current. It has been shown that largest second harmonic content may not necessarily appear at the first cycle. The effect of remanent flux on the first cycle peak current shows that it has large changes when the remanent flux varies. They also concluded that to

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reduce the magnitude of inrush current, an appropriate switching angle by considering remanent flux, must be selected.

VARIOUS DIFFERENTIAL PROTECTION TECHNIQUES

The scholars have researched a lot and found different methods to distinguish magnetizing inrush current from internal faults shown in figure1. Some techniques to distinguish between inrush current and internal fault currents in transformers are reported here based on different principles.

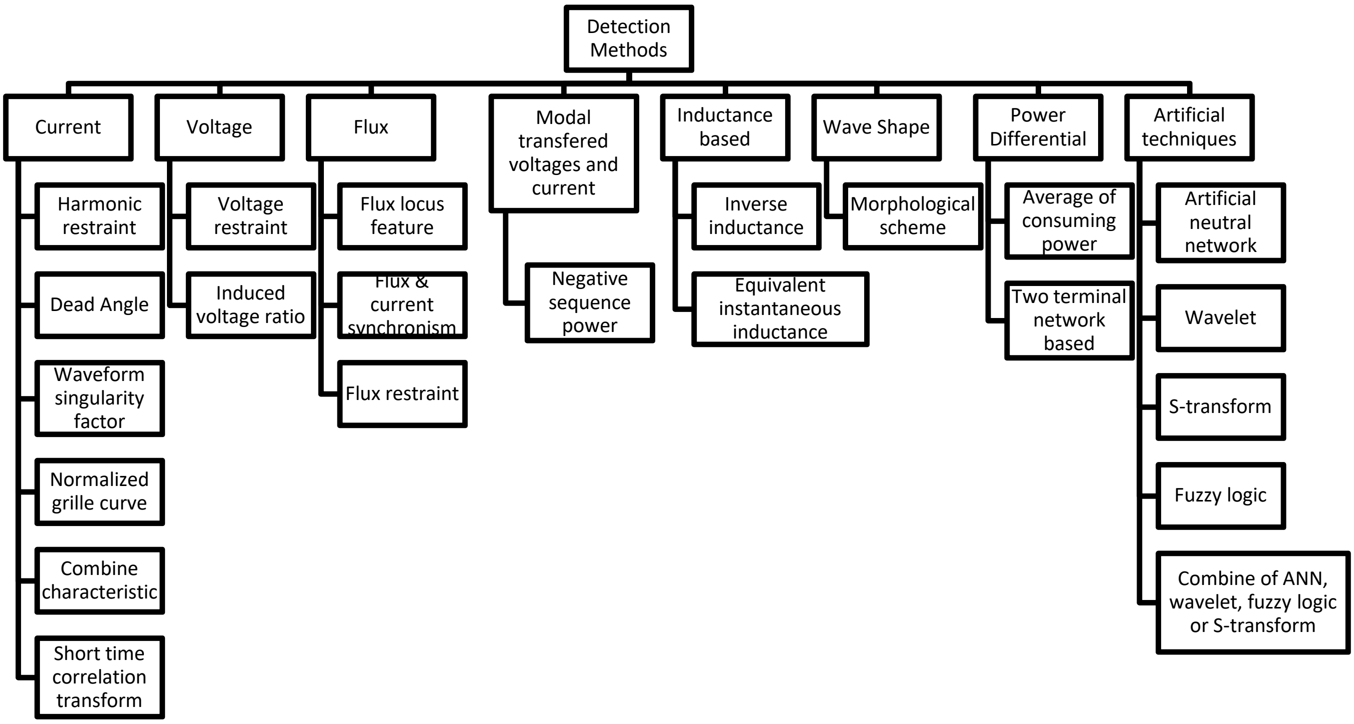

Figure 1. Different methods to distinguish magnetizing inrush current from internal faults

R. L. Sharp et al [2] developed a high-speed variable-percentage differential relay for 2- and 3-winding transformer protection which will not trip for external faults and magnetizing inrush currents, but it will trip for internal faults. The developed design uses second harmonic only for restraint of the inrush supervision unit, as this harmonic will always be presented to the relay during an inrush, and is much less predominant for internal faults.

