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Influence of Superconductor Fault Current Limiter on Transformers Lifetime

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Abstract

In this article the impact of the superconducting current limiter and reducing the incidence of stress single phase short circuit has been analyzed with this method and conventional method of current limiting resistance has been compared. For this purpose a saturated core high temperature superconducting current limiter model considered and its effects on network performance in different modes has been studied. PSCAD software for simulating the network is used.

Keywords: Power transformers, Short circuit forces, Superconducting current limiter, High temperature superconducting

1. INTRODUCTION

Electrical short circuit in the network is inevitable. Statistical Review of faults occurred in electrical networks illustrated that most of these faults are single phase to ground faults. Short circuit current has led to tension in transformers that supply network. On the other hand the continuously electrical network expanding and increasing short circuit power to these networks. Short circuit power has direct effect on tensions. Thermal tensions usually don't have significant effect due to high thermal time constant of transformers [1]. Created tensions in transformers (especially transformers with high life) will lead to damage to transformers. In this article several methods to limit short circuit current and their impact on

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network performance to normal has been studied. Classical offer various method has been introduced to limit single phase short circuit current [2]. In recent years, use of superconducting current limiter to reduce injuries of incidence of network equipment short circuit has been considered [3].

2. REVIEW

A. Short-circuit forces in power transformer

Electromagnetic force Calculated in general form as follow [1]:

$$F = LI \times B[N] \tag{1}$$

Where ***B*** is the leakage flux density vector, ***I*** is current vector and the length is ***L***. Short circuit current value in transformer secondary side with upstream infinite bus assumption calculated from the equation (2). [4]

$$I_{SC} = \frac{10^6 kS_n \sqrt{2}}{VZ\sqrt{3}}[A] \tag{2}$$

If the forces analysis to be done in a two-dimensional space and current flow through Z axis direction, Leakage flux density at each point is the decomposition of two components to be radial $\boldsymbol{B_x}$ and the other in order to axial $\boldsymbol{B_y}$, so a radial force component and a component for the axial force due to fluxes is available. Figure 1 showing these forces.

B. Radial forces

Axial flux and radial forces in a transformer with concentric windings calculated based on proposed method in Reference [9]. Amounts axial flux obtained equation (3).

Vol. 2(4), Jul, 2012, pp 76-87, ISSN: 2305-0543
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$$B_y = \frac{4\pi(ni)}{10^4}[T] \tag{3}$$

Where ***n*** is the number is winding period and ***i*** is the current flowed through transformer windings. This flux in contrast with current cause to radial force the value of this force obtained by equation (4)

$$F_x = \frac{2\pi(ni)^2 D_m}{h} 10\ {}^{7}[N] \tag{4}$$

h is height of transformer Windings and $\boldsymbol{D_m}$ is the average diameter of windings that radial force is calculated over there. This force causes the HOPE tension on external windings and compression force in inner windings. Mean HOPE stress and compression stress in concentric windings with cross section

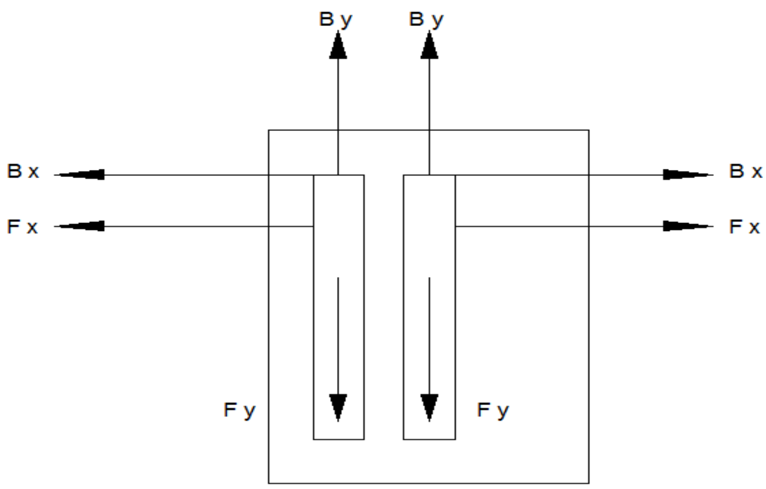

Fig. 1. Mechanical force on transformer windings

$\boldsymbol{a_c}$ *is:*

$$\sigma_{mean} = \frac{F_x}{2na_C}\ \frac{N}{m^2} \tag{4}$$

International Journal of Mechatronics, Electrical and Computer Technology

Vol. 2(4), Jul, 2012, pp 76-87, **ISSN**: 2305-0543
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C. Axial forces

