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Modeling Of Power Transformer for Differential Protection Using PSCAD

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ABSTRACT—The differential protection of power transformer is a unit protection scheme. The protective scheme for power transformer should operate only for the internal fault, and it must be insensitive for any fault outside the zone of protection. That means the protection scheme should not operate for any external through fault and the magnetizing inrush current due to energization of the transformer under no load condition and also due to external fault removal. Transformer inrush currents are high-magnitude, harmonic-rich currents generated when transformer cores are driven into saturation during energization. These currents have undesirable effects, including potential damage or loss-of-life to the transformer, protective relay mal-operation and reduced power quality on the system. In power transformer differential protection second and fifth harmonics are analyzed using Fast Fourier Transform (FFT) technique to provide the dual slope differential relay operating chartrictics. The relay logic and the algorithm that uses fast fourier transform for extraction of fundamental and higher harmonics components of differential current which are used to block the Inrush current. The simulations were performed using PSCAD Simulation software. The proposed systems can be used to test new transformer differential protection algorithms and the actual differential relays available on the market.

KEYWORDS— Differential protection of power transformers, Magnetizing inrush current, Fast Fourier Transform, harmonics, PSCAD software

I. INTRODUCTION

The basic operating principle of differential protection is to calculate the difference between the current entering and leaving the protected zone. There is a phenomenon that occurred during removal of external through fault or due to energization of the transformer under no load condition named magnetizing inrush current. The differential protection scheme should remain insensitive for such magnetizing inrush current. The differential relay should not operate for the external/through fault. The protective scheme should operate only for the internal fault, and it must be insensitive for any fault outside the zone of protection. The protection operates when the differential current exceed the set bias threshold value. For external faults, the differential current should be zero, but error caused by the CT saturation and CT ration error leads to non-zero value. To prevent maloperation the operating threshold is raised by increasing the relay setting. Maloperation of the differential protection of power transformer may occur due to Magnetizing inrush current, CT saturation and Through Fault Inrush. Among all these three; magnetizing inrush results during excitation of Transformer under no load condition. It can also come in to picture during the energization of parallel connected power transformer. For this setting of four relay parameter is very important.

IS1: The basic differential current setting
K1: The lower percentage bias setting
IS2: The bias current threshold setting
K2: The higher percentage bias setting

The tripping criteria can be formulated as:

Case 1

$$I_{bias} < I_{s2} \quad (1)$$
$$I_{diff} > K1 * I_{bias} + I_{s1} \text{ THEN TRIP}$$

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Case 2

$$I\ bias >= Is2 \qquad (2)$$
$$Idiff > K2 * I\ bias - (K2 - K1) * Is2 + Is1 \text{ THEN TRIP}$$

Fast Fourier Transform technique is used for preventing the maloperation. The secondary current signals from the CTs are sampled at a regular interval. This is an online Fast Fourier Transform (FFT), which can determine the harmonic magnitude and phase of the input signal as a function of time. The input signals first sampled before they are decomposed into harmonic constituents.Using the FFT technique to block the 2nd and 5th harmonics of the diffrential current to avoid mal-operation of diffrential relay due to inrush current.

II. MODELED SCHEMES FOR TESTING THE TRANSFORMER DIFFERENTIAL PROTECTION ALGORITHMS

In [1] thesis there are presented the descriptions of simulation systems projects containing transformers and modeled differential relays for their protection. These projects, made in the PSCAD software, reproduce the power transformers with different vector groups and rated powers, lines (as PI-type two-terminal-pair networks), power source and the load on higher-voltage sides. For the modeled systems there are possibilities of switches control in both a manual and automatic (by simulating differential relay) way.

In addition, depending on the transformer vector group and its rated power, there have been used proper algorithms for appropriate operation of modeled transformer differential protection in simulation projects. The signals injected to the differential relay may be brought from actual or ideal current transformers (depending on the requirements)

