TRANSFORMER DIFFERENTIAL PROTECTION SCHEME WITH INTERNAL FAULTS DETECTION ALGORITHM USING SECOND HARMONICS RESTRAIN AND FIFTH HARMONICS BLOCKING LOGIC

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ABSTRACT

In this paper, a differential protection using second harmonic restrain and fifth harmonic block schemes for power transformer protection is presented. First we review the concept of differential protection, and describe the magnetizing inrush current and over-excitation phenomena as they belong to the causes of the protection male-operation. Second, we investigate harmonics restrain scheme and microprocessor based-protection on power transformer differential protection. Relay logic and the algorithm that uses Discreet Fourier transformer for extraction of fundamental and higher harmonics components of differential current are presented. Finally simulations cases were performed by the PSCAD – EMTDC package.

I. INTRODUCTION

Differential protection is a unit-type protection for a specified zone or piece of equipment. It is based on the fact that it is only in the case of faults internal to the zone that the differential current (difference between input and output currents) will be high. However, the differential current can sometimes be substantial even without an internal fault. This is due to certain characteristics of current transformers (different saturation levels, nonlinearities) measuring the input and output currents, and of the power transformer being protected.

with the exception of the inrush and overexcitation currents, most of the other problems, can be solved by means of the percent differential relay, which adds to the normal differential relay two restraining coils fed by the zone-through current, by proper choice of the resulting percent differential characteristic, and by proper connection of the current transformers on each side of the power transformer.

II. TRANSFORMER DIFFERENTIAL PROTECTION

Percentage restraint differential protective relays have been in service for many years [1]. Fig. 1 shows a typical differential relay connection diagram. Differential elements compare an operating current with a restraining current. The operating current (also called differential current), Id, can be obtained from the phasor sum of the currents entering the protected element:

$$I_d = \left| \vec{I}_{W1} + \vec{I}_{W2} \right| \quad (1)$$

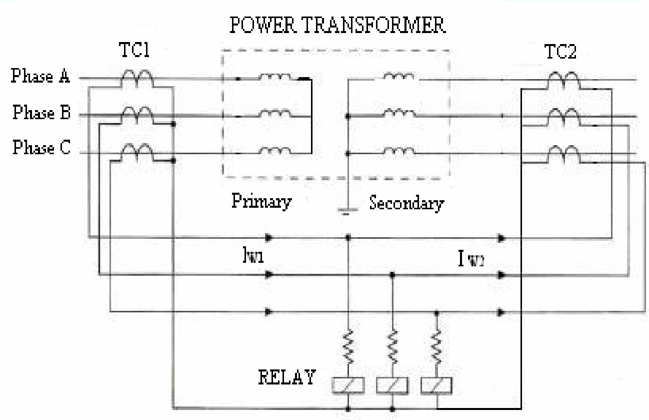


Fig.1. Simple diagram connection for differential power transformer protection.

Id is proportional to the fault current for internal faults and approaches zero for any other operating (ideal) conditions. There are different alternatives for obtaining the restraining current, IRT. The most common ones include the following:

$$I_{RT} = k \left| \vec{I}_{W1} - \vec{I}_{W2} \right| \quad (2)$$

$$I_{RT} = Max\left(\left| \vec{I}_{W1} \right|, \left| \vec{I}_{W2} \right| \right) \quad (3)$$

Where k is a compensation factor, usually taken as 1 or 0,5. The differential relay generates a tripping signal if the differential current, Id, is greater than a percentage of the restraining current, I_{RT} :

$$I_d > SLP.I_{RT} \quad (4)$$

Differential relays perform well for external faults, as long as the CTs reproduce the primary currents correctly. When one of the CTs saturates, or if both CTs saturate at different levels, false operating current appears in the differential relay and could cause relay male-operation.

Some differential relays use the harmonics caused by CT saturation for added restraint and to avoid male-operations. In addition, the slope characteristic of the percentage differential relay provides further security for external faults with CT saturation. A variable-percentage or dual-slope characteristic, further increases relay security for heavy CT saturation.

III. CAUSE OF FALSE DIFFERENTIAL CURRENT

Certain phenomena can cause a substantial differential current to flow, when there is no fault, and these differential currents are generally sufficient to cause a percentage differential relay to trip. However, in these situations, the differential protection should not disconnect the system because it is not a transformer internal fault. Such phenomena can be due to the non-linearities in the transformer core. Some of these situations are considered below.

