Discrimination of Fault from Non-Fault Event in Transformer Using Concept of Symmetrical Component

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Abstract

In this paper a overcurrent protection using concept of symmetrical component for power transformer is presented .first we review the concept of symmetrical component. Secondly we investigate how the concept of symmetrical component can be used to improve the transformer protection scheme and how it helps to discriminate the fault and non fault events. For this an algorithm and discrimination criteria is analysed for various fault condition and switching event.

Keywords : Fault, overcurrent relay, symmetrical Components, type of Faults, Transformer energizing, PSCAD, Switching event

1. Introduction

The Concept of symmetrical components provides a practical technology for understanding and analyzing power system operation during unbalanced conditions such as those caused by faults between phases and/or ground, open phases, unbalance impedances, and so on. Also, many protective relays operate from the symmetrical component quantities. Thus a good understanding of this subject is of great value and a very important tool in protection.

1.1 Methodology For Improved Protection Schemes:

For any unbalanced or nonsymmetrical network, such as unsymmetrical fault occurs or having unbalanced load, symmetrical component conversion can decouple three-phase system into three independent sequence equivalent networks, namely positive, negative and zero sequence network. Therefore these three sequence networks can be analyzed separately. Then we can convert the sequence value back into phase variables. This analysis procedure is commonly used in analyzing the unbalanced system network, including fault. Symmetrical components can be viewed as a mathematical tool on which we can entirely based to analysis system without converting back to phase variable. For example, the amplitude of zero sequence signifies the degree of unbalance, and therefore can be used to detect the unbalanced fault.

1.2 Theoretical background

The symmetrical component transformation for an arbitrary three-phase set of variables (balanced or unbalanced), for example the three-phase current, and inverse transformation is given in (1) and (2).

$$\begin{bmatrix} I0 \\ I1 \\ I2 \end{bmatrix} = \frac{1}{3} \times \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix} \times \begin{bmatrix} Ia \\ I\,b \\ Ic \end{bmatrix} \text{-------- (1)}$$

Here I_1 , I_2 and I_0 denote the positive, negative and zero sequences respectively. And

$$\alpha = 1 \angle 120^0 = -0.5 + j0.866$$

In general application in power system analysis, we typically begin with information in "phase variables" denoted by subscripts a, b, and c. Note that phase variables corresponds to actual physical quantities. The value of converting physical quantities to symmetrical components is in visualizing and quantization the degree of unbalanced system network. For a balanced three-phase system, it won't be difficult to calculate that the zero and negative sequences are zero, and the positive sequence is equal to phase a, no matter current or voltage.

2. Operation And Principle Of Overcurrent Relays

There are two characteristics for overcurrent relays:

1) definite- time characteristic and 2) inverse-time characteristic. In the definite-time characteristic relays, if the current amplitude exceeds a pre-defined value, the relay trips after a definite time. In the protection of motors, these relays are used to prevent the unbalanced operation of the motors. According to IEC standard [19], the characteristic of inverse time overcurrent relays (excluding induction type) is depicted by the following expression:

$$T = \frac{c}{(\frac{I}{Is})^{\alpha} - 1} \text{ ----- (2)}$$

T- the relay operation time;
C- constant for relay characteristic;
I_s-current setting threshold;
I- current detected by relay (normally the effective value) ; $I > I_s$
α- constant representing inverse-time type α> 0
By assigning different values to α and C, different types of inverse characteristics are obtained.

