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Modeling and analysis of 100 KVA distribution transformer including the core saturation effect

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Abstract: Magnetic core saturation of transformers and rotating machines generate harmonics. Harmonics are integer multiples of the fundamental frequency. Harmonics is caused by nonlinear devices in the power system. Due to the non-linear loads, power frequency harmonics exist mainly in distribution systems. The current harmonics cause voltage harmonics, hence resulting in nonsinusoidal supply voltage in the system. Harmonic voltage distortion may cause additional losses and heating in laminated transformer cores due to the distorted flux waveform. Meaning of saturation means that further increase in magnetic field force (mmf) do not result in proportional increase in magnetic field flux. This paper includes the effect of saturation on hysteresis and excitation current of 100kVA Distribution transformer. This paper presents a hysteresis based transformer simulink model to estimate transformer saturation. The basic idea of the method is to evaluate the transformer excitation current and hysteresis with and without core saturation effect. The whole system is studied in the MATLAB-Simulink Software and the corresponding results are obtained and analysis.

Keywords: Transformer modeling, saturation, hysteresis, MATLAB.

Introduction

Saturation is the state reached when an increase in applied external magnetic field *H* cannot increase the magnetization of the material further, so the total magnetic flux density *B* levels off. Saturation limits the maximum magnetic fields achievable in ferromagnetic-core electromagnets and transformers to around 2 T, which puts a limit on the minimum size of their cores. In electronic circuits, transformers and inductors with ferromagnetic cores operate nonlinearly when the current through them is large enough to drive their core materials into saturation. This means that their inductance and other properties vary with changes in drive current. In linear circuits this is usually considered an unwanted departure from ideal behavior. When AC signals are applied, this nonlinearity can cause the generation of harmonics and intermediation distortion.

In saturation a transformer core act as a source of current generating harmonics some of which will flow directly towards the primary windings and secondary windings. When a transformers primary winding is overloaded from excessive applied voltage, the core flux may reach saturation levels during peak moments of the alternating current sine wave cycle. If this happens the voltage induced in the secondary winding will no longer match the wave shapes as the power given to the primary winding.

In other words, the overloaded transformer will distort the wave shape from primary winding to the secondary winding by creating harmonics in the secondary winding outputs. Another cause of abnormal transformer core saturation is operation at which the frequencies lower than normal. Transformer saturation is also occurred due to presence of DC current in the primary winding. Any amount of DC voltage dropped across the primary winding of a transformer will cause additional magnetic flux in the core. This additional flux bias or offset will push the alternating flux waveform closer to the saturation in one half cycles than the other. 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].

1. Research Methodology

Transformer is one of the most common nonlinear elements in power systems. The nonlinearity is caused by the magnetizing characteristics of transformer iron core. The circuit model given below represents the transformer with windings resistances and leakage inductances [4].

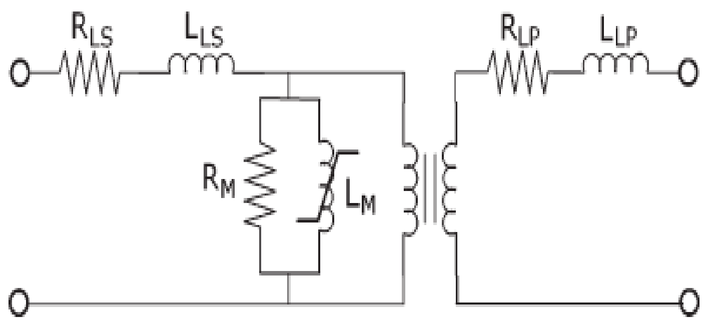

Fig.1: Single phase equivalent circuit of transformer

Examples of magnetic core saturation

There are many situations which contribute to magnetic core saturation. The following are some common examples [6].

Normal excitation

Even under normal excitation condition, transformer core may have entered, slightly, the saturation region and begin to generate some harmonics in the excitation current. The degree of the saturation depends on the transformer design.