Radial leakage field and therefore axial forces analytical calculations are not simple [4]. However, an acceptable method for this calculation method is ampere-turns method. This method is based on the principle that any combination of windings can be divided into two categories, each winding has related ampere-turn. The first group obtain axial field and second group creates radial field [9]. Method mentioned for calculating axial force need for having mean way flux effective path $\boldsymbol{H_{eff}}$, average radial flux density $\boldsymbol{B_y}$ and average amount of ampere-turn $a(ni)/2$, variable $\boldsymbol{a}$ is length away is part of the asymmetric part calculated as fraction of the overall length is winding. This part can be model such as short circuited coils. Average radial flux density is:

$$B_y = \frac{4\pi a(ni)}{2 \times 10^4 \times h_{eff}} [T] \tag{5}$$

Calculate the axial forces for a transformer with external winding asymmetry can be done as follow:

$$F_x = \frac{2\pi^2 (ni)^2 a D_m}{h_{eff}} 10^{\ 7} [N] \tag{6}$$

Reference [4] purposed an equation to calculate electromagnetic force for different asymmetric conditions is that include transformer taps effect. Axial forces caused by bending radial separator of transformers. Stress caused by this force is calculated from the equation 7.

$$\sigma_{mean} = \frac{F_x L^2}{2tb^2} \quad \frac{N}{m^2} \tag{7}$$

In this equation $\boldsymbol{F_x}$ is distributed axial force in N/M, $\boldsymbol{L}$ is distance between stampings $\boldsymbol{m}$ and $\boldsymbol{b}$ is dimensions of axial conductor in $\boldsymbol{m}$ and $\boldsymbol{t}$ is the radial dimension is conductor.

International Journal of Mechatronics, Electrical and Computer Technology

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D. Fault current limiter:

Several types of fault current limiter use in high, medium and low voltage networks. Some of these fault current limiters