2.1 Proposed Algorithm

Any three-phase voltage and current consist of three components in sequence space which are related to each other as follows:

$$\begin{bmatrix} I0 \\ I1 \\ I2 \end{bmatrix} = \frac{1}{3} \times \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix} \times \begin{bmatrix} Ia \\ I\,b \\ Ic \end{bmatrix}$$

Here I_1 ,I_2 and I_0 denote the positive, negative and zero sequences respectively. And
$\alpha = 1 \angle 120^0 = -0.5 + j0.866$

Also $1+\alpha+\alpha^2=0$ if currents I_a, I_b and I_c are balanced (i.e., $I_{a,=} I \angle 0$, $I_b = I \angle -120^0$ and $I_c = I \angle +120^0$). So existence of the negative components means that the system is unbalanced. except over a transient period that may be as a result of different switching method or non identical saturated case of three-phase transformers, three phases are almost affected simultaneously during switching event. Consequently, the negative component is not considerably changed in this case. On the other hand, faults are classified into symmetrical and asymmetrical parts. The major feature of these faults is the large value of the negative component, such that there are the theoretical following cases-

For phase–ground fault

$$I_2 = I_1 = \frac{V_f}{Z_0 + Z_1 + Z_2 + (3Z_f)} \text{ …… (4)}$$

Where Z_f is the fault impedance between the line and ground Z_0, is the zero component impedance Z_1, is the positive component impedance, and Z_2 is the negative component impedance.

For phase-phase fault:

$$I_2 = -I_1 = \frac{V_f}{Z_1 + Z_2 + Z_f}. \text{ ….. (5)}$$

For phase-phase- ground fault:

$$I_2 = (-I_1) \times \frac{Z_0 + 3Z_f}{Z_0 + 3Z_f + Z_2}. \text{ …… (6)}$$

Therefore, the negative component in the asymmetrical faults is considerable. For symmetrical faults the negative component tends to zero. Not often, the three-phase fault occurs and the negative component of the current is negligible and almost equal to zero similar with the switching case. The criterion function for discriminating fault from nonfault switching is defined as follows

. The criterion function for discriminating fault from non fault switching is defined as follows:

$$R = \frac{|I1| - |I2|}{|I1| + |I2|} \text{ ----- (7)}$$

Since there is a considerable negative component in the asymmetrical fault case, according to criterion function the value of R is close to zero. In the switching case, the negative component is very small and R is close to 1.

In the switching case, the negative component is very small and R is close to 1. Except over a transient period that may be as a result of different switching methods or a non identical saturated case of three-phase transformers, three phases are almost affected simultaneously and the three-phase network has not a major unbalance, during the switching event. In the calculation of I2 and I_1 in equation (1), Ia ,Ib , and Ic are phasor value (amplitude of the fundamental harmonic). Therefore, dc values and its harmonics are largely eliminated. So the difference in dc value in the current is not important. According to the above, R<0.35 indicates the fault; otherwise, over current is the result of switching. The suggested criterion is based on the different behavior of the current components during fault and non fault conditions and is independent of the amplitude of the current which is advantageous. The reason is that it operates based on the relative difference between the negative and positive component of the current. Another advantage of the suggested criterion function is that its proper operation is independent of the power system balancing. Actually, the suggested criterion function in the asymmetrical distribution networks also operates properly. The reason is that during the asymmetrical fault, the negative component of current increases and the value of R is much smaller than that before fault event. Thus, it is enough that the threshold value be lower than at the value of R in the normal state of the network.

3. Simulation

To show the advantage of the proposed algorithm, a part of a distribution system shown in Fig.1 is modeled; using the EMTDC/ PSCAD package. The network parameter of the 2-bus distribution system is illustrated in this figure. Several nonfault events are applied to this system along with some short circuit events at different times. The simulation results show that how the proposed algorithm could help the overcurrent relay to discriminate fault from nonfault events. The following cases are presented here:

• Transformer energizing;
• Induction motor starting;

4. Transformer Energizing

When the primary winding of an unloaded transformer is switched on to normal voltage supply, it acts as a nonlinear inductor. In this situation there is a transient inrush current that is required to establish the magnetic field of the transformer. The magnitude of this current depends on the applied voltage magnitude at the instant of switching, supply impedance, transformer size and design. Residual flux in the core can aggravate the condition. The initial inrush current could reach values several times full load current and will decay with time until a normal exciting current value is reached. The decay of the inrush current may vary from as short as 20 cycles to as long as minutes for highly inductive circuits. The inrush current contains both odd and even order harmonics.In order to study a transformer energizing, various inrush current conditions were simulated at different parts of the power system. Various parameters which have considerable effect on the characteristic of the current signal (e.g., core residual magnetization, nonlinearity of transformer core and switching instant) were changed and the current signal was analyzed by the proposed method. In all cases, correctness of the proposed algorithm has been proved.

