Review: Different Techniques for Transformer Inrush Current Protection

Prajakta P. Dhokane[1] Prof. N. V. Jumale[2]
[1]PG Scholar [2]Assistant Professor
[1,2]G. H. Raisoni College of Engineering, Amravati, India

Abstract— Transformer is one among the vital components of electric power system. Transformers are invariably protected by using differential protection. But the differential protection sometime may malfunction thanks to inrush current whenever a transformer is energized. Several methods like per-phase method, cross blocking method, percent average blocking method and Harmonic sharing method are already alive. With the day to day increase of the facility and therefore the increasing rate of industrialization. The quantity of power to be developed and therefore the safety of the facility transformers have increased manifolds. For optimum results it's required to possess nearly a no fault operation of power transformer. The target of this work is to present a controller or method which could predict the unwanted outages during a small interval of your time and with accuracy. The controllers like PI, PID are in use in industries over a decade and located to be very useful also. But during this case these controllers aren't found to offer reliable results thanks to the oscillating and non – periodic nature of the facility transients. This paper is reviewing the various past technologies for transformer inrush current protection. This paper are going to be considerably useful for future researcher and students those curious about field of transformer protection system.

Keywords: Transformer, Electro Magnetic Transient Program (EMTP)

I. Introduction

Power transformers reliability depends upon adequate design, care, erection, proper maintenance and therefore the provision of certain protective equipment. An honest design includes adequate insulation of windings, laminations, core bolts, etc., bracing of conductors against short-circuit stresses. It's important that the faulted transformer be isolated as quickly as possible after the fault has occurred, not only to limit the damage to the transformer, but also to attenuate the length of your time the system voltage is depressed. As a result the operation of transformer protection must be reliable, sensitive, accurate and fast. Fault statistics show that about 12% of total power grid faults are thanks to power transformer failures. The event of recent power systems has been reflected within the advances in transformer design. The differential protection is really considered the most protection of the facility transformer. Discrimination between the interior faults and transformer inrush current must be rapid and accurate in decision. In recent years, many tripping restrain techniques are analyzed for the aim of correct discrimination. The inrush current contains all harmonic orders, but in practice, only the second harmonic is employed. The harmonic restraint methods work on the idea that the magnetizing inrush current contains high levels of second harmonic current [1,2]. The present for an indoor transformer fault typically has very low levels of second order harmonic current. Moreover, it had been found that in certain cases, the second order harmonic generated during internal faults in transformers is comparatively large and a few inrush events initially produce low levels of second harmonic within the differential current, which impairs the power of this type of the criterion [3]. Consequently, the commonly used conventional differential protection technique supported the second harmonic restraint will thus have difficulty in distinguishing between internal fault currents and inrush currents.

II. Different Technology for Transformer Inrush Current Protection

A new technique for transformer protection was proposed [1]. The technique was concerned with the detection of the fault generated high frequency current transients by means of a specially designed relay unit. The relay, tuned to a band of high frequencies, was wont to capture the transient currents from each side of the transformer; the differential and average currents between the two sides were then calculated. The spectral energies of those current signals were extracted to supply the operate and restraint signals; a comparison between the amount of the two signals determines whether the fault was internal or external to the protected zone. The technique detects inrush current by using the high frequency components contained in its current transient signal. The restraint signal was derived by computing the ratio of the spectral energy of the transient signal to the elemental current. A comparison between the extent of restraint signal and a pre-defined threshold determines whether a magnetizing inrush was in process.

A typical high voltage power transformer connected to a cable system was simulated by using the EMTP software which incorporates an embodiment of the high frequency modeling of the transformer. Results show that the proposed technique wasn't only ready to give in no time and proper responses to different fault conditions, but was also ready to detect transformer internal low level and inter-turn faults. Results also show that the proposed technique for inrush detection was ready to give in no time response and accurately distinguish between a current inrush and an indoor fault.