III.1 Inrush currents

Magnetizing inrush current in transformers results from any abrupt change of the magnetizing voltage. Although usually considered as a result of energizing a transformer, the magnetizing inrush may be also caused by [2]:

- Occurrence of an external fault,
- Voltage recovery after clearing an external fault,
- Change of the character of a fault (for example when a phase-to-ground fault evolves into a phase-to-phase-to-ground fault).
- Out-of-phase synchronizing of a connected generator.

Since the magnetizing branch representing the core appears as a shunt element in the transformer equivalent circuit, the magnetizing current upsets the balance between the currents at the transformer terminals, and is therefore experienced by the differential relay as a "false" differential current. The relay, however, must remain stable during inrush conditions. In addition, from the standpoint of the transformer life-time, tripping-out during inrush conditions is a very undesirable situation (breaking a current of a pure inductive nature generates high overvoltage that may jeopardize the insulation of a transformer and be an indirect cause of an internal fault) [3].

The following summarizes the main characteristics of inrush currents [4] [5]:

- Generally contain dc offset, odd harmonics, and even harmonics.
- Typically composed of unipolar or bipolar pulses, separated by intervals of very low current values.
- Peak values of unipolar inrush current pulses decrease very slowly.
- Time constant is typically much greater than that of the exponentially decaying dc offset of fault currents.
- Second-harmonic content starts with a low value and increases as the inrush current decreases.

III.2 Overexcitation conditions

Overexcitation of a transformer could cause unnecessary operation of transformer differential relays. This situation may occur in generating plants when a unit-connected generator is separated while exporting VARs [3]. The resulting sudden voltage rise impressed on the unit transformer windings from the loss of VAR load can cause a higher than nominal volts per hertz condition and, therefore, an overexcitation event. This could also occur in transmission systems where large reactive load is tripped from a transformer with the primary winding remaining energized.

When the primary winding of a transformer is overexcited and driven into saturation, more power appears to be flowing into the primary of the transformer than is flowing out of the secondary [6]. A differential relay, with its inputs supplied by properly selected CTs to accommodate ratio and phase shift, will perceive this as a current differential between the primary and secondary windings and, therefore, will operate. This would be an undesirable operation, as no internal fault would exist, with the current imbalance being created from the overexcitation condition.

Since overexcitation manifests itself with the production of odd harmonics, and since the third harmonic (and other triples) may be effectively cancelled in Δ transformer windings, then, the fifth harmonic can be used as a restraining or a blocking quantity in the differential relay in order to discriminate between the over-excitation and the faulty state. [4].

III.3 Current transformer saturation [4]

The effect of CT saturation on transformer differential protection is double-edged. Although, the percentage restraint reduce the effect of the unbalanced differential current, in the case of an external faults, the resulting differential current which may be of very high magnitude can lead to a relay male-operation. For internal faults, the harmonics resulting from CT saturation could delay the operation of differential relays having harmonic restraint.

IV. HARMONICS RESTRAIN

Harmonics restrain is based on the fact that the inrush current has a large second-harmonic component of the differential current which is much larger in the case of inrush than for a fault (see fig 2). The over-excitation current has also a larger fifth-harmonic component. Therefore, these harmonics may be used to restrain the relay from tripping during those two conditions.

In contrast to the odd harmonics ac that CT saturation generates, even harmonics are a clear indicator of magnetizing inrush. As even harmonics resulting from dc CT saturation which are transient in nature are a clear indicator of magnetizing inrush, then it is important to use them (and not only the second harmonic) to obtain better discrimination between inrush and internal fault currents.

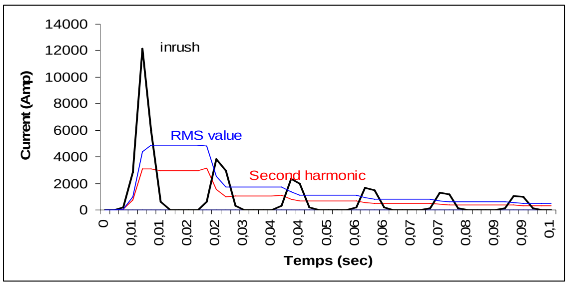


Fig.2 Magnetizing inrush and its second harmonic components

The use of even harmonics (second and fourth) in a restraint scheme ensures security for inrush currents having very low second-harmonic current.
The operating equation is:

$$I_d > SLP.I_{RT} + k_2 I_2 + k_4 I_4 \quad (5)$$

Where k_2, k_4 are constant coefficients.
I_2, I_4 are the second and fourth harmonics components of differential current.