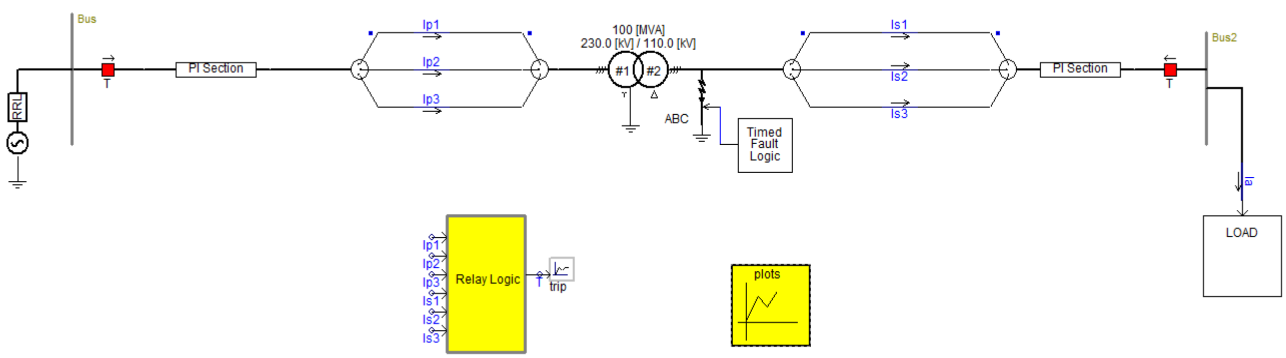

Fig. 1.Transformer differential protection system

Fig.1 shows the transformer differential protection system. The system containing two buses bus1 is connected to source and bus2 is connected to load and the transformer is connected between the buses. Breaker B1 and B2 connected both sides of transformer, during internal faults the relay should trip the breakers.Ip1,Ip2, Ip3 and Is1 Is2, Is3 are the transformer primary and secondary line currents. This currents are input signal of the relay logic block the output of relay logic block is trip signal that signal used to trip the breaker.

In addition to the elements shown in the figure 1, in the simulation project there are blocks which contain the following elements:

- elements of modeled differential relay,

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- diagrams of analog signals (currents and voltages on higher- and lower-voltage sides of the transformer and signals made available in the transformer model) and binary signals (states of switches),
- elements related to the control (choice of location and type of fault, breakers control, control of saving the analog variables waveforms to COMTRADE-format file.

In all the modeled systems with transformers it is possible to visualize all the courses of currents and voltages on the higher and lower-voltage sides and in the fault point. The observed voltage and current time-courses at relaying points, on the secondary side of current and voltage transformers, can be saved as the COMTRADE format.

As a result this time- courses can be retraced by microprocessor testers, and thus be used to test the real differential relays (functional performance tests [4]).Additionally, there is a possibility in modeled systems to observe variation of differential current (I_{diff}) as a function of stabilized current (I_{bias}) for the A, B, C phases, occurring during disturbances, with respect to the beginning characteristics I_{diff} = f(I_{bias}) for modeled differential protections.With the modeled test schemes can be checked (within the functional performance tests) the operation correctness of the differential protection functions in case of:

- internal and external single and multi-phase faults, with current transformers saturation absence and for various pre-load of transformer (the impact of the appearance of non-periodic current component in fault current),
- metallic and resistive internal faults,various level of saturation of the CTs (on one or both sides of the transformer) and various pre-load of transformer, in the case of external faults (whether there is no unnecessary pick-up of differential function),
- external single-phase faults on the transformer side of a grounded star-point (whether there is no unnecessary pick- up of differential function, and thus the differential function correctly eliminates the zero-sequence component of the current)
- switching on (energizing) the unloaded transformer (whether there is no unnecessary pick-up of differential function during the inrush of magnetizing current and appearance of a high content of 2nd harmonic in differential current),
- transformer over-fluxing (whether there is no unnecessary pick-up of differential function due to the large rise of supply voltage and the emergence of a high content of 5th harmonic in the differential current).

III. A SCHEME OF MODELED TRANSFORMER DIFFERENTIAL PROTECTION

The protection modeling process has been focused on protection operation logic, not on digital signal processing in order to computing the 1st, 2nd and 5th harmonics of phase currents. For the calculation of particular harmonics of phase currents (phasors), the *On-Line Frequency Scanner* module (from PSCAD/EMTDC *Master Library*, [3]) has been used. The description of direct calculation method for measurement signals (current phasors), without using the *On-Line Frequency Scanner* module, may be found in [2]. Fig. 1 shows the location of differential relay model in the simulation project. Example of implementation in PSCAD software of the modelled relay. To build a simulation model of differential relay, there were used ready-to-use modules from PSCAD *Master Library* such as:

- logic gates, timers, summing/difference junctions, multipliers, dividers,
- module which can determine the harmonic magnitude and phase of the input signal as a function of time (*On-Line Frequency Scanner*),
- modules from the *Relays* (*Dual Slope Current Differential Relay*, *Over current detection block*).