This new relay retains the simple principle and design of the variable-percentage differential unit. It also provides inrush supervision through second-harmonic restraint of a simple sensitive overcurrent unit connected in the differential current circuit of the main current transformers. The tuned circuits of the inrush supervision unit were selected not only to provide the proper response of the unit for inrush and fault conditions, but also to provide a very good response under reduced -frequency conditions.

The second harmonic restraint method is the most common one used by various relay manufacturers and application engineers. There are a few variations of harmonic restrained differential protection.

In Fifth Harmonic blockade technique, OuahdiDris et al [3] has stated in their paper, based on the fact that the inrush current has a second-harmonic component of the differential current which is much larger in the case of inrush than for a fault, and the over-excitation current has a larger fifth-harmonic component. And as the use of digital protection offers the advantage to implement complexes algorithms such as DFT to ensure better extraction of fundamental and other harmonic components, then the use of the second and the fifth harmonics for restraining and blocking, by the differential protection will give a possibility to discriminate between the faulty and the normal state of power transformer.

There are many other methods in which researchers had worked upon to distinguish between inrush current and internal fault currents in transformers. In the year 2002, A. Rafa et al [4] described the design and implementation of the micro controller-based system for protecting power transformer. The system includes facilities for discrimination between internal fault current and magnetizing inrush current, differential protection, over current protection, over voltage protection and under voltage protection. In their work, the results demonstrated that the discrimination time is around 1.6msec, to discriminate between inrush current and internal fault, which means the relay, is fast.

In 2010, H. Abniki et al [5] employ symmetrical components technique. When transformer is switched on, inrush current occurs. This current has some features, which it is enough to identify itself. In their work, they extracted these features; a new criterion is proposed to discriminate inrush currents from internal faults in power transformers. In faulty time such as switching or short circuit, the value of negative sequence for differential current is different from positive sequence value. Helping this feature, new criterion is introduced. Their result shows that the criterion works properly in over-flux and CT saturation condition also. The simulated results presented clearly, the proposed algorithm can accurately discriminate between an internal fault and a magnetizing inrush current in power transformer protection in all cases.

In 2009, another technique namely ‘Morphological Scheme’ is used by W. H. Tang et al [6]. They presented a novel morphological scheme for the identification of transformer magnetizing inrush. This scheme decomposes a current signal into multi resolution levels based on synthesis and analysis operators of mathematical morphology. It is able to discriminate between inrush and internal fault currents even in the case of an inrush with a low second harmonic component and an internal fault current with a high second harmonic component.

Recently, in 2015, an auto-correlation function based technique for discriminating magnetizing inrush and internal fault currents in three-phase transformers is introduced by Haidar Samet et al [7]. In this method, for each phase, the auto-correlation function of the differential current is calculated for a specified range of lags. Their standard deviation is determined in the next step. Criterion function can be defined as the difference between the maximum and minimum of the auto-correlation function lags standard deviations for the three phases. The result shows that the proposed technique is efficient in terms of speed response, reliability, and accuracy.

In 2016, Manjula B K et al [8] introduced a new method of detection of magnetizing inrush current and internal fault current considering current waveform and its magnitude and time samples as ADC emulated data. They had developed an algorithm which is used to compare the data of magnitude and time of both inrush and fault current with the help of FPGA. Decision can be made based on the output of FPGA whether to provide trip circuit for fault current and allow the inrush current to pass through as it exist for a duration lesser than the fault. The results prove that the proposed technique is able to offer fast responses in detection of inrush and fault current.

In 2015, Mohammad Ahmad [9] proposed a discrimination technique based on sine-wave least-squares curve fitting method. In this method, a sine wave is fitted to the normalized differential current by using the least squares technique for each phase. The difference between the normalized differential currents and the fitted signals are calculated, called as residual signals (RSs). Maximum range of the RSs variations is utilized for the definition of a simple criterion. Based on this criterion, the discrimination is realized within less than a half cycle of power frequency. In order to eliminate the impact of the current transformer (CT) saturation on the performance of the proposed technique, the currents are compensated by a CT saturation compensation algorithm in the first step. Furthermore, the proposed algorithm is evaluated in the case of a transformer, which is fed through a feeder with series capacitors. The results confirm that reliability, accuracy and speed response of the proposed technique is good.

In 2015, an equivalent instantaneous inductance (EII)-based scheme is proposed by Ge Baoming et al [10] to distinguish between inrush current and internal faults in power transformers. This scheme is derived from the inherent difference of the magnetic permeability, due to the saturation and unsaturation, in the transformer iron core between the inrush current and an internal fault. The experimental results verify the dependability, security, and fast operation of the proposed scheme. Besides, its easy implementation in real time is another advantage of the proposed method because of its simplicity.