Transformer inrush currents were high-magnitude, harmonic-rich currents generated when transformer cores were driven into saturation during energization. These currents have undesirable effects, including potential damage or loss-of-life to the transformer, protective relay mis-operation, and reduced power quality on the system. Controlled transformer switching can potentially eliminate these transients if residual core and core flux transients were taken under consideration within the closing algorithm [2].

Rapid closing strategy closes one phase first and therefore the remaining two phases within 1 / 4 cycle. It requires knowledge of the residual flux altogether three phases, independent pole breaker control, and a model of the transformers transient performance (no studies were run to match transient performance of various transformer designs to work out error from assuming a typical model).

Delayed closing strategy closes one phase first and therefore the remaining two phases after 2–3 cycles. It requires knowledge of the residual flux in one phase only, independent pole breaker control, but doesn't require any transformer parametric data.

Simultaneous closing strategy closes all three phases together at an optimum point for the residual flux pattern. It doesn't require independent pole breaker control, but requires knowledge of the residual flux altogether three phases which the residual flux magnitudes in two phases were high and follow the foremost traditional residual flux pattern.

A new algorithm supported processing differential current harmonics was proposed for digital differential protection of power transformers [3]. This algorithm has been developed by considering different behaviors of second harmonic components of the differential currents under fault and inrush current conditions. Within the new method, a criterion function was defined in terms of time variation of second harmonic of differential current. By evaluating the sign of the criterion function for the three phases, the interior faults are often accurately recognized from inrush current conditions about half cycle after the occurrence of disturbance; this was one advantage of the tactic. Another advantage of the proposed method was that the fault detection algorithm doesn't depend upon the choice of thresholds.

Internal fault conditions are often detected by evaluating signs of criterion functions of the three phases. Additionally to acceptable accuracy, the proposed method was so fast for fault detection that it can recognize fault conditions from inrush current conditions about half cycle after the occurrence of disturbance. The proposed fault detection algorithm doesn't require choosing any coefficients or threshold values. This was another advantage of the tactic.

A wavelet based scheme, for distinguishing between transformer inrush currents and power grid fault currents was proposed [4], which proved to supply a reliable, fast, and computationally efficient tool. The operating time of the scheme was but half the facility frequency cycle (based on a 5-kHz sampling rate). During this work, a wavelet transform concept was presented. Feature extraction and method of discrimination between transformer inrush and fault currents was derived. A 132/11-kV transformer connected to a 132-kV power grid were simulated using the EMTP. The proposed scheme proved to be reliable, accurate, and fast.

The application of WT reveals that every waveform has distinct features. Using features within the waveform signature, automated recognition are often accomplished. The utilization of WTs as a feature extraction naturally emphasizes the difference between fault and inrush currents as generated by the EMTP, since their frequencies were very different. This paper demonstrates that the algorithm successfully differentiates between magnetizing inrush and fault conditions in but half power frequency cycle.

The classification scheme was powerful yet the specified calculations were simple (10 multiplications and 10 additions each sampling interval) which data window required for the algorithm was but half the facility frequency cycle (40 samples supported 5 kHz sampling rate). It can actually be implemented in real time.

Inrush currents in transformers were non-sinusoidal, high magnitude currents generated to flux saturation within the core during energization. For cover purpose, an efficient method for detection of inrush current in distribution transformer supported wavelet transform was presented [5]. Using this method inrush current are often discriminated from the opposite switching transients such as: load switching, capacitor switching and single phase to ground fault. Inrush current and other events for feature extraction and discrimination were simulated using Electro Magnetic Transient Program (EMTP).

The proposed technique was supported the decomposition of three phase currents recorded at the HV/MV substation using WT with symmlet_1 as mother wavelet and therefore the summation of absolutely the of d6 coefficients was used for the discrimination of inrush current from other usual transients in distribution systems such as: ground fault, load switching and capacitor switching.

