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A Review: Transformer Protection for Magnetizing Inrush Current and Different Protection Schemes

Ruchita Pimpalkar[1], Naushin Khan[2]

[1]Student, Wainganaga College of engineering & management, Nagpur
[2]Assistant Professor, Wainganaga College of engineering & management, Nagpur

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Abstract - *The power transformer is one of the most vital links in a power system. Because of its relatively simple in construction, it is highly reliable piece of equipment. This reliability, however, requires proper design methodologies, annual overhauling and different protection schemes for different possible issues. The primary aim of transformer protection is to avail the mechanism to detect faults inside the protective zone not only with sensitivity, but also with a high degree of immunity to such operating conditions for which tripping is not at all required. Internal faults are of major concern since there is always the risk of havoc. Primarily it's the magnetizing inrush current which brings instability in power system. In this paper, the review is conducted on magnetizing inrush current which occurs in transformer*

Key Words: *Transformer, Magnetizing inrush Current, Protection schemes.*

1.INTRODUCTION

As a primary element in today's world power system, transformers are inherent part of Global transmission and distribution systems. A corrective maintenance work especially replacement of damaged transformer is costly. Winding and core of the transformer is subjected to heavy disturbances in its life time, for example:

• Through Fault Current
• Heating due to reactive power
• Harmonic vibrations
• From No load to full load heating and cooling vice versa.
• Overheating due to lack of maintenance.

This factors lead to detoriation of life of healthy transformer [1]. In general transformer need to install with certain protective system which depends upon the size of the transformer, load it is going to carry and load dependant protections incorporated in system [2]. The empirical method for protection of the transformer is Differential Protection. As a thumb rule, differential protection holds good up to 5MVA size transformer. Beyond this, special protections are required. The different protections availed in transformer system depends upon following key factors:

1. Size and rating of transformer
2. Vector configuration
3. Source and neutral earthing.
4. Type of transformer (Two winding, three winding, Auto transformer, Reactive transformer etc.)
5. In feed conditions (Radial, parallel, interconnecting).
6. OLTC Range.

The working principle of differential protection is shown in Fig. 1, wherein the primary and secondary of the transformer is shared by a CT. Under normal working condition, the amount of primary and secondary current is zero. As soon as internal fault occurs in transformer, the differential current (Id) shoots up, and it enables the relay to isolate the protected power transformer [3].

The protection is not issue to elaborate. The key issue is the false tripping of the relay due to mal-operation. It misidentifies the magnetizing inrush current. The amount of magnetizing inrush current surges in transformer may held up to 15-20 times and it separates them from the traditional internal fault currents.

A good amount of research has been conducted on these and researchers have come up with some good approaches as well. Harmonic restraint, voltage and flux restraint, inductance based method and pattern recognition is most worked on area in this domain. The pattern recognition approach based on wavelet transform and artificial intelligence like neural network and fuzzy logic are developed so far. In this paper, review is conducted to address different approaches available to distinguish internal fault current and magnetizing inrush current. The characteristics of magnetizing inrush current is elaborated further Different protection schemes for discrimination between internal fault and magnetizing inrush have been introduced under Heading 3. The paper is concluded in Heading 4.

2. Magnetizing Inrush Current

A high speed unit type of protection such as differential/ restricted earth fault protection is applied as a primary protection against internal faults.

1. Differential Protection: Based on Principle of Merz Price circulating current, differential protection is a complete earth and phase fault protection. Differential protection for detecting internal faults is an attractive option for transformer because both ends of transformers are physically located near each other [4].

Consider an ideal transformer with the CT connection as shown in Fig. 1 Let us consider that current rating of primary winding is 100 A and secondary winding is 1000A .Then if we use 100:5 and 1000:5 CT on primary and secondary windings respectively, then under normal operating condition the scaled CT currents will match in magnitudes and no current will flow through the branch having over-current relay. Now if an internal fault occurs within the device like inter turn short circuit etc., then the normal mmf balanced is upset i.e. $N_1I_1 = N_2I_2$ and differential current will flow through over-current relay. If the pickup setting of over-current relay is near to zero, it will immediately pick up and initiate the trip decision.