Over excitation

Over excitation is basically caused by overvoltage. This problem is particularly onerous in the case of transformers connected to large rectifier plant following load rejection.
As in Fig.2, overvoltage drives the peak operation point of the transformer excitation characteristics up to saturation region so that more harmonics are generated.

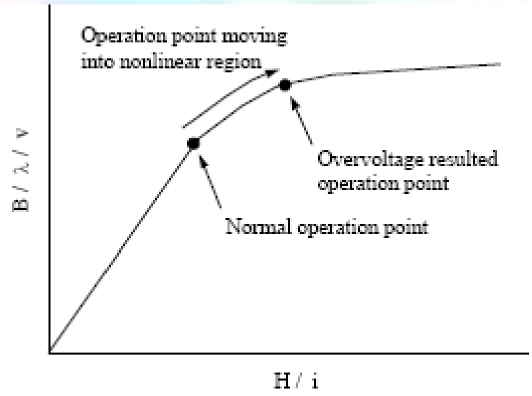

Fig. 2 Principle of overexcitation resulted transformer saturation

Converter load

Converter loads may draw DC and low frequency currents from supplying transformers. The transformer cores are biased by these load currents and driven to saturation

Geomagnetically Induced Currents (GIC)

Geomagnetically Induced Currents (GIC) flow on the earth surface due to Geomagnetic Disturbance (GMD). They are typically 0.001 to 0.1 Hz and could reach peak values as high as 200A. As in Fig. 3, they can enter transformer windings by way of grounded wye connections and bias the transformer cores to cause half cycle saturation.

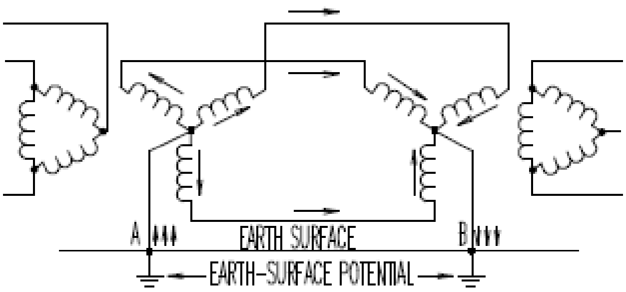

Fig:3: GIC entering the transformer winding

II. Data Analysis

In this section, calculation and simulation of transformer with and without core saturation will perform. Then results are compared.

2.1 Theoretical Data

3 phase, 50 Hz, 100 KVA, 11/0.433 KV 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

2.2 Transformer Model: To analyses the excitation current, the equivalent circuit of an unloaded single phase transformer was used. The simulink model for the setup is given below.