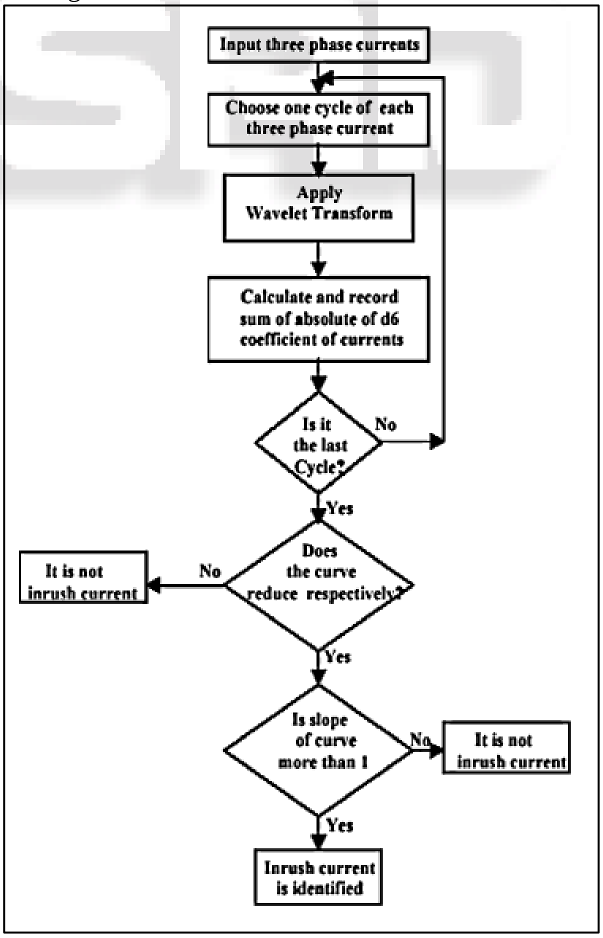

Fig. 1: Flow chart of proposed wavelet transform based approach [5]

The effect of adjusting the rate in data gathering process for locating its optimal value for inrush current identification using proposed method with tests in real networks was under study.

A new algorithm supported processing differential current was proposed for digital differential protection of power transformers by considering different behaviors of the differential currents under fault and inrush current conditions [6]. During this method, a criterion function was defined in terms of difference of amplitude of wavelet coefficients over a selected wave band. The criterion function was then used for 3 phases, and internal faults were precisely discriminated from inrush current but 1 / 4 a cycle after the disturbance; this was one advantage of the tactic. Another advantage of the proposed method was that the fault detection algorithm doesn't depend upon the choice of thresholds.

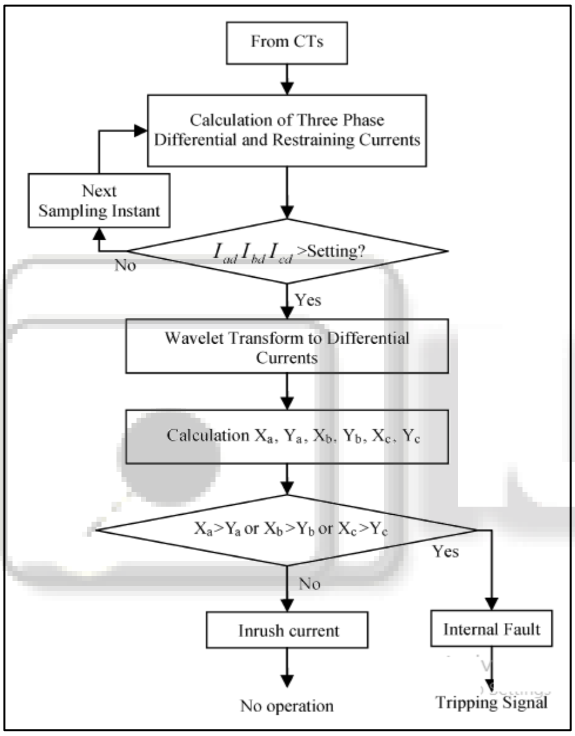

Fig. 2: Flowchart of the wavelet based algorithm

This method was supported the various behaviors of differential currents. A criterion function was defined using the difference of the amplitude of the WT over a specific frequency spectrum thanks to a fault and inrush current, internal fault conditions are often detected by evaluation of the criterion functions of the three phases. Additionally to acceptable accuracy, the proposed method can discriminate fault from inrush current quickly, but 1 / 4 a cycle after the disturbance.