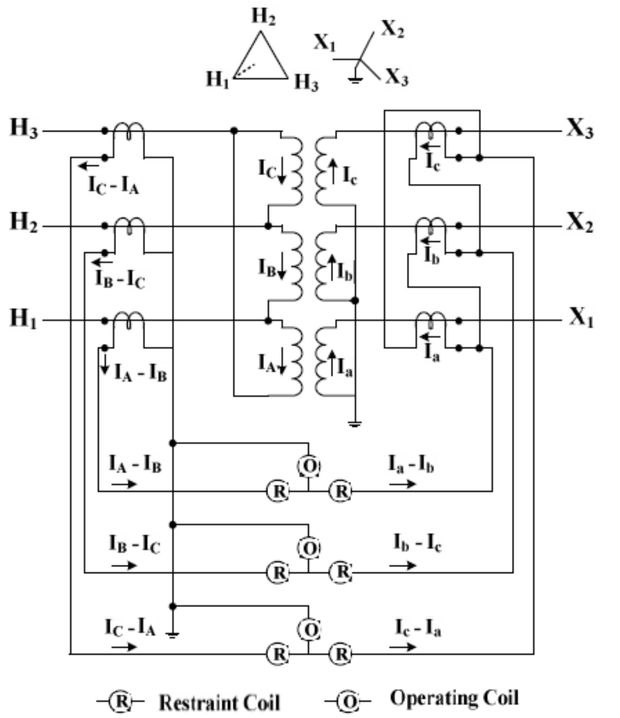

Fig.1: Differential Protection Scheme for power transformer

Magnetizing inrush currents broadly categorized into three parts:
1. **During energization:** During initial energization, the inrush current is present after a last instance of de-energizing and it has the capability to introduce heavy current.
2. **During Recovery:** The phenomenon of recovery inrush also exists in transformer and takes place during the return of voltage back to normal level from fault. During a solid three phase external fault, the voltage level fall down almost to zero level. Then, when the fault is attended, the voltage instantaneously rises to normal level. In this case, due to partial energized core, maximum value of inrush current will be less.
3. **Sympathetic inrush current**: There is still possibility of existence of inrush current even when transformer is nearly energized [5], [6]. In the situation where one bank is in service and the second, parallel bank is switched into the service, their inrush current owing in the newly switched bank can find a parallel path in the previously energized bank. This is called as sympathetic inrush and this inrush will not be large as an initial inrush.

Most severe among all is the magnetizing inrush current during energization due to switching. When a transformer is de-energized the magnetizing voltage cuts off, the magnetizing current goes to zero wherein the flux follows the hysteresis loop of the core results in certain residual flux even after de-energization. Later on when the transformer is re-energized by an AC voltage, the flux becomes sinusoidal but biased by the residual flux. The residual flux may be less and goes up to 80-90% of the rated flux, and therefore, it may shift the flux-current trajectories far above the knee-point of the characteristic resulting in both large peak values and heavy distortions of the magnetizing current.

Now with the advent in advanced core types, the magnetizing inrush current during energization lower down and it is very difficult now-a-days to separate the internal faults from magnetizing inrush current. But the typical waveform of the magnetizing inrush current remain same. Only pick magnitude varies. Fig. 2 shows typical magnetizing inrush current for 50 MVA transformer.

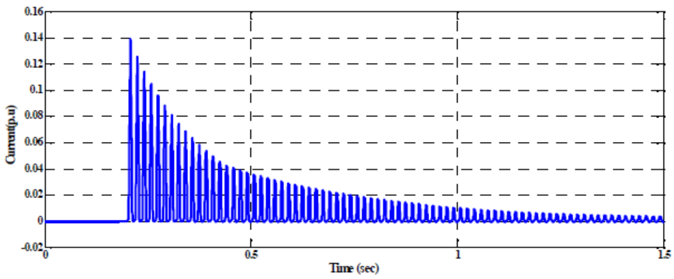

Fig 2. Typical inrush current in 50MVA transformer

3. Different Protection Approaches

In the literature of protection schemes for power transformer, the important issue is differentiating between transformer magnetizing inrush condition and internal fault condition.