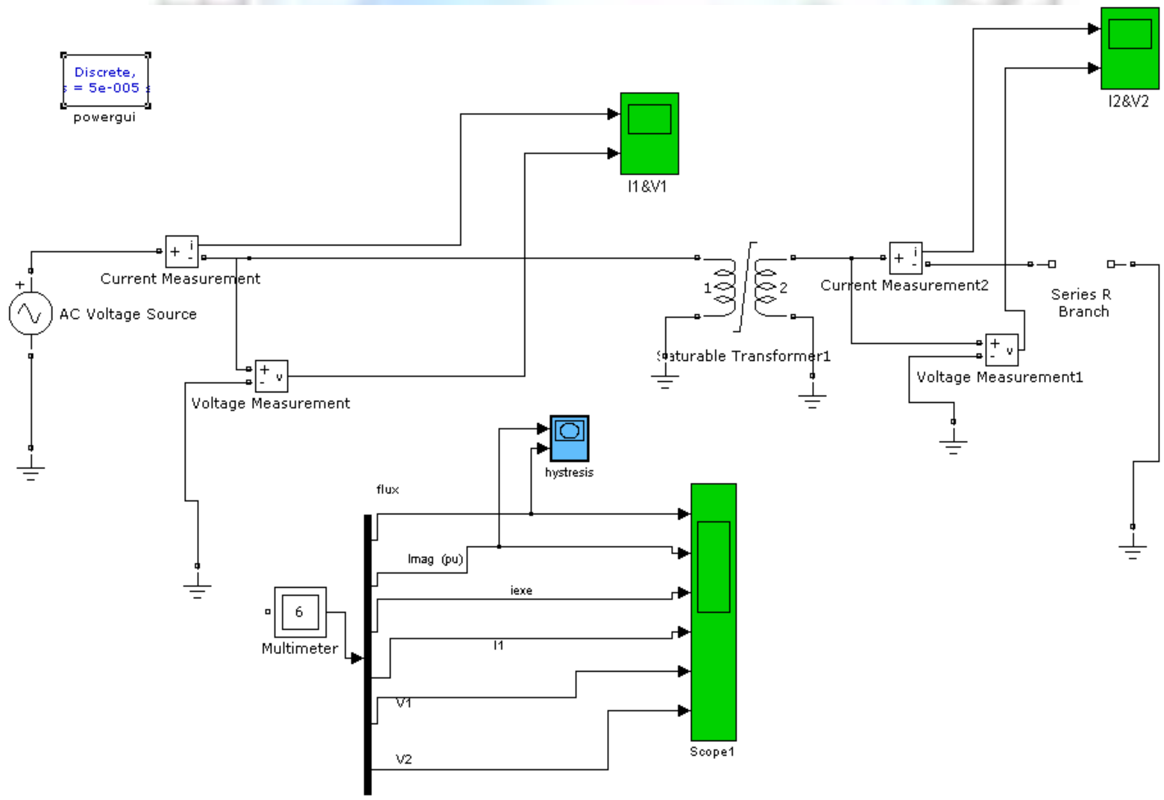

Fig 4: Simulink model of transformer for with and without core saturation

III. Experimental Results

The waveforms of the excitation current and hysteresis curve of the 100 KVA distribution transformer with secondary open circuited are given below.
There are 2 cases arising from the transformer model. These are the following

Case1: Modeling with sinusoidal supply without core saturation.
Case2: Modeling with sinusoidal supply with core saturation.