The proposed algorithm doesn't require choosing any coefficient or threshold values. This was another advantage of the tactic. the power of the new method was demonstrated by simulating various cases on a typical power grid and therefore the proposed algorithm was also tested offline using data collected from a prototype laboratory three-phase power transformer. The test results show that the proposed algorithm was also quick and accurate.

It was documented that differential protection was best suited for transformer protection. However, inrush current thanks to transformer energization can appear as fault to the protective relay. To enhance the safety while maintaining the specified levels of sensitivity, many restraint methods are proposed to inhibit operation of the differential element. The magnetizing inrush current during transformer energization with a simplified excitation curve was analyzed [7]. It derives mathematical equations to compute the inrush current supported the residual flux and saturation flux for the worst case energization event.

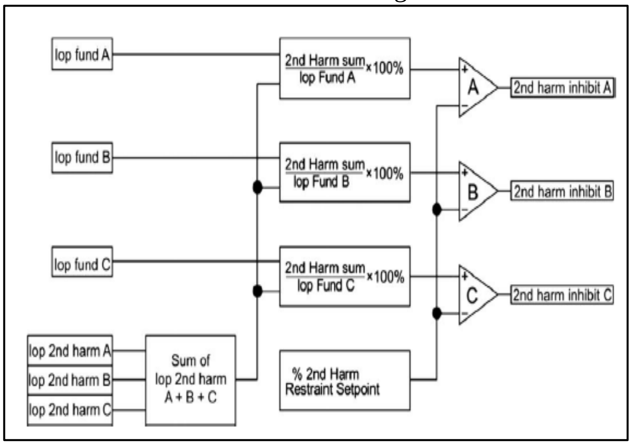

Fig. 3: Restraint method with summing-type harmonic sharing [7]

Inrush current occurs mostly in just one side of the transformer and will cause a false differential trip. A standard restraint method was to use the second harmonic information within the inrush current to secure differential protection when energizing transformers.

An analysis of things like residual flux, saturation flux, and energizing angle on the second harmonic ratio in inrush current has been provided during this technique [7]. Higher residual flux and/or lower saturation flux in transformers may end in higher differential operating current and a lower second harmonic ratio, which was likely to cause a security concern in differential protection during transformer energization. The restraint with summing-type harmonic sharing provides excellent dependability while maintaining the safety for differential protection.

A new methodology for distinguish between inrush currents and internal faults supported the differential current gradient was presented [8]. The scheme was supported calculating the differential current gradient vector angles in phases A-B-C in the least points of the info window. Using statistical calculations, the inrush current was then identified, because its gradient vector behavior are going to be different within the case of a brief circuit occurrence.

The proposed algorithms performance has been evaluated simulating several cases of transformer energization under normal conditions and within the presence of internal faults. The foremost challenge within the methods implementation lies in choosing the most appropriate value for the activation threshold for every power grid. Fine adjustments around 3◦ to 5◦ have demonstrated satisfactory results. The proposed methods have shown that, when properly adjusted, they will correctly identify the various situations of inrush of inrush currents, also as occurrences of internal and external faults, specially using the Gradient µ method which presented better results.