Algorithms of elements for elimination of the zero-sequence current and for vector group adaptation, was written using a programming language Fortran.The modeled relay consists of (Fig. 3):

- the amplitude adjustment of the lower- (LV) and higher- voltage (HV) power transformer side.
- systems to eliminate zero-sequence current symmetrical component on the higher-voltage transformer side (grounded transformer windings connected in star): mathematically or using current from the transformer star point.
- adaptation to vector group made on the lower-voltage transformer side.
- transformation of instantaneous current values (the upper- and lower-voltage transformer sides) to a phasor (amplitude and phase separation) for harmonic 1st, 2nd and 5th.

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- calculation of the differential currents (I_{diff}) and stabilized currents (I_{bias}) for the 1st harmonic currents of phases A, B, C, and checking the performance criteria for each phase, i.e., whether the point of the calculated currents I_{diff} and I_{bias} are above the operating characteristics $I_{diff} = f(I_{bias})$ of the relay.
- calculation of the differential currents (I_{diff}) for 2nd and 5th harmonic currents of phases A, B, C, and checking the performance criteria for each phase, i.e. whether the differential currents calculated 2nd and 5th harmonic with respect to the corresponding differential currents 1st harmonic exceeds the set threshold.
- checking whether the current differential 1st harmonics for each phase exceeds the set threshold, i.e. checking the performance criteria of non-stabilized differential relay function.
- checking the performance criteria of the stabilized differential function for at least one of the three phases (calculated diffrential first harmonic current are in the area of operation for stablized characteristics of relay, the content of the 2nd and 5th harmonic does not exceed the threshold values), and the verification of the performance criteria for the non-stabilized differential at least one of the three phases and sending an impulse to open breakers signal (signal T) on the higher- and lower-voltage transformer side .

From the Fig. 2. the transformer primary (Ip1, Ip2, Ip3) and secondary (Is1 Is2, Is3) currents are giving to CT's. From the CT's secondary side currents are given to FFT. And also (Fig. 2.) shows the fundamental and harmonic extraction logic of the transformer CT's secondary currents. Calculation of the differential currents (Idiff) and stabilized currents (Ibias) for the 1st harmonic currents of phases A, B, C, and checking the performance criteria for each phase, i.e., whether the point of the calculated currents Idiff and Ibias are above the operating characteristics Idiff = f(Ibias) of the relay (Fig. 3.), calculation of the differential currents (Idiff) for 2nd and 5th harmonic currents of phases A, B, C, and checking the performance criteria for each phase, i.e. whether the differential currents calculated 2nd and 5th harmonic with respect to the corresponding differential currents 1st harmonic exceeds the set threshold Checking whether the current differential 1st harmonics for each phase exceeds the set threshold, i.e. checking the performance criteria of non-stabilized differential relay function (Fig. 4.).

From fig 5 brk1, brk2, brk3, a1, a2, a3, b1, b2, b3, c1 ,c2 ,c3 denotes the output signals from the relay(Fig. 3.) and the signal values are 0 and 1 is given to AND gate. (Fig. 4.) checking the performance criteria of the stabilized differential function for at least one of the three phases (calculated differential 1st harmonic currents are in the area of operation for stabilized characteristics of relay, the content of the 2nd and 5th harmonic does not exceed the threshold values), and the verification of the performance criteria for the non-stabilized differential at least one of the three phases and sending an impulse to open breakers. Breaker operation is considering 0 and 1.Figure 5 shows the value 1 denoted the breaker is ON position and 0 denoted the breaker closed position. When trip signal given from the relay. Instantaneously breaker open position 1 and after the fault clear suddenly breaker closed 0.