It is a common practice to use the fifth harmonic of the operating current to avoid differential relay operation for transformer overexcitation conditions. The best solution is a harmonic blocking scheme in which there is independent fifth harmonic comparison with the operating current. In this scheme a given relay setting, in terms of fifth-harmonic percentage, always represents the same overexcitation condition. The relay operates if

$$I_d < K_5 I_5 \quad (6)$$

Where I_5 is the fifth harmonic of the operating current, and K_5 is a constant coefficient.

In a fifth harmonic restraint scheme a given setting may represent different overexcitation conditions, depending on the other harmonics that may be present. Relay tripping in this case requires fulfilment of (5) and not equation (6).

V. MICROPROCESSOR BASED RELAY

A microprocessor based transformer relay scheme consists of several subsystems, such as, analog processing, analog to digital (A/D) conversion, digital processor, relay output, and power supply subsystems [6]. Fig.3 shows a block diagram representing these subsystems. This scheme receives low level currents from each of the transformer phases via CTs. The analog pre-processing uses surge suppression circuits and low pass filters. The surge suppression circuits protect the relay from voltage surges. Low pass filters are used to band limit the inputs to avoid aliasing. The cut-off frequency of the low pass filters is selected considering the sampling frequency and the predominant high frequency components expected in the inputs. The outputs of the analog preprocessor are digitized using A/D converters.
The digitized values representing currents are processed in a digital processor that performs two main functions. The first function is to estimate the parameters of the fundamental, second harmonic, fifth harmonics and other harmonic frequency current phasors. The second function of the processor is to use the parameters of the calculated phasors to compute the required additional parameters and thereby decide if the system is experiencing a fault. In the present case, the second function involves determining the percentage of the second, fourth and fifth harmonic components in relation to the fundamental component. Based on this percentage, appropriate trip decision is issued to the circuit breakers.

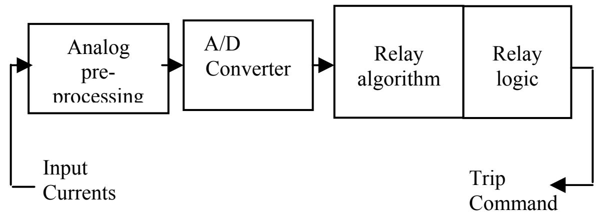


Fig. 3. Block diagram of a microprocessor-based transformer relay

V.1 Relay algorithms

Several algorithms have been proposed in the literature to calculate the fundamental and other harmonics component phasors [7]. These algorithms take sample values of currents as input and provide the fundamental, second and fifth harmonic components phasors as output. These algorithms can be classified as

1. Discrete Fourier transform technique,
2. Correlation techniques,
3. Least error square approach,
4. Kalman filtering approach.

Discrete Fourier transformer is a power tool that helps us to extract the fundamental and higher harmonics from differential current [8]. The differential current is analyzed in terms of its Fourier series and the amplitude of each harmonic can be found as follows:

$$F_k^2 = S_k^2 + C_k^2 \quad (7)$$

Where F_k is the Fourier coefficients, and S_k, $C_k$are the sinus and cosines of Fourier coefficients.For power transformers protection, *F1, F2* and F_5 represent the Fourier coefficients of the fundamental, second harmonic and the fifth harmonic components respectively of current waveform. F_2 is higher than *F1* for inrush current and F_5 is also higher than *F1* by a certain percentage in the over-excitation case. For a three phase transformer, the combined harmonic components of the differential currents are [9]:

$$F_{combined}^2 = S_{ka}^2 + C_{ka}^2 + S_{kb}^2 + C_{kb}^2 + S_{kc}^2 + C_{kc}^2 \quad (8)$$

V.2. Relay logic

The relay logic part of the scheme accepts the phasor current values of the fundamental, second and fifth harmonic components from the relay algorithm. Based on theses phasors, a trip decision is made. The trip decision is based on the relative amplitude of the fundamental component compared to the second (plus the four components) and fifth harmonic components. These relative amplitudes for single phase case can be calculated using these following ratio indexes:

$$K_{even} = \frac{\sqrt{S_2^2 + C_2^2} + \sqrt{S_4^2 + C_4^2}}{\sqrt{S_1^2 + C_1^2}}$$
$$K_{fifth} = \frac{\sqrt{S_5^2 + C_5^2}}{\sqrt{S_1^2 + C_1^2}} \qquad (9)$$

A trip signal is issued when the computed indexes are less than predefined values.