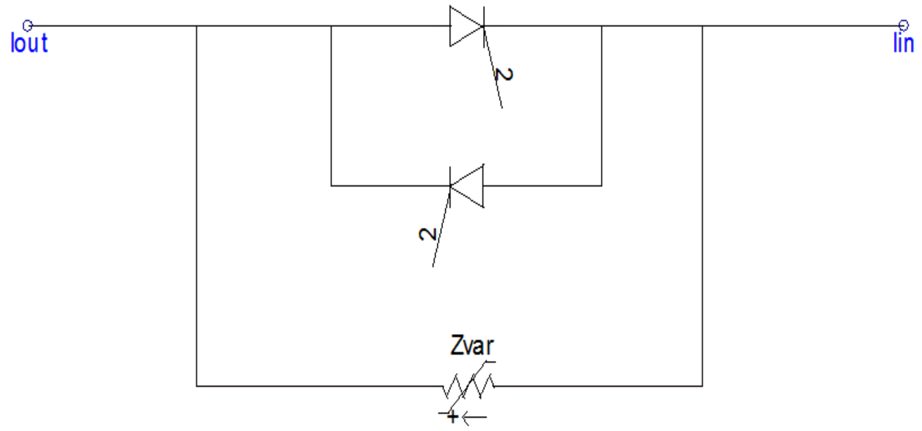


Fig. 2. FCL per phase model

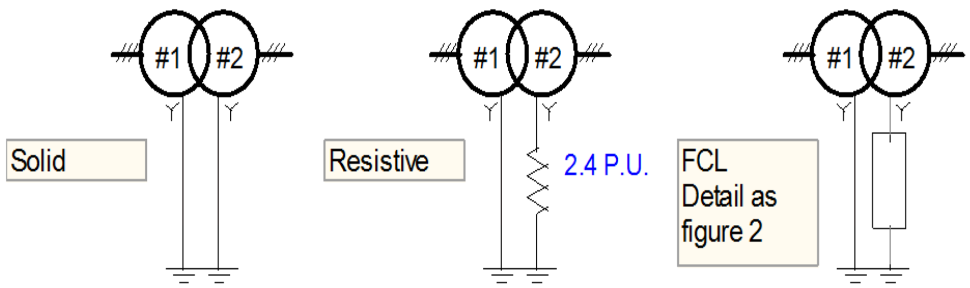


Fig. 3. Solid, Resistive and FCL

International Journal of Mechatronics, Electrical and Computer Technology

Vol. 2(4), Jul, 2012, pp 76-87, ISSN: 2305-0543

Available online at: http://www.aeuso.org

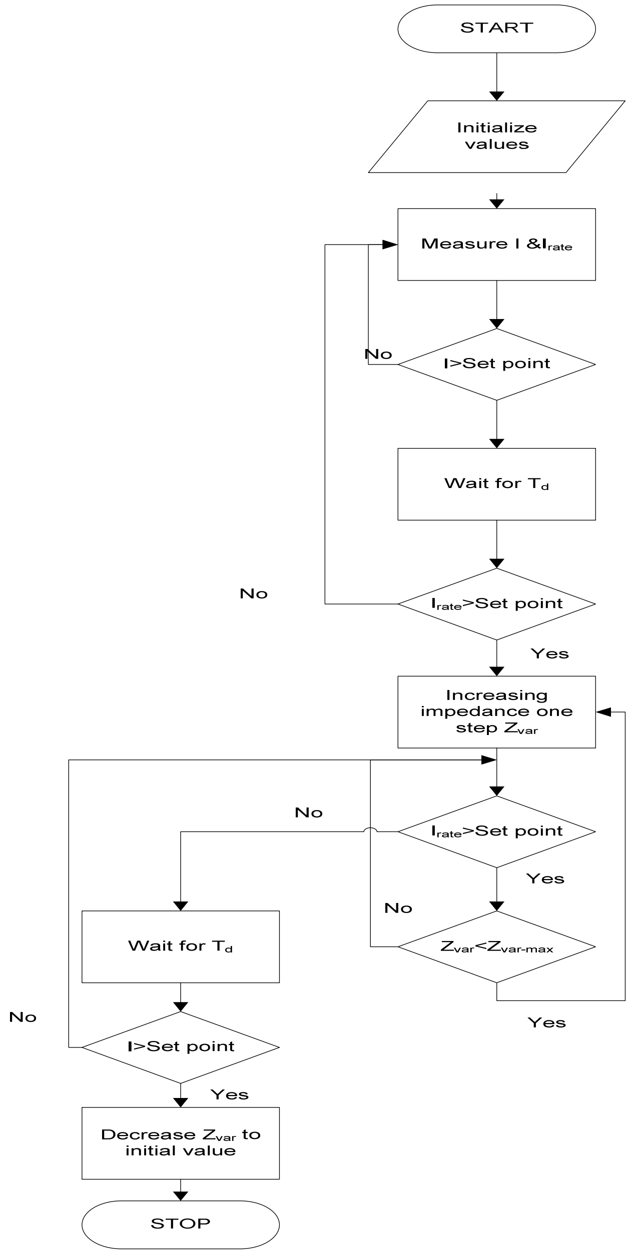


Fig. 4. Zvar control algorithm

Vol. 2(4), Jul, 2012, pp 76-87, ISSN: 2305-0543
Available online at: http://www.aeuso.org

