Mitigation of Switching Transient in Transformer

Sagar Devidas Bole

***Abstract*— an inrush current is a transient current with high amplitude that may occurs when a transformer is energized under no load or lightly loaded conditions. The magnitude of inrush current may be as high as several times of transformer rated current. The magnitude of inrush current depends upon leakage reactance, source strength, impendence of winding, residual flux. Inrush current causes huge mechanical and thermal stress on transformer in addition to inadvertent operation of the protective relay systems. The conventional method like pre-insertion of resistor, point on wave is used to minimize the inrush current. Inrush current in transformer can be reduced by selecting appropriate switching angle with respect to the remnant flux. In this paper dynamic modeling of transformer is used for detailed analysis of the inrush current and the effect of switching angle on the magnitude of inrush current is observed.**

***Index Terms*—Dynamic modeling, switching transient.**

I. INTRODUCTION

Energizing the transformers and reactors in power systems are related to the inrush currents generated and distributed in the system. The factors affecting the inrush current magnitude are residual flux, source strength, core design, impendence of winding, switching angle. Several methods are utilized for controlling and reducing the amount of the inrush currents of energizing transformers. The conventional method *i.e*. preinseration of resistor suffer from the high values of the resistances and the great amount of the loss, therefore the studies on proposing and applying newer methods with less problems and loss are under investigation [1] [2]. The other significant disadvantages of the inrush currents are as follows:

- Incorrect operation and failures of electrical machines and relay systems
- Electrical and mechanical vibrations among the winding of the transformer
- Irregular voltage distribution along the transformer windings
- High amount of voltage drop on the power system at energization instant
- Possibility of resonances in the power system due to the various frequencies of the inrush current

Inrush current in transformer causes injection of harmonic component in power system [3] [4]. To minimize power quality problem, it is necessary to decrease the amount of the inrush current generated by energizing the transformers. For analysis of magnetizing inrush current mathematical modelling of transformer is used [5].

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II. INRUSH CURRENT

Transformer will experience large magnetizing inrush current during energization. Inrush current occurs in a transformer whenever the residual flux does not match the instantaneous value of the steady-state flux which would normally be required for the particular point on the voltage waveform at which the circuit is closed [6]. Magnetizing inrush current is formed due to the incorrect switching instant. Its magnitude depends upon initial flux developed during energization. Saturation of core causes magnetizing inrush current reach to the highest value. Due to inductive nature of transformer circuit, current is lagging the voltage. When transformer is energized at voltage zero, at that instant magnitude of current is high. Hence current transient is added in normal magnetizing current. The magnitude of inrush current reaches the highest value. To avoid inrush current, transient in current must be die out. To remove transient component in current, transformer is energized at voltage peak, since at that instant current is zero [7].

III. MATHEMATICAL MODELING OF SINGLE PHASE TRANSFORMER

Mathematically single phase transformer without core saturation can be represented in terms of voltage equations. The equivalent circuit of transformer is shown in fig.1. In this case nature of transformer is linear [8].

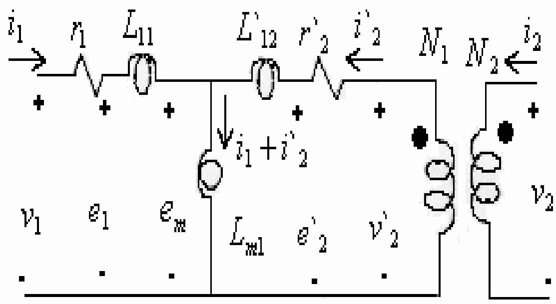

Fig.1: Equivalent circuit of transformer

x_m - Magnetizing reactance of transformer

X_m - Total reactance of winding

x_{11} - Total leakage reactance of winding1

x'_{12} - Total leakage reactance of winding2

ψ_1 - Total flux linkage of winding 1

ψ'_2 - Total flux linkage of winding 2 referred to primary winding

ψ_m^{unsat} - Unsaturated mutual flux

ψ_m^{saat} - Saturated mutual flux

v_1 - Voltage on primary side

v'_2 - Equivalent voltage on secondary side

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referred to primary

r_1 - Resistance of primary winding

r'_2 - Resistance of secondary winding referred to primary

$$v_1 = i_1 r_1 + \frac{1}{\omega}\frac{d\psi_1}{dt}$$

$$v'_2 = i'_2 r'_2 + \frac{1}{\omega}\frac{d\psi'_2}{dt}$$

$$\psi_1 = \omega\lambda_1 = x_{11} i_1 + \psi_m \qquad ....(1)$$

$$\psi'_2 = \omega\lambda_2 = x_{12} i_2 + \psi_m \qquad ..(2)$$

$$\psi_m = x_m (i_1 + i'_2) \qquad ....(3)$$

current i_1 can be express in terms of flux ψ_1 and ψ_m

$$i_1 = \frac{\psi_1 + \psi_m}{x_{11}}$$

$$i'_2 = \frac{\psi'_2 + \psi_m}{x'_{12}}$$

putting the values of i_1 and i'_2 in equation (3)

$$\psi_m = x_m\left(\frac{\psi_1 - \psi_m}{x_{11}} + \frac{\psi'_2 - \psi_m}{x'_{12}}\right)$$