Early methods for discrimination were based on deactivating or delaying the relay to compensate the transients [7].These methods are not up to the mark since the transformer may be exposed to fault for longer period. Another method was proposed on the ratio of second harmonic to fundamental which improves the security and dependability of transformer protection [8]. However, in some literatures, existence of a significant amount of second harmonic in some winding faults is reported [9]-[10]. With this, the new generations of power transformers use low-loss amorphous material for construction of core, which have lower second harmonic contents in inrush current [7]&[11], [12].For such cases, use of smaller ratio of second harmonic to fundamental is reported by some authors and have used some other ratio defined at higher frequency [13].While other researchers have proposed fuzzy logic based techniques[9], correlation analysis method[14] wave comparison and error estimation method[15] and principal component analysis[16] to discriminate magnetizing inrush current from internal faults.

Power flow can also be used as basis to detect inrush current in transformer [17]. However, all the preceding approaches depend on a single basis and therefore to designate a proper threshold for differentiation is very difficult. Recently, wavelet transform have been applied for analyzing power system transients [18], power quality [19] and fault detection problems [20]. Wavelet transform can extract raw data transients both in frequency and time domain. Wavelet feature extraction based methods have been used by many of the earlier researchers to discriminate between an internal fault and an inrush current [21]-[30].Wavelet transform is used for feature extraction and Support Vector Machine (SVM) is used as a classifier for discrimination [31].Many of the earlier researchers have used Artificial Neural Network (ANN) or another type of ANN model like Probabilistic Neural Network(PNN) to discriminate between internal fault and inrush current [32]-[34]. In [35], discrimination is done based on Clark's transform and fuzzy systems. In [36][37], PSO trained ANN based differential protection scheme for power transformers is suggested.

3.1 Harmonics Restrain Method

It is most commonly used approaches for protecting power transformers. It is a classical way to protect transformer. Further modification were incorporated in this method.

It is assumed that the magnetizing current have high amount of second harmonics. The easiest of harmonic restrain method compares the magnitude of the second harmonic in the differential current compared to the magnitude of the fundamental frequency component in the differential current. The extraction of the second harmonic components can be achieved using either of these methods like passive filters, Fourier transforms (FT), sine-cosine correlations, rectangular transforms, Haar functions, Walsh functions, Kalman filters, least-square algorithms [38].

In [9] and [10], sine and cosine Fourier coefficients are used to compute the fundamental, second and fifth harmonies. Operation decision can be based on the relative amplitude of the fundamental compared to the combined amplitude of second and fifth harmonics.

While in [11] and [12] Fourier sine and cosine coefficients required for fundamental, second, third and fifth harmonies determination have been calculated using rectangular transfer technique. These harmonics have been used in harmonics restrain and blocking techniques used in differential protection system.

An algorithm depends on the change of negative sequence power to cancel second harmonic restraint is proposed in [13]. The differential protection will operate even if be restrained when the percentage of ratio between the secondary and primary of any phase differential current is larger than the given value if the change of negative sequence power is larger than the setting value.

In [14] the authors use second harmonic for blocking differential relay in power transformers. The ratio of the power spectrum (PS) of second harmonic to the PS of fundamental based on autoregressive processes used for inrush identification.

Estimation algorithms were developed in [15], a combination of Walsh and Fourier series algorithm and Least Squares (LS) algorithm. This technique is an extension of the traditional second harmonic method, which uses the angular relationship between the first and second harmonics of the differential current.

3.2 Voltage and Flux Restraints

Voltage restraint is based on the fact that phase voltages decrease only in the case of an internal fault, not under inrush or external conditions.

Therefore, the relay is restrained from tripping if the phase voltages are above a certain threshold [19]. The algorithm described in [20] uses voltages rather than current harmonics for the restraint function. The authors in [21] suggest the possibilities of using the transformer flux as a restraining quantity. If the flux could be estimated correctly, then it would provide a sound discriminate for external as well as magnetizing inrush conditions. Although the voltage at the transformer terminals shows severe distortions, the flux levels during these periods are high. Consequently, the uncertainties associated with the windows of voltage magnitude for restraining function no longer exist when the flux is used as a restraining quantity.

Authors in [22] present method based on the ratio of voltage and fluxional differential current to overcome flux-restraint limitation. When the transformer has internal faults, the ratio is usually small even to zero in one cycle. While, in magnetizing inrush currents in the transformer, the ratio is very big in one part of one cycle and very small in the other part

3.3 Inductance Based Method

In the internal fault and normal operation states of power transformer, the iron core is not saturated and the magnetizing current is very little, which results in the approximate constant magnetizing inductance owing to the operation in the linear area of the magnetizing characteristic. However, the inrush current is a result of the transformer core saturation.