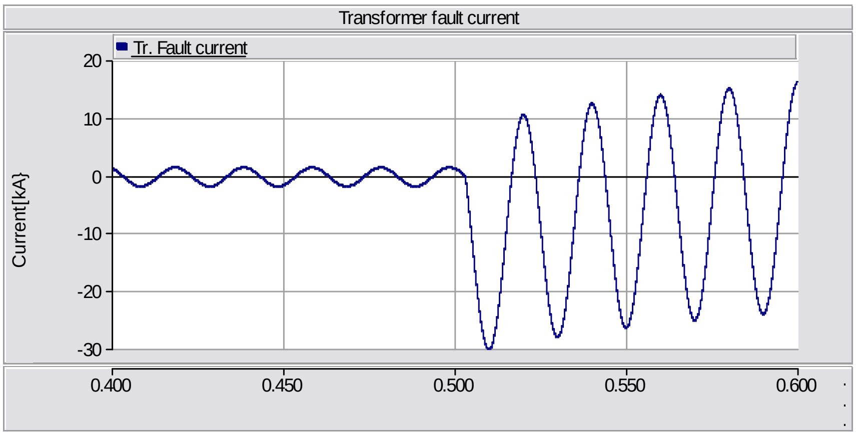
in recent years are in research phase and some of these has made a sample and has been tested [9]. Various type of fault current limiter in recent years has examined that can be categorized as:

- Fault current limiter with pyrotechnic method
- Fault current limiter with using power electronic switches
- Superconducting fault current limiter with

In this article a model of high temperature Saturated superconductor fault current limiter is used [9]. High temperature super conductor's work at temperatures above the temperature of common superconductor act so cooling costs is significantly reduced. Figure 2 Showing per phase equivalent circuit model of the current limiter.

TABLE 1. SUPER CONDUCTOR FAULT CURRENT LIMITER MODEL'S PARAMETERS

PARAMETERS	VALUE
Z_{max}	2.4 (pu)
Z_{step}	0.1 (pu)
$I_{set\ point}$	1.5 kA
$di/dt_{set\ point}$	1 kA/Sec



a) Current Flow through transformer with solid ground

International Journal of Mechatronics, Electrical and Computer Technology

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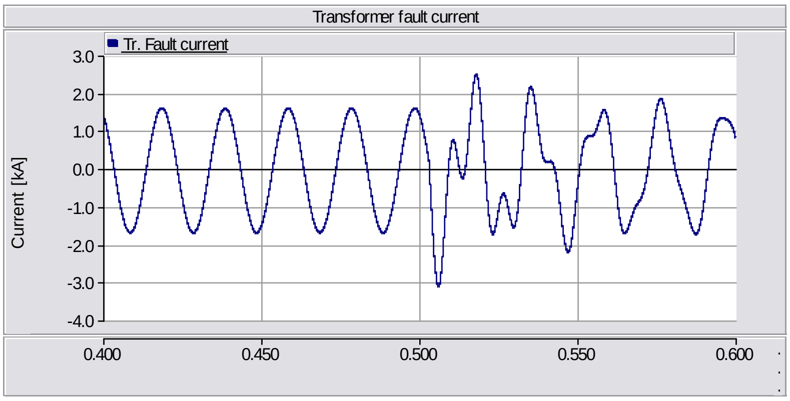
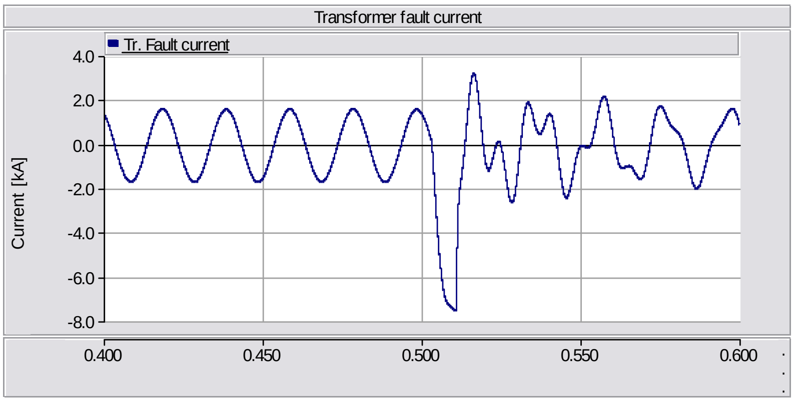


b) Current Flow through transformer with resistive ground



c) Current Flow through transformer with resistive ground

Fig. 5. (a,b,c) Short circuit currents on various networks

connected via resistance. In other hand the star - zigzag transformers possible to supply asymmetrical loads. If using ground connection resistance during normal operation the network when transformer feeding asymmetric load transformer neutral point voltage and consequently phase voltage displaced. Value of this displacement can be calculated through the ohms law. Equation between the amplitude of displacement in this neutral point is:

International Journal of Mechatronics, Electrical and Computer Technology

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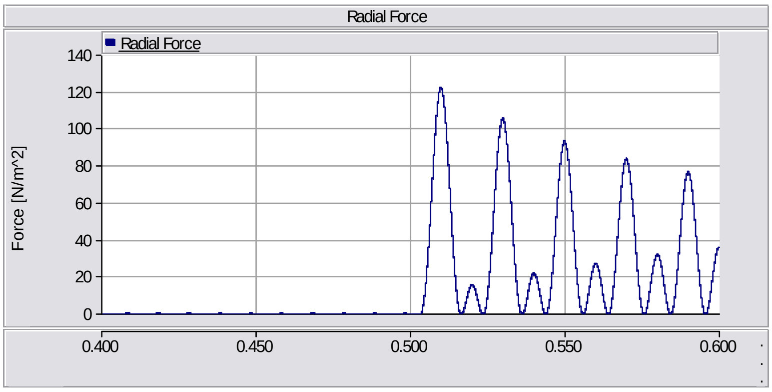
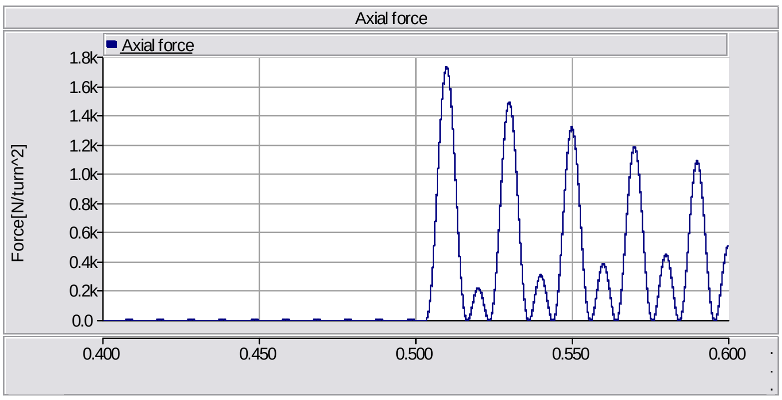
$$V_n = I_n \quad R \tag{8}$$

If 15% current asymmetry exists in load current neutral point and consequently phase voltage displaced as 36% that cause to asymmetry in voltage, but by using fault current limiter this displacement is negligible. Impedance of fault current limiter is very low at state that thyristor is on.