Malfunctioning of transformers is mainly because of following reasons:
Due to magnetizing inrush current, Harmonics generated due to occurrence of internal faults, Short Circuit in core winding, Symmetrical or Asymmetrical Faults Symmetrical components consist of three quantities: positive-sequence (exists during all system conditions, but are prevalent for balanced conditions on a power system including three-phase faults); negative-sequence (exist during unbalanced conditions); zero-sequence (exist when ground is involved in an unbalanced condition). Negative and zero-sequence components have relatively large values during unbalanced fault conditions on a power system and can be used to determine when these fault conditions occur. Negative-sequence components indicate phase-to-phase, phase-to-ground, and phase-to-phase-to-ground faults. Zero sequence components indicate phase-to-ground and phase -to-phase-to-ground faults

4.1 Inrush due to switching-in

Initial magnetizing due to switching a transformer in is considered the most severe case of an inrush. When a transformer is de-energized (switched-off), the magnetizing voltage is taken away, the magnetizing current goes to zero while the flux follows the hysteresis loop of the core. This results in certain remanent flux left in the core. When, afterwards, the transformer is re-energized by an alternating sinusoidal voltage, the flux becomes also sinusoidal but biased by the remanence. The residual flux may be as high as 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 A detailed study of a typical case is presented below. In this case transformer at busbar 1-2 is switched on at instant t= 0.25s and three-phase currents are measured at busbar 7. Fig. 2 shows these three-phase currents. As shown in Fig. 3, except over a transient period, R is close to 1 and is larger than setting R= 0.35s that shows nonfault case. In this case tripping signal is prevented.

4.2 Fault

In this case a phase-ground fault (A-G) occurs at busbar 1 at instant t= 0.25s and three-phase currents are measured at busbar 7. Fig. 4 shows these three-phase currents. As shown in Fig. 5, *R* is close to zero that shows a fault case in which the tripping signal is issued.