Furthermore, the iron core will alternate between the saturation and non-saturation during the inrush current, which causes a drastic variation of the magnetizing inductance [23].

In [23], [24], and [25] authors use the equivalent instantaneous inductance (EII) to distinguish between internal fault and magnetizing inrush.

3.4 Pattern Recognition

As protective relaying shifted toward digital and microprocessor implementations, pattern recognition approach have been proposed for power transformer protection. Some techniques to increase reliability, speed and robustness of existing digital relays are reported in recent literature. Those techniques are based on artificial intelligence, wavelet transform and hybrid approach. These developments are discussed in the following section of this paper.

Artificial Intelligence (AI) is a subfield of computer science that investigates how the though and action of human beings can be mimicked by machines. The most widely used and important ones of AI tools, applied in the field of differential power transformer protection are NN and FL.

The application of ANN to discriminate the fault has given a lot of attention recently. Neural networks can be used to discriminate between magnetizing inrush and internal fault currents based on wave shape analysis of current signals. Neural networks are trained using feed forward back propagation algorithm. Many papers are presented in past, only few recent papers are discussed here.

Two approaches to detect inrush current by recognizing its wave shape, more precisely from the wave shape of internal fault current have been proposed in [29]. In the proposed algorithm, the Neural Network Principal Component Analysis (NNPCA) and Radial Basis Function Neural Network (RBFNN) are used as a classifier. The proposed algorithm is used to discriminate between internal faults from inrush and over-excitation condition. The algorithm also makes use of ratio of voltage-to-frequency and amplitude of differential current for detection transformer operating condition. A comparison among the performance of the FFBPNN (Feed Forward Back Propagation Neural Network), NNPCA, RBFNN based classifiers and with the conventional harmonic restraint method based on DFT method is presented in distinguishing between magnetizing inrush and internal fault condition of power transformer. The results confirm that the RBFNN is faster, stable and more reliable.

In [30], authors proposed differential algorithm based on ANN to discriminate between inrush and internal fault current of power transformer. The ANN based method is designed and trained with experimental inrush and fault current data obtained from a laboratory prototype power transformer. Both off-line and on-line test results show that the algorithm is capable of distinguishing between the internal faults and magnetizing inrush currents. Also, the method neither depends on the transformer equivalent circuit model nor the harmonic contents of the differential currents.

A fuzzy logic based differential protective algorithm for power transformers have been presented in [31] and [32]. Fuzzy logic is used for internal fault detection. The protection criteria, criteria signals and their fuzzy settings have been formulated. Algorithm of fault detection is based on ruled out non-internal fault phenomena. For internal fault detection are considered some criteria for inrush current, over excitation, saturation of current transformers and mismatch of current transformers and are defined appropriate membership functions and criteria signals.The criteria have been aggregated and combined with two supporting factors in order to generate more reliable tripping signal.

In [33] fuzzy logic approaches are used, to enhance the fault detection sensitivity of traditional percentage differential current relaying algorithm. Input variables of the proposed fuzzy based relaying are flux differential current derivative curve, second harmonic restraint, and percentage differential characteristic curve. In [34] authors propose an extended magnetizing inrush restraining technique employing a fuzzy-logic based method. This technique uses the angular relationship between the first and second harmonics of the transformer currents as well as the magnitude relation of them. The fuzzy logic approach fits this problem because of the uncertainty involved in the phase and magnitude relationship between fundamental and second harmonics of differential currents.

5. Conclusions

Power transformers play an important role in modern power systems, and their protection is of great importance to assure stable, reliable and secure operation of the whole system. The nature of inrush current has been presented in this paper. Protection approaches used with transformer differential protection to eliminate mal-operation due to magnetizing inrush current during energization, magnetizing inrush current during fault removal and sympathetic inrush current have been presented. Among these techniques are harmonic restraints, voltage and flux restraints, the inductance based method and pattern recognition using artificial intelligence and wavelet transform. As shown in this paper each approach has its advantages and disadvantages. The choice of the protection approach used is mainly depending on the rating of transformer, application and detection time.