A new technique for blocking the operation of the transformer differential relay when subjected to magnetizing inrush current was presented [9]. The relay differential and restraint currents were calculated first, and therefore the fundamental-frequency components of the two currents were then compared to spot the phase difference (PAD) between the corresponding transformer primary and secondary currents. Distinguishing the magnetizing inrush current from an indoor fault current was accomplished by the presence of quite 90◦phase shift between the two currents during internal faults, and therefore the absence of this within the case of magnetizing inrush and unfaulted transformer currents. This system was investigated using an EMTP-RV simulation based model of a typical 3-phase 2-winding power transformer embedded during a power grid fed from both ends.

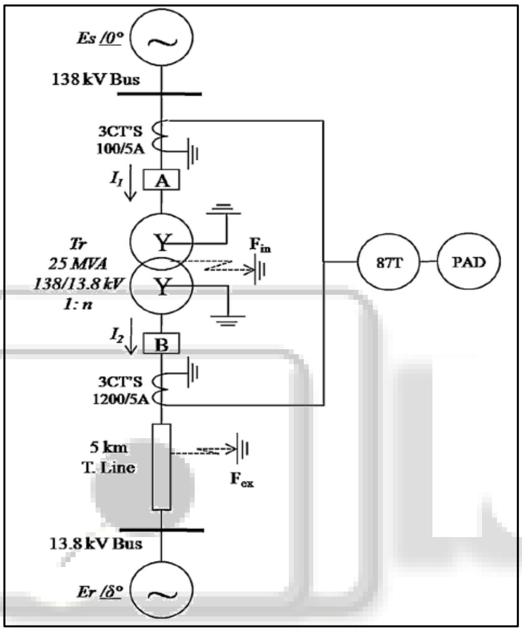

Fig. 4: Power system with percentage differential relay and PAD scheme [9]

The technique, comprising a percentage differential relay supervised by a PAD scheme, uses the phase shift between the 60 Hz components of the respective line currents as a restraint signal to stop differential relay from mal-operation on magnetizing inrush current. The PAD calculations were conducted using an amplitude comparator with inputs of the difference and therefore the sum of the road currents and an output indicates the phase relative to a threshold value 90◦. If the phase was greater than the edge value, it implies that the facility transformer experiences an indoor fault and, hence, a visit signal from the PAD was generated to release the differential relay for switching-off the facility transformer. Otherwise, the transformer was assumed unfaulted and it should stay in commission. A typical 3-phase core-type power was analyzed. The simulation results show that the mixing of the phase shift between the 60 Hz components of the respective line currents has substantially improved the reliability of the differential relay. Discriminating internal fault currents from other disturbances in power transformers was efficiently performed within at the most one cycle of the facility system frequency. The performance was largely independent of harmonic contents within the differential current, transformer parameters and adversely effect of CT saturation. The implementation of the PAD scheme doesn't require complex computation and may be easily incorporated into existing digital differential relays.

Due to increase in penetration of Distributed Generations (DGs) in power systems, fault current level was being increased, which ends up in some problems within the systems. Fault Current Limiters (FCLs) were attractive devices to tackle these problems for transmission and distribution systems [10]. The utilized FCLs may have considerable impact on the signals used for differential protection of power transformers, which results in mal-operation of those protections. It seems a comprehensive analysis was necessary for performance evaluation of differential protection algorithms in presence of FCLs.

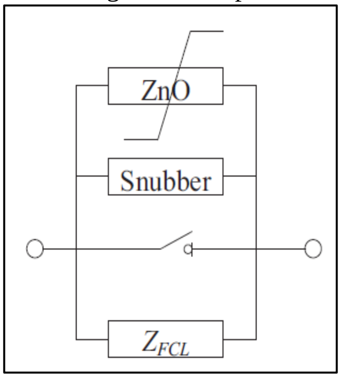

Fig. 5: Configuration of fault current limiter

Differential protection was the foremost common sort of protection in power transformers. However, inrush current thanks to transformer energization may appear as fault current to the protective relay, causing a false trip of the transformer. Therefore, discrimination of the transformer inrush current from internal faults was necessary for improving the safety of the protection scheme.