For a decade, researchers have developed a technique for power transformer protection using Wavelet Transform [11][12][13][14]. Wavelets allow the decomposition of a signal into different levels of resolution (frequency octaves). The basis function (Mother wavelet) is dilated at low frequencies and compressed at high frequencies, so that large windows are used to obtain the low frequency components of the signal, while small windows reflect discontinuities. Wavelet Transform has a special feature of variable time – frequency localization which is very different from the windowed Fourier Transform.

One of the researcher OkanOzgonenel et al [11] proposed a selection algorithm of wavelet based transformer differential current features. In this technique, the minimum description length with entropy criteria are employed for an initial selection of the mother wavelet and the resolution level, respectively; whereas stepwise regression is applied for obtaining the most statistically significant features. The proposed algorithm highlights the potential of utilizing synergism of integrating multiple feature selection techniques as opposed to an individual technique, which ensures optimal selection of the features.

Another researcher, A. Rahmati et al [12] presented an algorithm for power transformer differential protection which differentiates internal faults from magnetizing inrush currents and saturation of current transformers using wavelet transform. The technique is based on pattern recognition of the instantaneous differential currents using the high-frequency components generated during the disturbance. These components are extracted using a wavelet-based processor stage. In this method, an appropriate criterion at a suitable frequency range is developed. Using the developed criterion for three phases, internal faults are correctly detected in about 1/8th cycle after occurrence of the disturbance.

Another method which combines d-q axis and wavelet packet transform is developed by M. A. Rahman et al [15] for the protection of power transformers. This characterization helps to develop an improved differential relay to detect and discriminate internal faults from inrush currents in power transformers. This hybrid method provides accurate information with only one level of the wavelet packet transform (WPT) of the d-q components of the differential current. The experimental results show the efficiency and reliability of the proposed technique.

Some techniques to increase reliability, speed and robustness of existing digital relays are reported in recent literature. Those techniques are based on Artificial Intelligence. Artificial Intelligence based techniques are well developed in the areas of pattern classification and recognition These developments are discussed in the following section of this paper.

After 1990, researchers have developed differential power transformer protection using fuzzy logic concept [16]. In 2009, Ahmad Abdulkader Aziz et el [17], reports that the fuzzy based relaying algorithm prevents mal operation of relay in the event of magnetizing inrush with low second harmonic component and internal faults with high second harmonic component. This results in improved accuracy and robustness against the change of condition in power system. And also the Relays obtain high sensitivity to the fault detection and operate with tripping time of within half cycle. Hence, the method is reliable and speedy.

In 2011, Mr. Iman Sefari Rad and et al, in one of their paper [18], used fuzzy logic for internal fault detection in differential protection of power transformers. In this method, algorithm of fault detection is based on ruling out non internal fault phenomena. For internal fault detection, it considered some criteria for inrush current, over excitation, saturation of current transformers and mismatch of current transformers and is defined appropriate membership functions and criteria signals. After testing, it has been found that, this method has good accuracy and confidence. Simulation results showed that protective system operates correctly in fault and non-fault cases and fuzzy system is able to detect occurrence of fault in less than half a cycle and the method improves protection system satisfactorily.

Another most powerful mathematical tool of recent times is Artificial Neural Networks (ANN) which attracts the researchers to tackle the transformer protection problem. Dr. Horward Silver in his session published in proceedings [19], mentioned that the characteristic feature of ANN is that once it is trained for any specific purpose, then it responds to new events in the most appropriate manner given the experiences gained during the training process. The ANN model can be determined by its network architecture, transfer function and its learning rule shown in Figure 2. The objective of ANN training is to get minimum deviation between the targeted outputs and the actual outputs. The criteria function for sum square error is minimizing according to gradient rule. The effectiveness of ANN depends on the quality of training given. In ANN, for transformer protection problem, pattern reorganization based on waveform analysis method is used to train the network.

