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Modeling and analysis of 100 KVA distribution transformer core saturation effect under non-sinusoidal supply

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Abstract: In transformers the main consequence of harmonic currents is an increase in losses, mainly in windings, because of the deformation of the leakage fields. Higher losses means that more heat is generated in the transformer so that the operating temperature increases, leading to deterioration of the insulation and a potential reduction in lifetime. This paper includes the effects of non-sinusoidal supply voltage on the 100kVA distribution transformer. This paper presents a hysteresis based transformer simulink model to estimate transformer saturation with nonsinusoidal supply. Magnetic core saturation of transformers and rotating machines generate harmonics. The phenomena of core saturation are described by the hysteresis curve. And also investigate the effect of supply voltage on the excitation current of a 100kVAdistribution transformer. This paper also observe the which harmonic is more dominating in a saturated transformer.

Keywords: non-sinusoidal supply, core saturation, hysteresis, transformer modeling, MATLAB.

INTRODUCTION

The transformers are an integral part of the power system. Due to the non-linear loads, power frequency harmonics exist mainly in distribution systems. Or we can say no-load current of transformers contain several harmonics. This is primarily because of the nonlinear relationship between the flux density and the magnetic field strength in a transformer core [5].

The transformer harmonics can cause the following effects:

a) Disturb the proper functioning of automatic network protection.
b) Interfere with the operation of telecommunication equipment.
c) Increase the temperature of the delta-connected windings due to the circulating triple currents.
d) Overload the neutral conductor of the star connected 4-wire windings.

Harmonic current produced by nonlinear loads are injected back into the supply systems. These current harmonics cause voltage harmonics, hence resulting in nonsinusoidal supply voltage in the system. Harmonic distortion is caused by nonlinear devices in the power system. A nonlinear device is one in which the current is not proportional to the applied voltage. Harmonic voltage distortion may cause additional losses and heating in laminated transformer cores due to the distorted flux waveform. Non-linear loads that produce harmonics on the power system are static converters, rectifiers, arc furnaces, electronic phase control, cycloconverter, switch mode power supplies, PWM drives etc[9], [3]. Due to the non-linear loads, the transformer is much affected by the distorted currents and supply voltages which reduce its efficiency due to overheating. Although transformer exciting current is rich in harmonics at normal operating voltage, it is typically less than 1 percent of rated full load current. Its effect will be noticeable, particularly on utility distribution systems. It is common to notice a significant increase in triple harmonic currents during the early morning hours when the load is low and the voltage rises. Transformer exciting current is more visible then because there is insufficient load to obscure it and the increased voltage causes more current to be produced [1].

RESEARCH METHODOLOGY

Transformer is designed to deliver the required power to the connected loads with minimum losses at fundamental frequency. Any periodic, distorted waveforms can be expressed as a sum of sinusoids. When a transformer is identical from one cycle to the next, it can be represented as a sum of pure sine waves in which the frequency of each sinusoid is an integer multiple of the fundamental frequency of the distorted wave. This multiple is called a harmonic of the fundamental. Usually the higher order harmonics are negligible for power system analysis. While they may cause interference with low-power electronic devices, they are usually not damaging to the power system [1].

If the power system is depicted as series and shunt elements, the vast majority of the nonlinearities in the system are found in shunt elements i.e. loads. The series impedance of the power delivery system (i.e. the short circuit impedance between the source and the load) is remarkably linear. In transformers, also, the source of harmonics is the shunt branch (magnetizing impedance) of the common "T" model, the leakage impedance is linear. Thus the main sources of harmonic distortion will ultimately be end-user loads.

In addition to the operation of transformers on the sinusoidal supplies, the harmonic behavior becomes important as the size and rating of the transformer increases [9].

The effects of the harmonic currents are:

1. Additional copper losses due to harmonic currents
2. Increased core losses
3. Increased electromagnetic interference with communication circuits.

On the other hand the harmonic voltages of the transformer cause:

1. Increased dielectric stress on insulation
2. Electro static interference with communication circuits.
3. Resonance between winding reactance and feeder capacitance.

In the present times a greater awareness is generated by the problems of harmonic voltages and currents produced by non-linear loads like the power electronic converters. These combine with non-linear nature of transformer core and produce severe distortions in voltages and currents and increase the power loss. Thus the study of harmonics is of great practical significance in the operation of transformers.