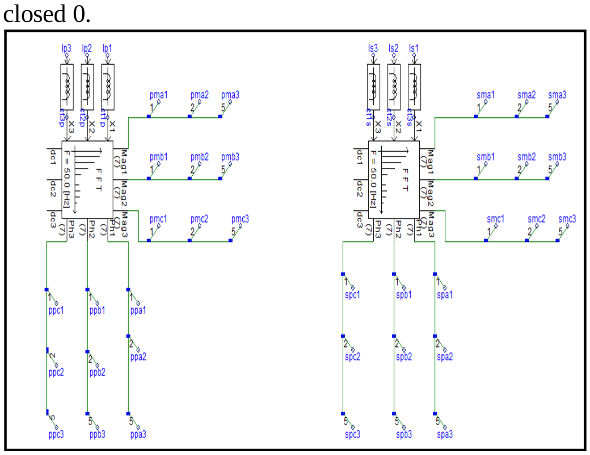

Fig. 2. Harmonic extraction using FFT

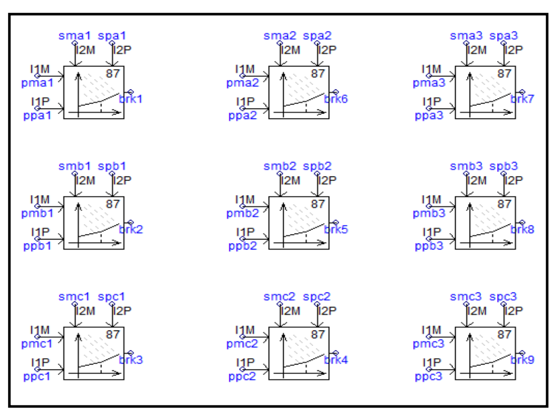

Fig. 3. dual slope diffrential relay

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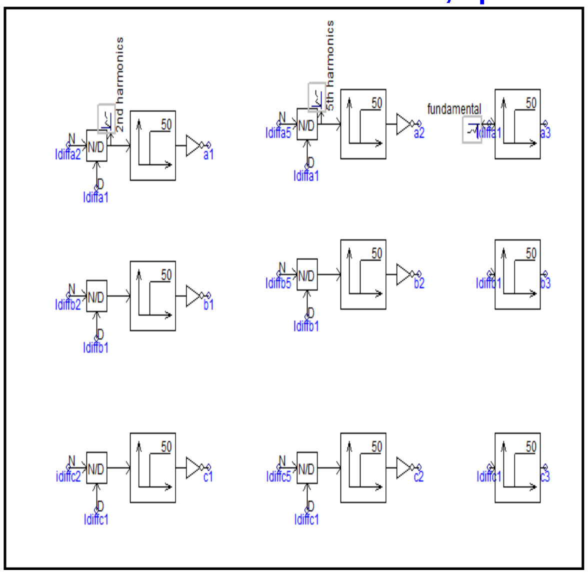

Fig. 4. over current detection block

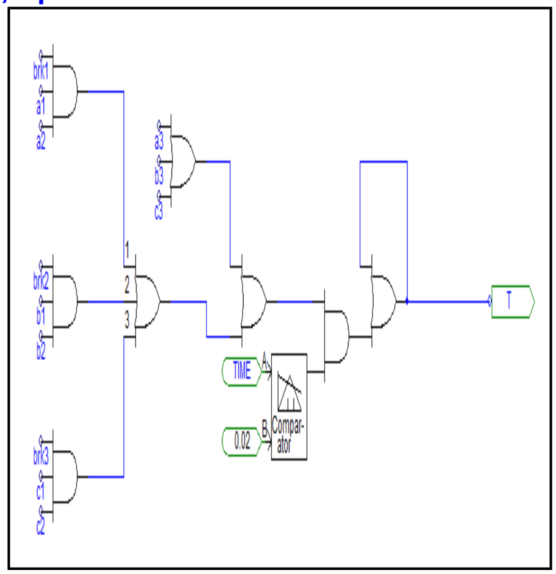

Fig. 5. Breaker trip logic

IV. EXAMPLE RESULTS OF FUNCTIONAL PERFORMANCE TESTS FOR MODELED DIFFERENTIAL PROTECTION

A. Short Circuit,A- B-C Metallic Type (Internal on HV Transformer Side)

This section presents selected results of disturbance simulations for modeled test schemes. The research, described in greater detail in [1], have been aimed to monitor and analyze the signals that occur during chosen disturbances related to transformers and to verify the operation of modeled transformer differential protection.

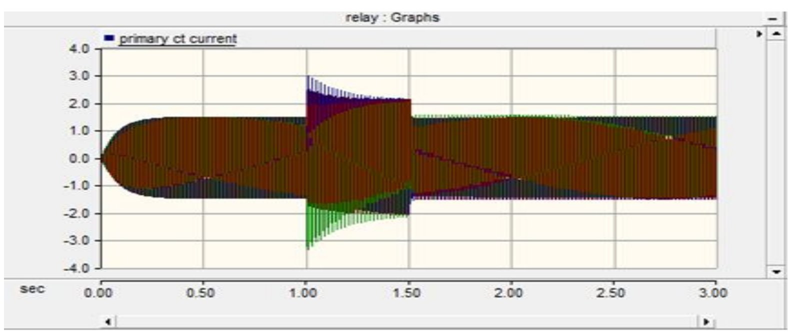

Fig. 6. Primary side CT saturation current during phase A-B-C internal fault condition