VI. SIMULATION AND RESULTS

The system includes a generator 15 MVA rated power, 33 KV rms line to line voltage and a power transformer 10MVA 33/11 KV rms, Delta-Star grounded and a resistive load 10 MW. CTs at the primary side are 1/250 ratio, star-delta connected and at the secondary 1/1200 ratio, delta star connected.

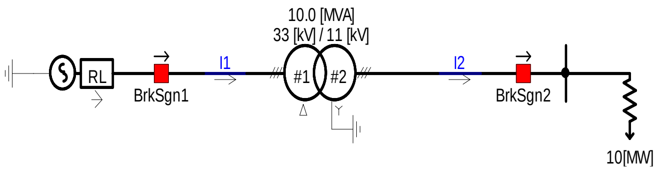
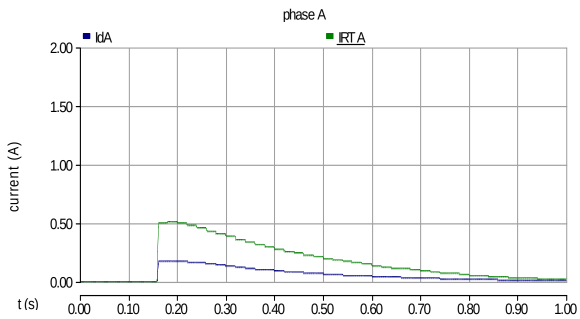


Fig 4. Simulation example.

Simulations were performed with the PSCAD EMTDC software package.

Three cases have been simulated,

1. Case of inrush current; where the results are presented in figure.5 for the three phases (phase a, b and phase c).
2. Case of short circuit Figure.6 (internal fault).
3. Case of the three phase short circuit Figure.7 located at the terminal end of the secondary of the power transformer.



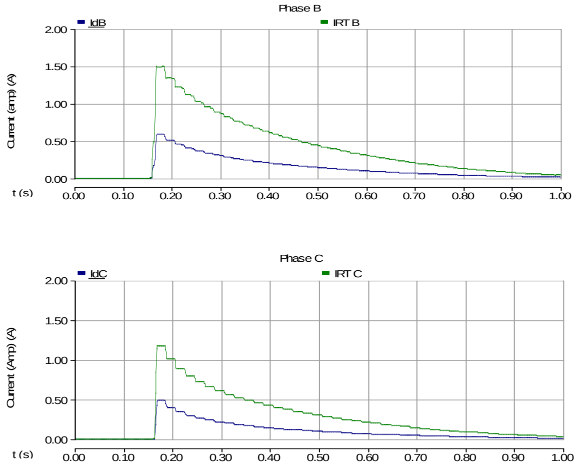


Fig. 5. Restraining scheme based on the even harmonics in the case of inrush current (Switch on time 0.018s)