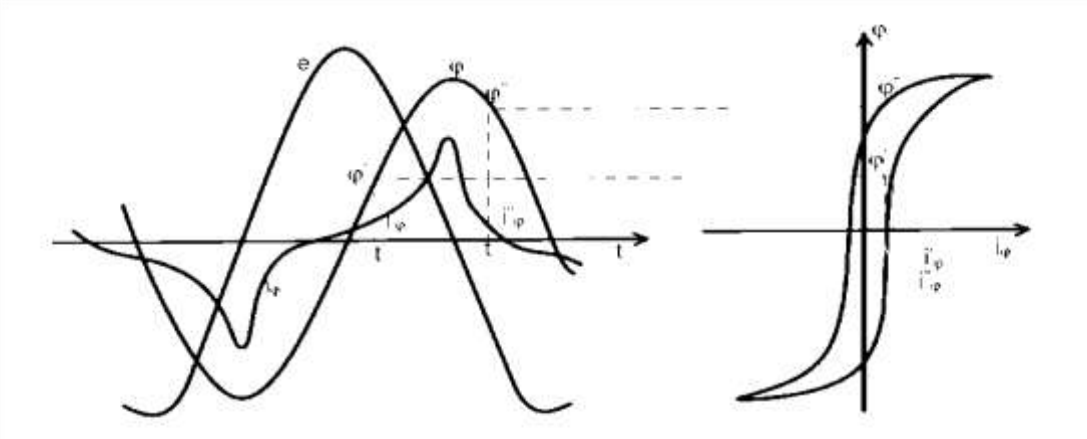

Fig. 1: Harmonic generated by transformers

Modern transformers operate at increasing levels of saturation in order to reduce the weight and cost of the core used in the same. Because of this and due to the hysteresis, the transformer core behaves as a highly non-linear element and generates harmonic voltages and currents. This is explained in the above given figure. This shows the manner in which the shape of the magnetizing current can be obtained and plotted.

The primary effect of harmonic currents on transformers is the additional heat generated by the losses caused by the harmonic contents generated by the nonlinear loads [3].
There are three effects that result in increased transformer heating when the load current includes harmonic components.

1. Rms current: If the transformer is sized only for the kVA requirements of the load, harmonic currents may result in the transformer rms current being higher than its capacity.

2. Eddy-current losses: These are induced currents in a transformer caused by the magnetic fluxes.
3. Core losses: The increase in nonlinear core losses in the presence of harmonics will be dependent under the effect of the harmonics on the applied voltage and design of the transformer core.

DATA ANALYSIS

In this section, calculation and simulation of unloaded saturated transformer with non sinusoidal supply will perform. Then results are compared.

THEORETICAL DATA:

3phase, 50Hz, 100kVA, 11/0.433KV delta/star connection distribution transformer used in this paper.

TABLE 1.TRANSFORMER PARAMETER

V1(V)	V2(V)	I1(A)	I2(A)	Io(A)	Po(W)	Psc(W)
11000	433	5.25	133.33	2.5	260	1760

TRANSFORMER MODEL: To analyze the core saturation effect, the equivalent circuit of an unloaded single phase transformer with non-sinusoidal supply was used. The non-sinusoidal supply voltage is created by summing up different voltage sources with different magnitude and frequency. The simulink model for the setup is given below.

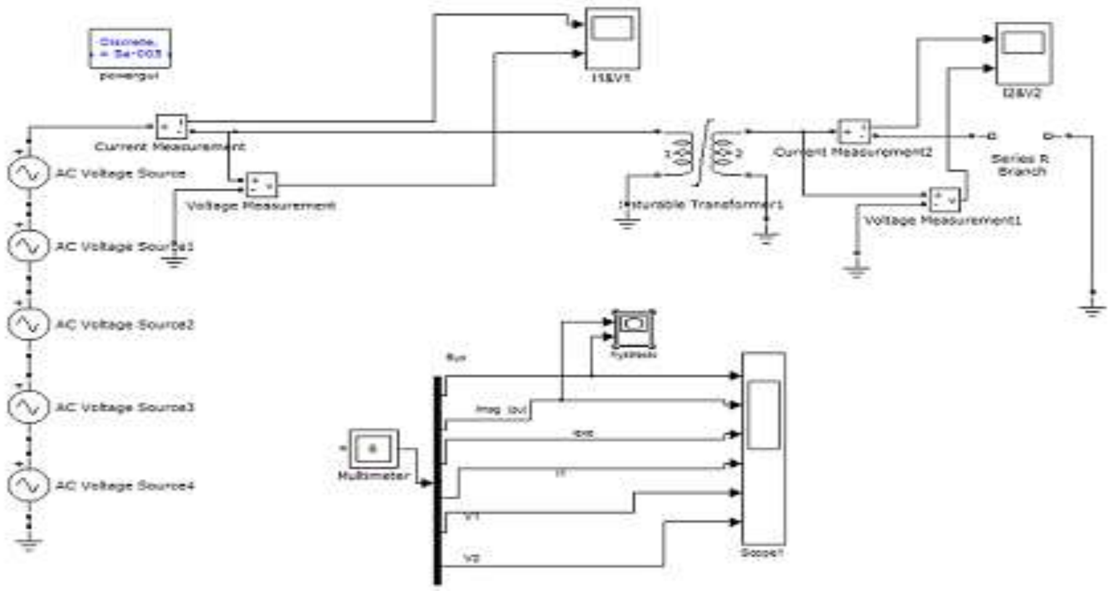

Fig 2: Simulink model of transformer with non-sinusoidal supply

EXPERIMENTAL RESULTS

The waveforms of the excitation current and hysteresis curve of the 100kVAdistribution transformer with non-sinusoidal supply are given below:

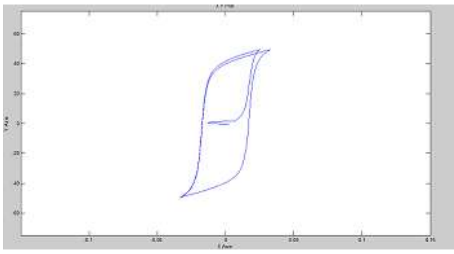

Fig 3(a)

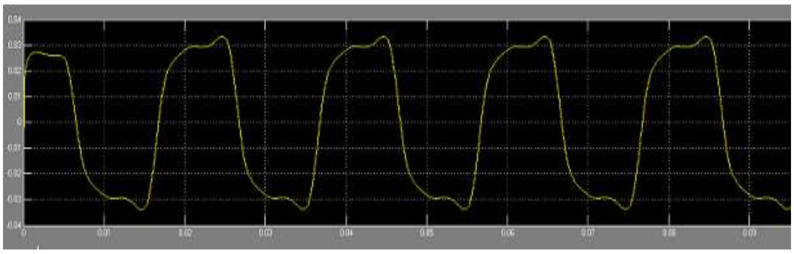

Fig 3(b)

Above figs are of hysteresis and excitation current waveforms at 1.0p.u

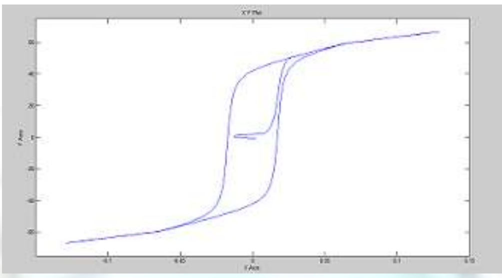

Fig 4(a)

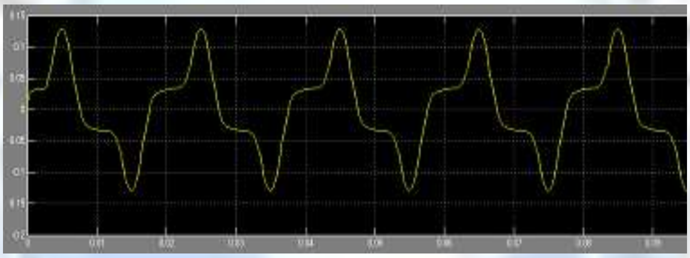

Fig 4(b)

Above figs are of hysteresis and excitation current waveforms at 1.35p.u

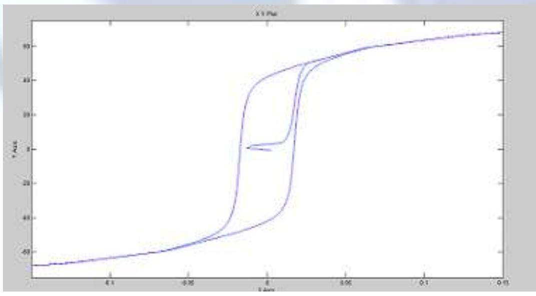

Fig 5(a)

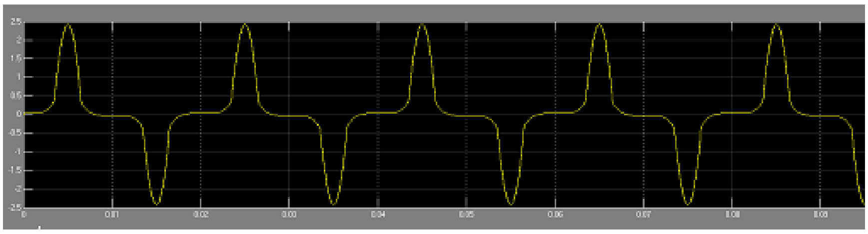

Fig 5(b)

Above figs are of hysteresis and excitation current waveforms at 1.75p.u**.**

CONCLUSION

From above result it concludes that at the non-sinusoidal supply the flux gets saturated due to the saturation in core. If supply voltage is non-sinusoidal then flux also becomes non-sinusoidal. As the non-linearity is increases in the supply voltage the total harmonic distortion is also increases. Total harmonic distortion is, 28.40% at 1.0p.u input voltage (nominal voltage), 50.20% at 1.35p.u of input voltage, and 85.25% at 1.75p.u (deep saturation) of supply voltage. From the above given values of the total harmonic distortion it is clear that total harmonic distortion is increases with increase in saturation. From the above results it is observed that the 3rd harmonic component in the supply voltage has the highest effect on the current harmonics and distortion.

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