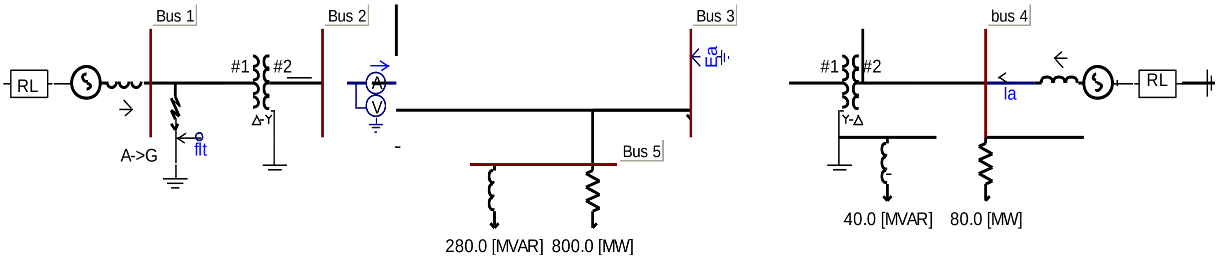

Fig 1. 5-bus system model

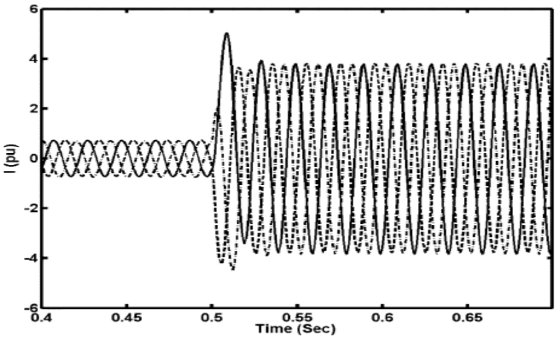

Fig.2. 3- phase current due to transformer energizing

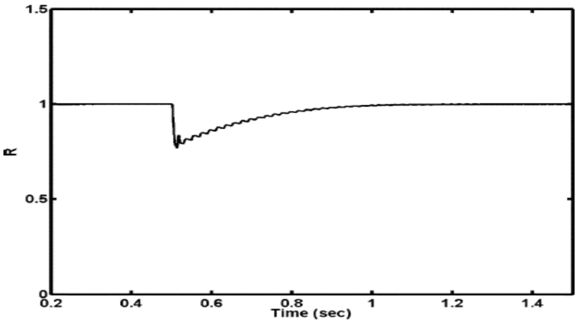

Fig 3. Value of R versus time due to transformer Energizing

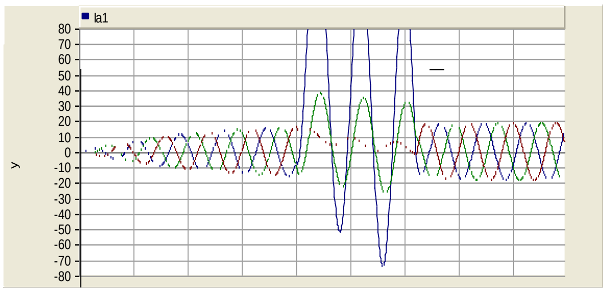

Fig. 4 Three phase current due to fault (A-G)

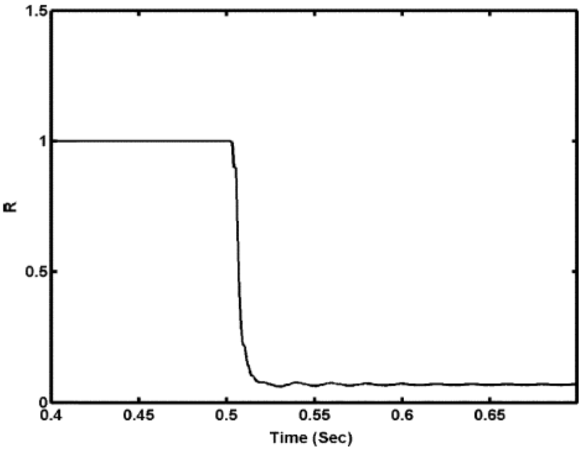

Fig. 5 Value of R versus time due to fault (A-G)

Three-phase currents are measured at the busbar 1 Fig. 4 shows these currents is close to zero which indicates that there is a fault and the relay trips. In fact, one more advantage of the suggested algorithm is that, in addition to the diagnosis of the fault in the individual occurrence from the nonfault case, it enables to discriminate a fault from simultaneous switching properly. This is necessary because, if in the case of fault, the operation of the relay is prevented and it is assumed switching case, it may lead to a serious damage.

5. Theoretical Analysis

Sr. No.	Calculated Parameter	Value
Positive and negative Sequence Network parameters		
	Transmission line voltage base	123.2Kv
	Motor line Voltage base	13.8 Kv
	% Reactance of transformer	7.843%
	% Reactance of motor	24.6%
	% Reactance of line	16.7%
Zero Sequence Network parameters		
	% Neutral Reactance	94.5%
	% Reactance of transformer	7.843%
	% Reactance of line	41.6%
	% Reactance of line	16.7%

6. Conclusion

In this paper, from simulations results it indicates that enhanced sensitivity can be achieved with a symmetrical component based overcurrent protection. Also the paper presents a new algorithm- overcurrent protection based on symmetrical component and shows vastly improved performance over conventional techniques, to discriminate fault and non fault events like switching and magnetizing inrushes in transformer. Undesirable operation of relay due to the switching is prevented. The capability of the new method has been demonstrated by simulating various cases on a suitable power system for various types of asymmetrical faults.

7. Future Scope

Here only the fault cases related to Transformer is studied but in future it can be studied for Alternator, Turbo-generators etc.

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