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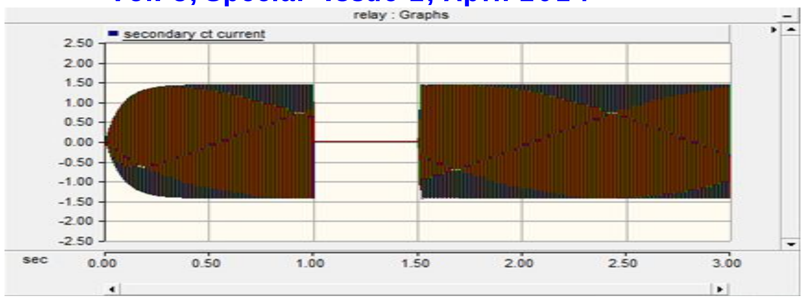

Fig. 7. Secondary side CT saturation current during phase A-B-C internal fault condition

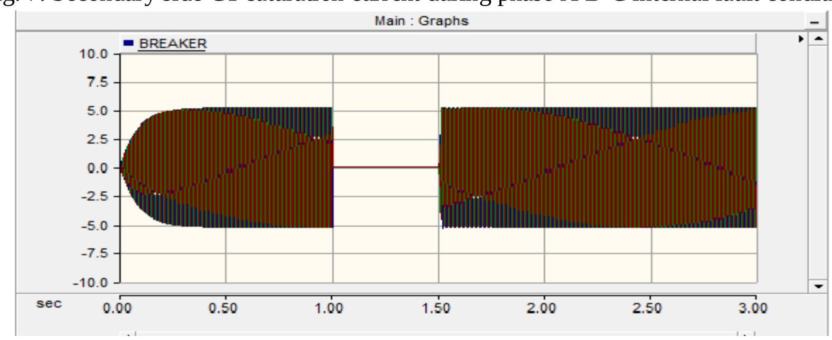

Fig. 8. Breaker current during phase A-B-C internal fault condition

During fault condition the relay gives trip signal to the breaker at the instant the breaker should be opened current flowing through the breaker is zero.After clearing the fault the breaker becomes closed. (fault occurred at 1.0 sec, duration of fault 0.5 sec).

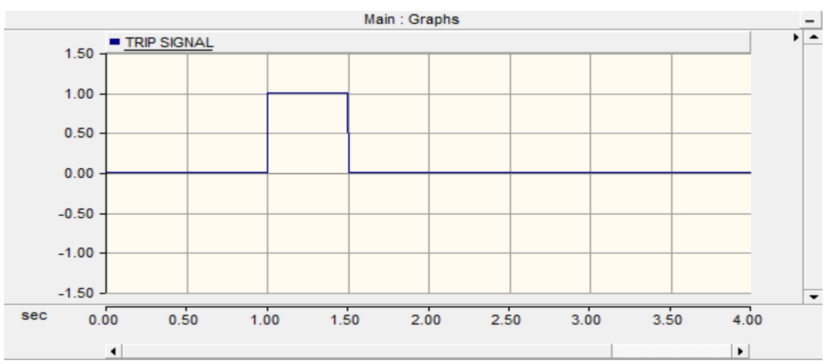

Fig. 9. The relay gives trip signal to the breaker

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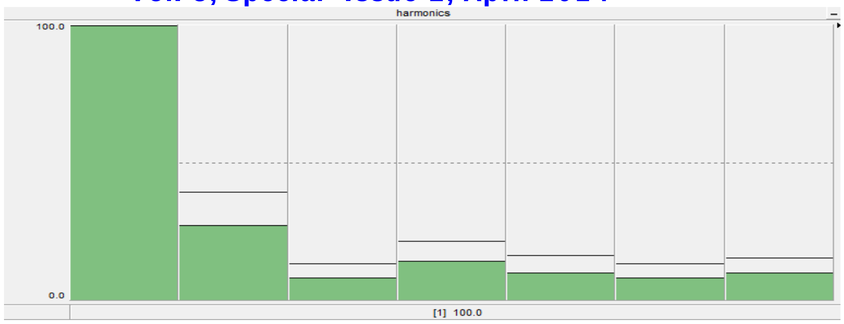