A new method for discrimination of the transformer inrush current from internal fault current was proposed [11]. First, nonlinear state-space model of a true single-phase transformer was derived, which includes the nonlinear phenomena of hysteresis and magnetic saturation. Supported the derived model, an Extended Kalman Filter (EKF) was used for estimation of the primary winding current. A residual signal was defined because the difference between the measured and estimated currents. When a healthy transformer was energized, the EKF perfectly estimates the primary winding current and hence, the residual signal was almost zero. However, when the transformer was faulty, the EKF cannot effectively estimate the present thanks to the prevailing large model mismatches. Consequently, an outsized residual signal was created. The superiorities of the proposed algorithm were demonstrated using different experimental scenarios.

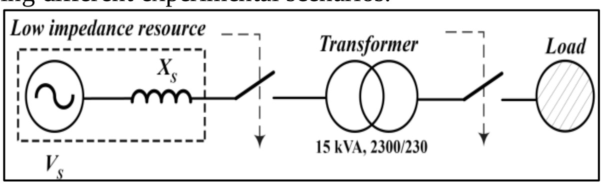

Fig. 6: Experimental setup for evaluation of the proposed algorithm [11]

The nonlinear state-space equations of the transformer were derived. Subsequently, an EKF estimator was developed for estimation of the present within the HV winding. When the transformer was healthy, the EKF-based estimator precisely estimates the HV current. However, when the transformer was at faulty condition, the EKF shows poor performance thanks to the massive model mismatches. Therefore, the difference between the estimated and measured HV currents was wont to distinguish the inrush currents from internal faults. Moreover, the covariance matrix of the estimation error presents valuable information about the severity of the fault within the transformer. So as to avoid the CT saturation problem, the HV current was compensated employing a CT saturation compensation algorithm. The proposed method was tested in several cases using experimental data. The presented results confirm that the proposed method was ready to discriminate the inrush current from internal faults in but 1 / 4 of cycle.

Transformer inrush currents during energization end in mal operation of transformer differential protection, thanks to the flow of magnetizing current only on the first / source side of the transformer. An easy approach in recognition of inrush currents was proposed here by checking the core explanation for this inrush phenomenon i.e. the magnetic saturation of the transformer core. During this method, the pseudo characteristics were approximated in terms of orthogonal polynomials, and was wont to distinguish between inrush currents and fault currents. During this method, the magnetic saturation characteristics of the transformer was modeled by defining pseudo characteristics, and was obtained over a half cycle data window of the differential current.

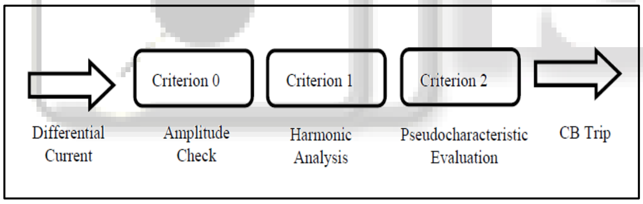

Fig. 7: Inrush blocking scheme for transformer [12]

The method identified inrush currents by detecting the magnetic saturation, rather than trying to find the indications of inrush current. During this method, the magnetic pseudo characteristic, which was just like the iron core magnetic characteristics, was extracted directly from the differential current data, and then was measured against certain criteria to detect saturation of the iron core, thus identifying inrush current.

Transformer inrush currents during energization end in mal-operation of transformer differential protection, thanks to the flow of magnetizing current only on the first or the source side of the transformer. Presence of dead angles i.e. dead period in magnetizing inrush was one among the classic characteristics of inrush current, leading to an asymmetric peaky non-sinusoidal waveform. A way of identifying this distortion in waveform employing a mathematical morphological scheme was presented, which was a sign and image processing technique. The weighted mathematical morphological (WMM) gradient operator was applied to the present signal and waveform correlation analysis are performed on the resultant waveforms. This data was assessed using certain criteria to detect inrush and fault currents.