REFERENCES

[1] *IEEE Guide for Protecting Power Transformers*, IEEE Power Engineering Society. 30 May, 2008.
[2] Badri Ram, D. N. Vishwakarma: *Power System Protection and Switchgear*. 1 Oct., 1994.
[3] M. A. Rahman: *Advancements in Digital Protection of Power Transformers*. In: Proceedings of International Power and Energy Conference, PECon '06, IEEE, 2006, p. 1 – 6.
[4] Blume L. F.:*Transformer Engineering*. Wiley & Sons, New York,1951.
[5] Karsai K., Kerenyi D. and Kiss L.: *Large Power Transformers*. Elsevier, New York, 1987.
[6] J. F. Witte, F. P. De Cesaro and S. R. Mendis: *Damaging Long-Term Overvoltages on Industrial Capacitor Banks due to Transformer Energization Inrush Currents*. In: IEEE Transactions on Industry Applications, Vol. 30, July – August 1994, p. 1107 – 1115.
[7] P. L. Mao and R. K. Aggarwal: *A Novel Approach to the Classification of the Transient Phenomena in Power Transformer Using Combined Wavelet Transform and Neural Network*. In: IEEE Transactions on Power Delivery, vol.16, Oct.2001, p. 654-660.
[8] Rich Hunt, Joe Schaefer and Bob Bentert: *Practical Experience in Setting Transformer Differential Inrush Restraint*. In: Proceedings of Annual Conference for Protective Relay Engineers, 1-3 April, 2008, p. 118 – 141.
[9] D. B. Fakruddin, K. Parthasarathy, B. W. Hogg and L. Jenkins: *Application of Haar Functions for Transmission Line and Transformer Differential Protection*. In: Electrical Power & Energy Systems, Vol. 6, July 1984, p. 169 – 180.
[10] S. R. Kolla: *Application of Block Pulse Functions for Digital Protection of Power Transformers*. In: IEEE Transactions on Electromagnetic Compatibility, Vol. 31, May 1989, p. 193 196.
[11] R. Bouderbala, H. Bentarzi and A. Ouadi: *Digital Differential Relay Reliability Enhancement of Power Transformer*. In: International Journal of Circuits, Systems and Signal Processing, Vol. 5, 2011, p. 263 - 270.
[12] Raju, K. Ramamohan Reddy, and M.Tech: *Differential Relay Reliability Implement Enhancement of Power Transformer*. In: International Journal of Modern Engineering Research (IJMER), Vol. 2, Sep-Oct, 2012, p. 3612 - 3618.
[13] Kaihua Tian and Pei Liu: *Improved Operation of Differential Protection of Power Transformers for Internal Faults Based on Negative Sequence Power*. In: Proceedings of International Conference on Energy Management and Power Delivery, EMPD '98, 1998, p. 422 – 425.

