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Impact of different harmonic loads on distribution transformers

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Abstract

The increased usage of electrical load devices causes non-sinusoidal waveforms of currents and voltages in the power system. These harmonic loads have a significant impact on distribution transformers. The primary effect of harmonic currents are the additional power losses in transformer components, which result in increase in generated heat, as well as reduction of transformer's life-expectancy. This study examines the effects of different nonlinear loads on a dry-type three phase distribution transformer with rated power of 4.5kVA and rated voltage 440/380V. Measurements are done to several relevant parameters, such as: current and voltage high order harmonics, active and reactive power, power factor, total harmonic distortion etc. with sophisticated instruments in laboratory conditions. Using the measurement data, additional power losses are calculated according to the mathematical model proposed in the IEEE Std. C57.110-1998. This study shows an experimental confirmation of theoretically expected results.

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Keywords: Nonlinear loads; Transformer losses; Transformer's capability equivalent

1. Introduction

In todays electricity distribution system has been noticed a sudden increase in nonlinear loads, such as: computers, fluorescent lights, adjustable electromotor drives, power converters etc. These loads draw non-sinusoidal currents from the utility and cause distortion in the sinusoidal current and voltage waveforms, which are known as 'harmonics' [1]. According to Fourier, distorted waveforms can be represented as an infinite sum of pure sine waves

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in which the frequencies are integer multiples of the fundamental frequency of the distorted wave [2]. Since power system components are designed to operate at rated frequency and conditions, harmonics cause various problems: additional power losses and overheating in the electrical machines, excessive neutral currents, uncontrolled relay actions, possible resonance etc. The most common effects of nonlinear loads on distribution transformers are [3,4]:

- Saturation of transformer's core by changing its operating point towards the knee of the nonlinear B-H curve,
- Increase in core (hysteresis and eddy current) power losses,
- Increase in fundamental and harmonic copper losses,
- Increase in the temperature of windings, cleats, leads, insulation and oil, which can cause overheating,
- Bushings, tap changers and cable-end connections will also be exposed to higher stresses, which can result in transformer's failure,
- Transformer's efficiency reduction and power factor decrease,
- Transformer's derating,
- Reduction of transformer's life-expectancy etc.

Transformers are designed to deliver the required power to the load with minimum losses at the fundamental frequency. These losses are generally classified as no-load loss (excitation loss) and load loss (impedance loss). The sum of those two components forms transformer total loss [5]:

$$P_{TL} = P_{NL} + P_{LL} \tag{1}$$

The no load losses occur due to the voltage excitation of the core and losses due to magnetic hysteresis and eddy currents. Load loss is subdivided into I^2R loss and "stray loss". Stray loss is determined by subtracting the I^2R loss (calculated from the measured resistance) from the measured load loss (impedance loss).

Stray loss can be defined as the loss due to stray electromagnetic flux in the windings, core, core clamps, magnetic shields, enclosure or tank walls etc. Thus, the stray loss is subdivided into winding stray loss (P_{EC}) and stray loss in components other than windings (P_{OSL}). The winding stray loss includes winding conductor strand eddy-current loss and loss due to circulating currents between strands or parallel winding circuits. All of this loss may be considered to constitute winding eddy-current loss. The total load loss can be calculated as [5]:

$$P_{LL} = P + P_{EC} + P_{OSL} \tag{2}$$

Nomenclature

I	RMS load current [A]
I_1	RMS fundamental load current [A]
I_h	RMS current at harmonic h [A]
I_R	RMS fundamental current under rated frequency and rated load conditions [A]
I_{1-R}	High voltage rms fundamental line current under rated frequency and rated load conditions [A]
I_{2-R}	Low voltage rms fundamental line current under rated frequency and rated load conditions [A]
P_{EC}	Winding eddy-current loss [W]
P_{EC-R}	Winding eddy-current loss under rated conditions [W]
P	I^2R loss portion of the load loss [W]
P_{LL}	Load loss [W]
P_{LL-R}	Load loss under rated conditions [W]
P_{NL}	No load loss [W]
P_{OSL}	Other stray loss [W]
P_{OSL-R}	Other stray loss under rated conditions [W]
P_{TSL-R}	Total stray loss under rated conditions [W]