Fig. 10. Under normal conditon THD in percentage

B. switching ON the un loaded transformer

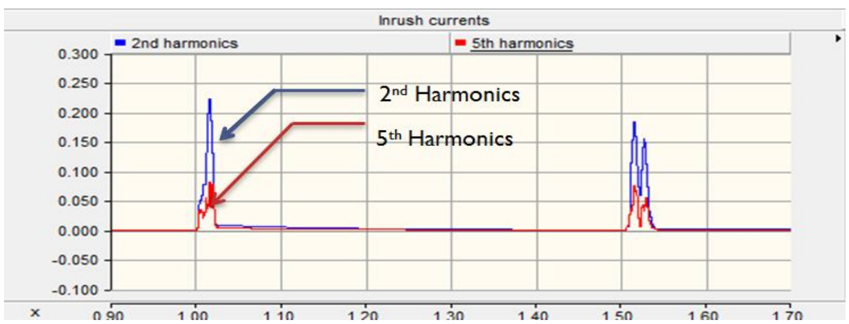

Fig. 11. The ratio of 2^{nd} and 5^{th} harmonic differential current to 1st harmonic when switching on unloaded transformer

Fig. 11 shows the waveforms of differential currents and stabilized currents (per phase) with a frequency of 1^{st} (fundamental) harmonic. They show that the differential currents are larger than the corresponding stabilized currents. If the differential (stabilized) function is not blocked in the analyzed case it comes to unwanted operation of the differential relay. Evidence of this change is status of output trip signals (*brk 1*, brk 6 and brk 7) coming from all phases (with leading logical zeros to logical ones) when switching the unloaded transformer on - as shown in Fig. 12. This is also evident transition the currents through the operation characteristics of the modeled relay.

Fig. 12. Mal-operation of relay due to inrush current

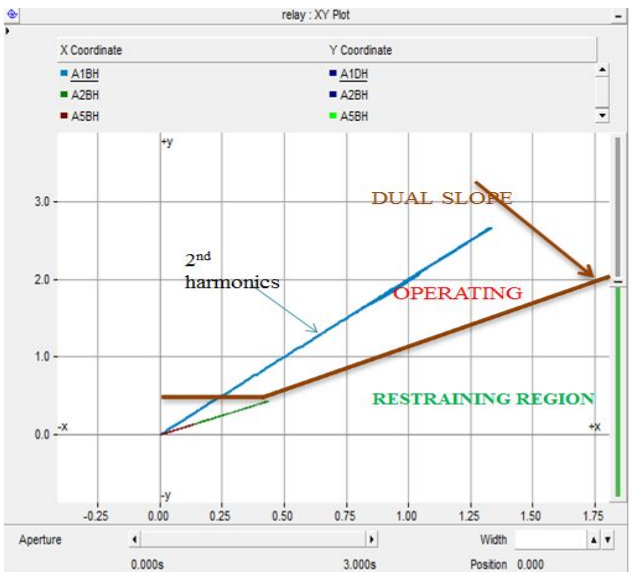

Fig. 13. Dual slope differential relay characteristics

Fig. 13. shows the transition of the current waveforms operating characteristics, which may correspond to unwanted tripping of modeled differential relay. Application (in modeled relay) of simple criterion detection of the stroke transformer magnetizing current (during switching transformer on), based on the exceeding specific content 2nd harmonic component in differential current (Fig. 4), can prevent unwanted activation of the differential relay. The lack of response course of the main tripping signal (*T* signal) demonstrates the correct operation of the modeled relay (Fig. 9).

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V. SUMMARY

The PSCAD/EMTDC software can be successfully used to modeling the disturbances in schemes with transformers and differential relays protecting transformer from effects of this disturbances occurrence. There can be created the simulation projects of schemes with power transformers, which allow to analyze various types of disturbances that may occur in this schemes, such as internal and external faults, switching on the unloaded transformers, voltage spikes on the transformer terminals, faults with current transformer saturation, etc. A lot of tests have been made for modeled test schemes. Example results of the tests, described in the article, have shown the usefulness of PSCAD/EMTDC for verifying the operation correctness of differential protections for power transformers. It is important that the calculations are in this program performed in the time domain. Thanks to this, instantaneous values of phase voltages and currents may be injected into the modeled protection device. Modeled in the thesis [1] test schemes can be used for testing the protection algorithms of real protection devices (thanks to the possibility of saving the waveforms of analog and binary signal to COMTRADE files) and for designing the new differential protection solutions. Also modeled in the thesis [1] differential relays, for protecting power transformers of different rated powers and different vector groups, and example tests results of its operating have proved that PSCAD/EMTDC can also be used for testing new protection function algorithms and verifying operating correctness of the existing algorithms (e.g. for educational or training purposes).

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