3.1 Modeling with sinusoidal supply without core saturation: at normal excitation

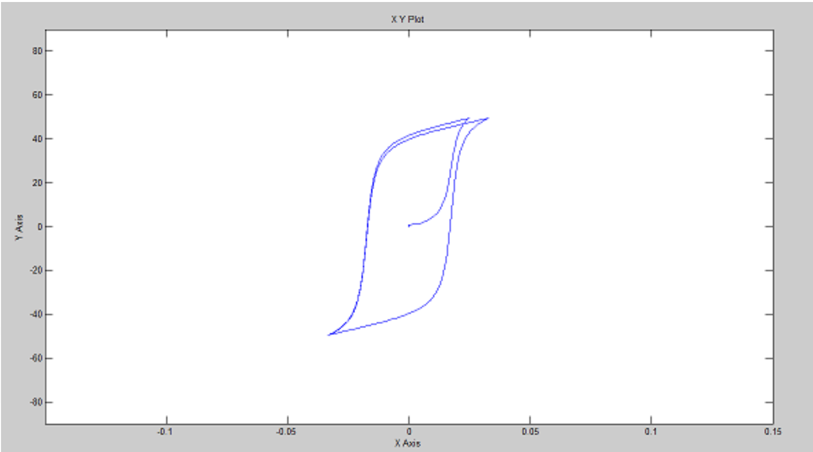

Fig 5. Hysteresis Curve for without Core Saturation

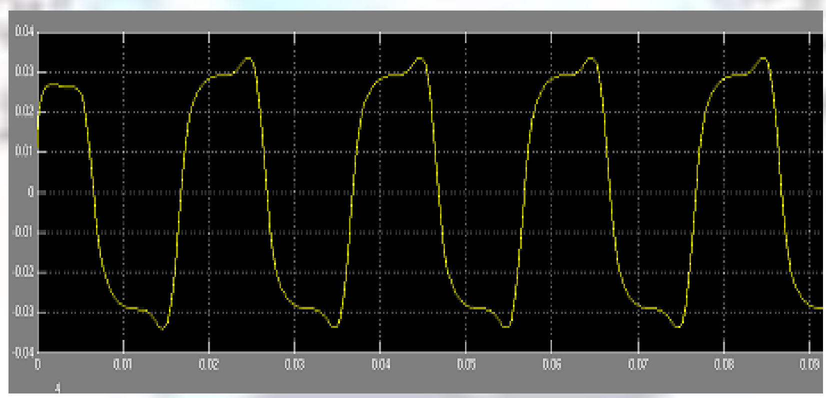

Fig 6. Excitation Current for without Core Saturation

3.2 Modeling with sinusoidal supply with core saturation: at overvoltage

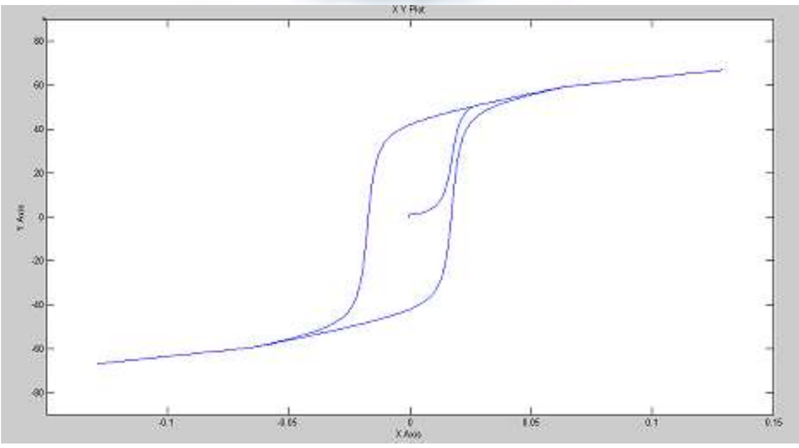

Fig 7. Saturated Hysteresis Curve

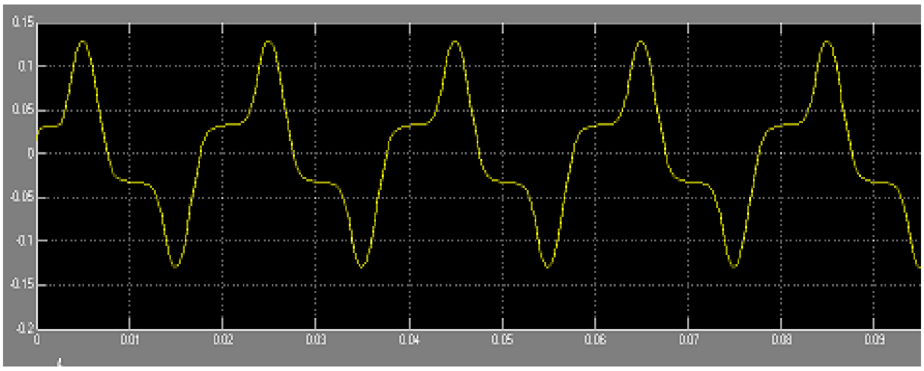

Fig 8. Excitation Current for Saturated Core

IV. Conclusion

Some of the modeling results are presented in figs 5-8. From above result it concludes that even under normal excitation saturated transformer core generate some harmonics in the excitation current and under over excitation i.e. 1.35p.u.voltage or above transformer core reached to saturation. Transformer core was just start to saturate at 1.21per-unit of the input voltage and at 1.35p.u of the input voltage transformer reached to deep saturation and their corresponding excitation current waveform are found as shown above. Transformer operation at deep saturation is suitable for power system and power electronics applications.

V. References

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