H. Khomhadi-Zadeh [20] in his paper proposes a differential protection scheme for power transformer using symmetrical component and neural network algorithm. It utilizes the Artificial Neural Network as the pattern classifier and symmetrical component of current as the Inputs to ANN. Extensive simulation study shows that the symmetrical component of current provide suitable inputs for classification of different transient cases. The proposed scheme achieves outstanding performance and the ability to discriminate internal faults fast and accurately

Under ANN, one strong method to discriminate between inrush and internal fault current is Probabilistic neural network (PNN) authored by ManojTripathy et al [21] in 2010, the optimal probabilistic neural network (PNN) is proposed as the core classifier to discriminate between the magnetizing inrush and the internal fault of a power transformer. The particles warm optimization is used to obtain an optimal smoothing factor of PNN which is a crucial parameter for PNN. It makes use of the ratio of voltage-to-frequency and amplitude of differential current for the determination of operating condition of the transformer. In this method, stability of differential relay is ensured during the magnetizing inrush or sympathetic inrush, over-excitation, and external fault conditions. Hence, the differential protection reliability is enhanced.

In the field of artificial intelligence, Neuro-fuzzy refers to combinations of artificial neural networks and fuzzy logic. Neuro-fuzzy was proposed by J. S. R. Jang. Neuro-fuzzy hybridization results in a hybrid intelligent system that synergizes these two techniques by combining the human-like reasoning style of fuzzy systems with the learning and connectionist structure of neural networks.

In some papers, the architecture of adaptive fuzzy network has been utilized. In 2005, H. Khorashdi-Zadeh et al [22], presented a new inrush detector algorithm for differential protection of power transformer based on the fuzzy-neuro method. Recently, the frequency environment of power systems has been made more complicated and the magnitude of the second harmonic in inrush current has been decreased because of the improvement of cast steel. Therefore, traditional approaches will likely mal-operate in the case of magnetizing inrush with low second component and internal faults with high second harmonic. In this paper, the results show that the proposed fuzzy-neuro based inrush detector represents a proper action. It can operate with proper sensitivity and even when internal faults with CT saturation occur. Thus, the use of fuzzy-neuro can make it possible to extend the use of reliable and sensitive differential relays to power transformer protection.

M. Tripathy et el[23] in their continuous work on the subject matter authored earlier that an approach based on Fuzzy-neuro techniques ensures relay stability against external faults, magnetizing inrush, sympathetic inrush, over excitation conditions and its operation on internal faults. It uses FBPNN, a Fuzzy Back Proposition Neural Network as a core classifier to discriminate and it uses an optimal number of layers and Neurons. It is hybrid intelligent system used for digital Differential Power Transformer protection which includes merits of ANN and Fuzzy systems.

Most recent development is done using Wavelet transform method with ANN. Wavelet transform is a powerful tool in the analysis of the power transformer transient phenomena because of its ability to extract information from the transient signals simultaneously in both the time and frequency domain.Raj K. Aggarwal et al [24] presented a technique for accurate discrimination between an internal fault and a magnetizing inrush current in the power transformer by combining wavelet transforms with neural networks. The wavelet transform is firstly applied to decompose the differential current signals of the power transformer into a series of detailed wavelet components. The spectral energies of the wavelet components are calculated and then employed to train a neural network to discriminate an internal fault from the magnetizing inrush current. The simulated results presented clearly show that the proposed technique can accurately discriminate between an internal fault and a magnetizing inrush current in power transformer protection.

Recently in 2016, Jessika Fonseca Fernandes et al [25] also used the methods based on artificial neural networks and wavelet transform. She proposes this method to detect and classify disturbance in the power transformer accurately. The algorithm uses wavelet based disturbance detector in order to detect any disturbance related to a power transformer, whereas a neural network based routine is used to classify the disturbance type (internal fault, external fault and transformer energization) appropriately, as well as to classify the internal faults. Several events were simulated, such as external and internal faults, with variations of fault resistance, fault inception angle, and fault type parameters, as well as transformer energization. The method presented an excellent success rate regarding the correct classification of the disturbance as well as an accurate fault classification

CONCLUSION

Despite the variety of the proposed methods, they still have essential restrictions, especially in practice. Some limitations are the low speed, large computation burden, large required memory, CT saturation, harmonic pollution, dependence on the parameters of transformer, etc. Therefore, finding a reliable, fast, and proficient approach for discriminating inrush current from internal fault current is essential and remains an open problem.

Among all the above-mentioned methods, the method based on the combination of wavelet transform and artificial neural network results in excellent success rate in pattern recognition which prevents the mal-operation of differential relay with quick response.

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