Again flux linkage in integral form

$$\psi_1 = \int\left((v_1 - i_1 r_1) + \omega r_1\left(\frac{\psi_1 - \psi_m}{x_{11}}\right)\right)$$

$$\psi'_2 = \int\left((v_2 - i'_2 r'_2) + \omega r_1\left(\frac{\psi'_2 - \psi_m}{x'_{12}}\right)\right)$$

Core saturation mainly affects the value of the mutual inductance and to a much lesser extent, the leakage inductances. The effects of saturation on the leakage reactance are rather complex and would require constructional details of the transformer that are not available. In many dynamic simulations, the effect of core saturation may be assumed to be confined to the mutual flux path. Core saturation behavior can be determined from the open-circuit magnetization curve of the transformer. The open-circuit curve is obtained by plotting the measured rms value of the terminal voltage against the no-load current drawn on winding 1 when the secondary terminal is open-circuited. The effects of core saturation in a dynamic simulation have been included after incorporating the relationship between saturated and unsaturated values of the mutual flux linkage

$$\psi_m^{unsat} = x_m^{unsat}(i_1 + i'_2) \qquad ...(4)$$

Similarly in terms of saturated flux linkage, saturated values of current are expressed as

$$i_1 = \frac{\psi_1 + \psi_m^{sat}}{x_{11}}$$

$$i'_2 = \frac{\psi'_2 + \psi_m^{sat}}{x'_{12}}$$

puting the values of i_1 and i'_2 in eqation (4)

$$\psi_m^{unsat} = x_m^{unsat}\left(\frac{\psi_1 - \psi_m^{sat}}{x_{11}} + \frac{\psi'_2 - \psi_m^{sat}}{x'_{12}}\right)$$

$$\nabla\psi = \psi_m^{unsat} - \psi_m^{sat}$$

$$\frac{1}{x_m} = \left(\frac{1}{x_m^{unsat}} + \frac{1}{x_{11}} + \frac{1}{x'_{12}}\right)$$

$$\psi_m^{unsat} = x_m\left(\frac{\psi_1}{x_{11}} + \frac{\psi'_2}{x'_{12}} - \frac{\nabla\psi}{x_m^{unsat}}\right)$$

IV. SIMULATION RESULT

Single phase transformer with saturable core having rating of 1.5 kV, 120/240 V, 50 Hz connected to source of voltage rating 120 V. Inrush current in transformer (37.5 A) is approximately equal to three times the rated current of transformer (12.5 A) shown in fig.2. First peak of flux is reached to high value i.e. 330 Wb. shown in fig.3

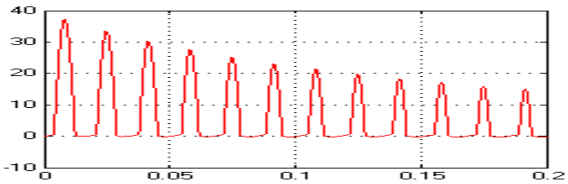

Fig.2.Inrush current in transformer

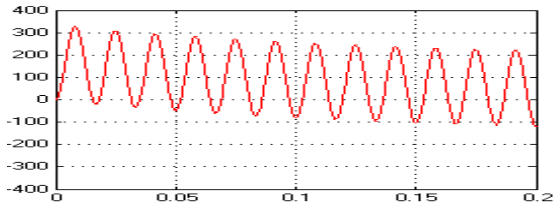

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Fig.3 Mutual flux in core

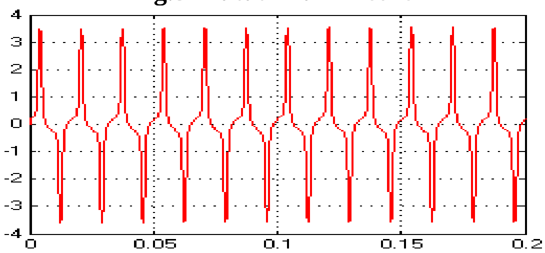

Fig.4.Primary current in transformer (switched at 90^0)

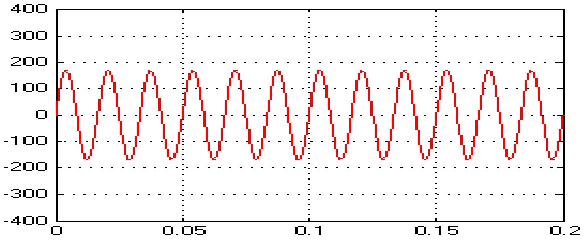

Fig.5. Mutual flux in core (switched at 90^0)

Transformer is energized at voltage peak, primary current and core flux reaches to normal value (3.75 A, 175 Wb). If increasing the switching angle, magnitude of inrush current decreases shown in fig.4 and fig.5.

V. CONCLUSION

The inrush current causes mal-operation of protective equipment. For the analysis of inrush current dynamic modeling of transformer is carried out. In this paper, variation of magnitude of inrush current with respect to switching angle is observed in MATLAB simulink. Time required by primary current to set up at steady state value is depending upon switching angle.

APPENDIX

Parameter	S.I. unit	R.M.S value
Rated power	kVA	1.5
Transformation ratio	-	120/240
Rated frequency	Hz	50
Resistance r_1	Ohm	0.25
Resistance r_2'	Ohm	0.134
Leakage reactance x_{l1}	Ohm	0.056
Leakage reactance x_{l1}	Ohm	0.056
Magnetizing reactance	Ohm	708.1

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