Validation of the performance of the proposed algorithm was wiped out two stages: MATLAB simulation and comparative analysis with a typical relay. Comparison between the signaling timings of a standard transformer differential protection relay and proposed methodology was investigated.

The investigational results confirm that this proposed method can detect inrush currents using just a half cycle data window. The performance evaluation of the algorithm confirms its precise operation and emphasizes the mal-operation of the harmonic restraint based conventional relay. Thus, this inrush blocking scheme improves on the prevailing method for transformer differential protection in terms of accuracy, reduced computational burden, improved restraint consistency and faster detection times.

III. Conclusion

The power transformers are very well protected being one of the vital components of providing reliable power supply. However, some phenomena can compel the differential protection to fail, which is used for the protection of the power transformer. Magnetizing inrush is one such phenomenon.

This paper is present the past different technologies for transformer inrush current protection and distinguish the fault current. In this paper, Wavelet transform approach, Summing type harmonics harmonic sharing, percentage differential relay, fault current limiter, EKF estimator and inrush blocking scheme are presented. This paper are going to be considerably useful for future researcher and students those curious about field of transformer protection system.

References

[1] Bo, Zhiqian, Geoff Weller, and Tom Lomas. "A new technique for transformer protection based on transient detection." IEEE transactions on Power Delivery 15.3 (2000): 870-875.

[2] Brunke, John H., and Klaus J. Frohlich. "Elimination of transformer inrush currents by controlled switching. I. Theoretical considerations." IEEE Transactions on power delivery 16.2 (2001): 276-280.

[3] Golshan, ME Hamedani, et al. "A new method for recognizing internal faults from inrush current conditions in digital differential protection of power transformers." Electric Power Systems Research 71.1 (2004): 61-71.

[4] Youssef, Omar AS. "A wavelet-based technique for discrimination between faults and magnetizing inrush currents in transformers." IEEE Transactions on Power Delivery 18.1 (2003): 170-176.

[5] Sedighi, A-R., and M-R. Haghifam. "Detection of inrush current in distribution transformer using wavelet transform." International Journal of Electrical Power & Energy Systems 27.5-6 (2005): 361-370.

[6] Faiz, Jawad, and S. Lotfi-Fard. "A novel wavelet-based algorithm for discrimination of internal faults from magnetizing inrush currents in power

transformers." IEEE Transactions on power delivery 21.4 (2006): 1989-1996.
[7] Hamilton, Randy. "Analysis of transformer inrush current and comparison of harmonic restraint methods in transformer protection." IEEE Transactions on Industry Applications 49.4 (2013): 1890-1899.
[8] Alencar, Raidson Jenner Negreiros, Ubiratan Holanda Bezerra, and André Maurício Damasceno Ferreira. "A method to identify inrush currents in power transformers protection based on the differential current gradient." Electric Power Systems Research 111 (2014): 78-84.
[9] Hosny, Ahmed, and Vijay K. Sood. "Transformer differential protection with phase angle difference based inrush restraint." Electric power systems research 115 (2014): 57-64.
[10] Sahebi, Ali, Haidar Samet, and Teymoor Ghanbari. "Evaluation of power transformer inrush currents and internal faults discrimination methods in presence of fault current limiter." Renewable and Sustainable Energy Reviews 68 (2017): 102-112.
[11] Naseri, Farshid, et al. "Fast discrimination of transformer magnetizing current from internal faults: An extended Kalman filter-based approach." IEEE Transactions on Power Delivery 33.1 (2017): 110-118.
[12] Saravanan, Balamurugan, and A. Rathinam. "Inrush blocking scheme in transformer differential protection." Energy Procedia 117 (2017): 1165-1171.
[13] Balamurugan, Saravanan, and A. Rathinam. "Mathematical morphology based inrush blocking scheme in transformer protection." 2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe). IEEE, 2017.