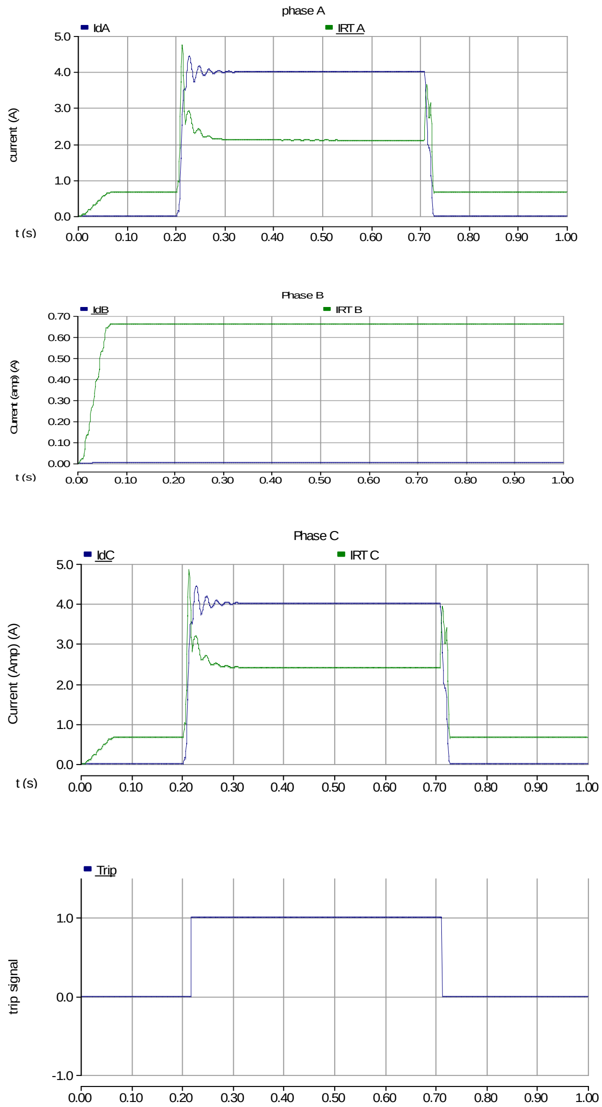


Fig 6. Performance for internal fault.

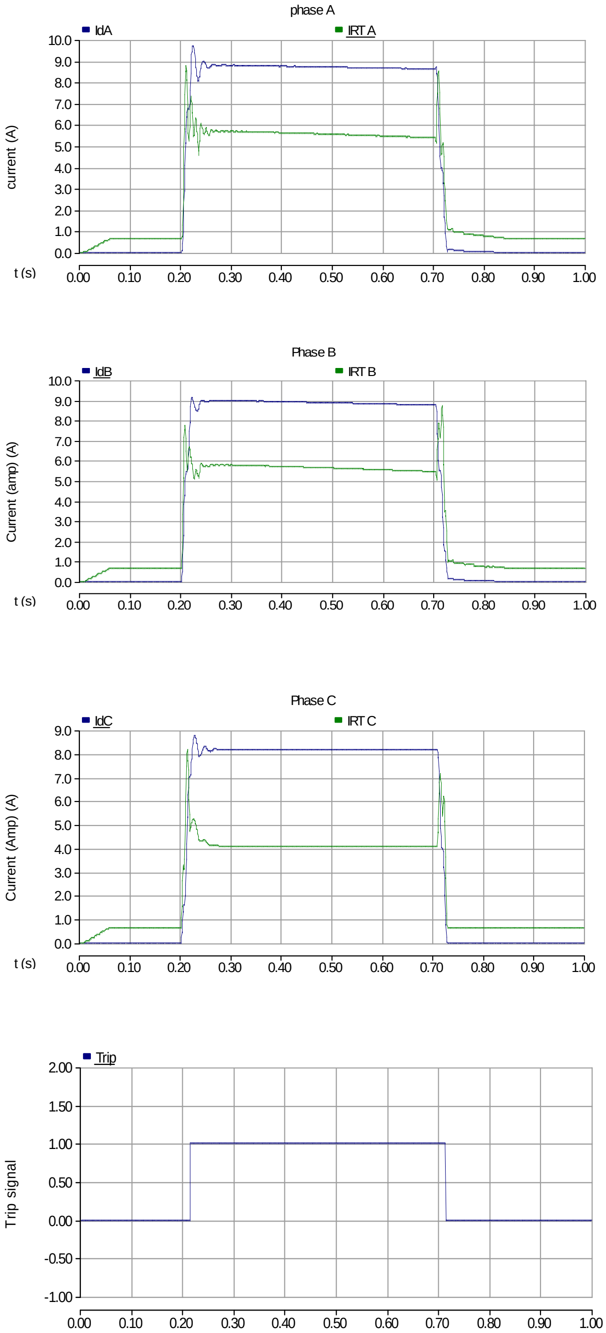


Fig 7. Three phase short circuit

The simulation results show that the protection based on the even harmonics gives a good results in term of discrimination between the normal state of the transformer and the inrush conditions (fig.5 a, b, c) and at the same time it is very sensitive to the internal faults, as it can be seen for the case of in internal fault in the secondary winding of phase A to ground (Fig.6) with 25% of interwinding short-circuited at the instant t=0.2 s. the transformer was loaded at rated load. The trip signal was generated at 0.213 ie less then ¾ of cycle. (fault duration 0.5 second). For the case of three phase short circuit at the terminal of the transformer (Fig.7 a,b,c) the time taken by the protection to detect the fault is less than ¾ of the period.

VII. CONCLUSION

As it has been stated in this 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 harmonics 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.

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