[14] Hao Zhang, Pei Liu and O.P. Malik: *A New Scheme for Inrush Identification in Transformer Protection*. In: Electric Power Systems Research 63, 2002, p. 81-86.
[15] M. Sanaye-Pasand, M. Zangiabadi and A.R. Fereidunian: *An Extended Magnetizing Inrush Restraint Method Applied to Digital Differential Relays for Transformer Protection*. In: IEEE Power Engineering Society General Meeting, 2003, p. 2077 - 2082.
[16] M.E. Hamedani Golshan, M. Saghaian-nejad, and A. Saha, H. Samet: *A New Method for Recognizing Internal Faults from Inrush Current Conditions in Digital Differential Protection of Power Transformers*. In: Electric Power Systems Research 71, 2004, p. 61- 71.
[17] Adel Aktaibi and M. A. Rahman: *A Software Design Technique for Differential Protection of Power Transformers*. In: International Electric Machines & Drives Conference (IEMDC), IEEE, 2011, p. 1456 – 1461.
[18] S. R. Wagh, Shantanu Kumar and Victor Sreeram: *Extraction of DC component and Harmonic Analysis for Protection of Power Transformer*. In: IEEE 8th Conference on Industrial Electronics and Applications (ICIEA), 2013, p. 32 – 37.
[19] Michel Habib and Miguel A. Marin: *A Comparative Analysis of Digital Relaying Algorithms for the Differential Protection of Three Phase Transformers*. In: IEEE Transactions on Power Systems, Vol. 3, August 1988, p. 1378 - 1384.
[20] J.S. Thorp, A.G. Phadke: *A Microprocessor Based Voltage-Restrained Three-Phase Transformer Differential Relay*. In: Proceedings of the South Eastern Symposium on systems Theory Conference, April 1982, p. 312 -316.
[21] J.S. Thorp, A.G. Phadke: *A New Computer Based, Flux Restrained, Current Differential Relay for Power Transformer Protection*. In: IEEE Transaction on power apparatus and Systems, Vol. PAS-102, November 1983, p. 3624 - 3629.
[22] Xu Yan, Wang Zengping, Liu Qing and Shang Guocai: *A Novel Transformer Protection Method Based on The Ratio of Voltage and Fluxional Differential Current*. In: IEEE Transmission and Distribution Conference and Exposition, 2003, p. 342 – 347.
[23] Ge Baoming, Aníbal T. de Almeida, Zheng Qionglin, and Wang Xiangheng*: An Equivalent Instantaneous Inductance-Based Technique for Discrimination Between Inrush Current and Internal Faults in Power Transformers*. In: IEEE Transaction on Power Delivery, Vol. 20, Oct. 2005, p. 2473-2482. [24] D. Q. Bi, X. H. Wang, W. X. Liang, W. J. Wang: *A Ratio Variation of Equivalent Instantaneous Inductance Based Method to Identify Magnetizing Inrush in Transformers*. In: Proceedings of Eighth International Conference on Electrical Machines and Systems, 29 Sept. 2005, p. 1775 – 1779.
[25] D. Q. Bi, S. S. Li, X. H. Wang and W. J. Wang: *A Novel Double-side Average Equivalent Instantaneous Inductance in Nonsaturation Zone Based TransformerProtection*. In: Proceedings of the International Conf. on Electrical Machines and Systems, Oct. 2008, p. 4364 – 4369.
[26] K. Inagaki, M. Higaki, Y. Matsui, K. Kurita, M. Suzuki, K. Yoshida, and T. Maeda: *Digital Protection Method for Power Transformers Based on An Equivalent Circuit Composed of Inverse Inductance*. In: IEEE Transaction on Power Delivery, Vol. 3, Oct. 1988, p. 1501-1510.
[27] Z. P. Wang, Y.Xu and Q. X Yang: *A Novel Transformer Protection Principle Based on The Change of Inductances*. In: Proceedings of the Eighth IEE International Conference on Developments in Power System Protection, Amsterdam, Netherlands, April 2004, p. 356-359.
[28] H. Abniki, H. Monsef, P. Khajavi, and H. Dashti: *A Novel Inductance-Based Technique for Discrimination of Internal Faults from Magnetizing Inrush Currents in Power Transformers*. In: Modern Electric Power Systems, 2010, p. 1 – 6.
[29] ManojTripathy: *Power Transformer Differential Protection Using Neural Network Principal Component Analysis and Radial Basis Function Neural Network*. In: Simulation Modeling Practice and Theory 18, 2010, p. 600-611.
[30] M.R. Zaman and M.A. Rahman,: *Experimental Testing of The Artificial Neural Network Based Protection of Power Transformers*. In: IEEE Transaction on Power Delivery, Vol. 13, April 1998, p. 510 - 518.
[31] Iman Sepehri Rad, Mostafa Alinezhad, Seyed Esmaeel Naghibi and Mehrdad Ahmadi Kamarposhti: *Detection of Internal Fault in Differential Transformer Protection Based on Fuzzy Method*. In: International Journal of the Physical Sciences, Vol. 6, 30 October 2011, p. 6150-6158.
[32] Myong-Chul Shin, Chul-Won Park and Jong-Hyung Kim: *Fuzzy logic-based Relaying for Large Power Transformer Protection*. In: IEEE Transactions on Power Delivery, Vol. 18, July 2003, p. 718 – 724.
[33] F. Zhalefar and M. Sanaye-Pasand: *A New Fuzzy- Logic-Based Extended Blocking Scheme for Differential Protection of Power Transformers*. In: Electric Power Components and Systems, 2010, p. 675–694.
[34] Daniel Barbosa, Ulisses Chemin Netto, Denis Vinicius Coury and Mário Oleskovicz: *Power Transformer Differential Protection Based on Clarke's Transform and Fuzzy Systems*. In: IEEE Transactions on Power Delivery, Vol. 26, April 2011, p. 1212 - 1220.