a) Radial Force with solid ground



a-1) Axial Force with solid ground

International Journal of Mechatronics, Electrical and Computer Technology

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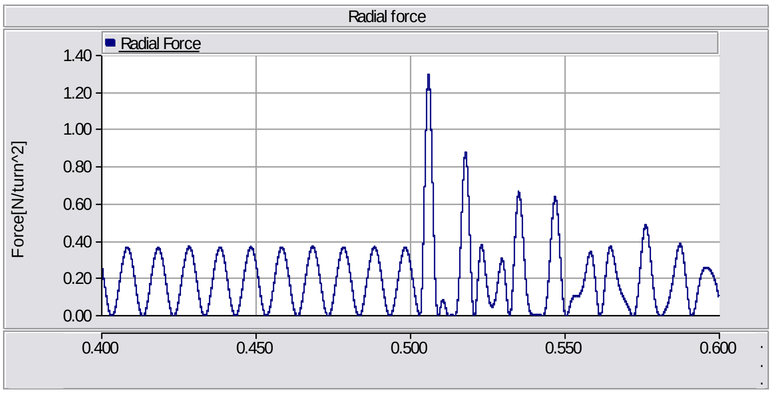
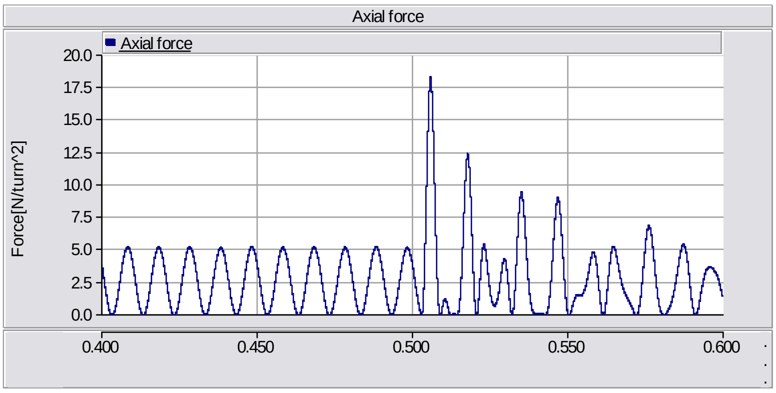
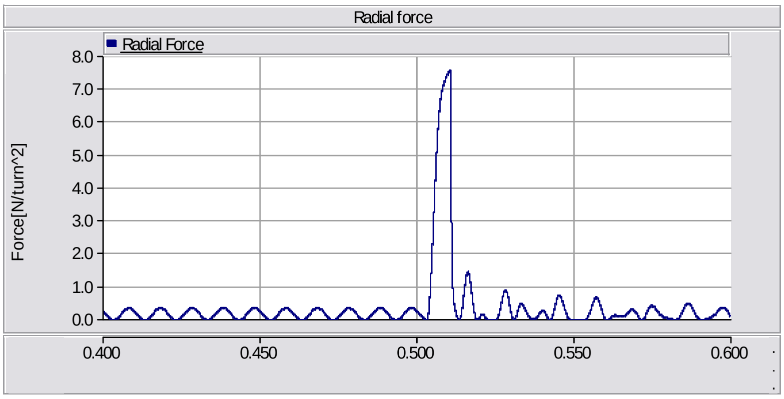


b) Radial Force with resistive ground



b-1) Axial Force with resistive ground



c) Radial Force with resistive ground

International Journal of Mechatronics, Electrical and Computer Technology

Vol. 2(4), Jul, 2012, pp 76-87, ISSN: 2305-0543
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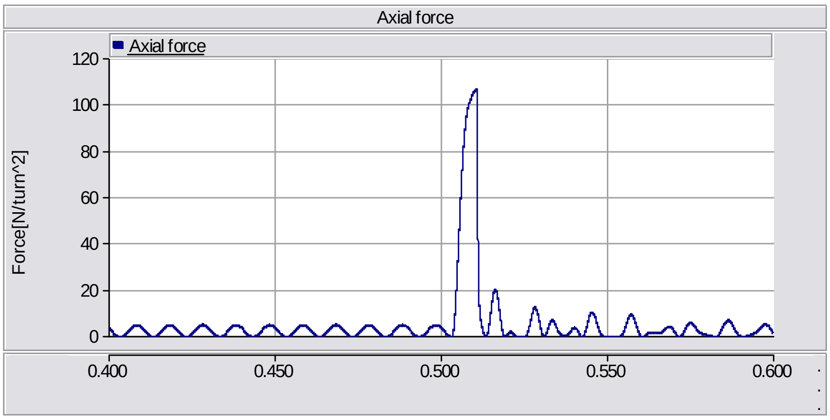

c-1) Axial Force with resistive ground

Fig. 6. (a,b,c) Radial forces due to short circuit in various network

Fig. 7. (a-1, b-a, c-1) Axial forces due to short circuit in various network

CONCLUSION

In this article, the destructive effects of single phase short circuit forces on the transformers considered and effect of using superconducting fault current limiter to reduce stress and damage the transformer were analyzed. Replacing traditional methods with superconductor current limiter can cause to reduce stress but main drawback of these elements is high cost (especially in cooling system). Important advantage of these devices is reducing short circuit destructive effect without affecting system voltage on asymmetric network load especially on transformers with asymmetric load.

Vol. 2(4), Jul, 2012, pp 76-87, ISSN: 2305-0543
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