HARMONIC EFFECTS ON DISTRIBUTION TRANSFORMERS AND NEW DESIGN CONSIDERATIONS FOR K-FACTOR TRANSFORMERS

A Thesis presented to
the Department of Electrical Engineering
University of Moratuwa – Sri Lanka

In Partial Fulfillment of the requirement for the Degree

Master of Engineering in Electrical Engineering

by

N.R. JAYASINGHE

Thesis Supervisors Prof. J R Lucas
K.B.I.M Perera

Department of Electrical Engineering
Faculty of Engineering
University of Moratuwa
Sri Lanka

December 2003

Abstract

This paper presents the effects of harmonic distortion of load current & voltages on distribution transformers, the standard ways of calculating the harmonic effects & design & development of K Factor transformer, which can operate under a specific harmonic environment. The usage of non-linear loads on power systems has increased the awareness of the potential reduction of a transformer's life due to increased heat losses. The performance analysis of transformers in a harmonic environment requires knowledge of the load mix, details of the load current harmonic content & total THD. The additional heating experienced by a transformer depends on the harmonic content of the load current & the design principals of the transformer.

Both No load & Load losses are effected by the presence of harmonics in load currents. But the variation in load losses contributes more to excessive heat generation in distribution transformer. Increment in no load losses in a distribution transformer due to harmonics is less compared to the load loss but it has a significant contribution to the capitalization cost when operating in longer term.

The load loss components get affected by the harmonic current loading are the I^2R loss, winding eddy current loss & the other stray losses. The methods of predicting extra losses are described in this thesis and standard ways of de-rating transformers are also discussed.

The K-FACTOR method is an approximation of the total stray loss heating effect, including the fundamental and harmonic contributions & finally new design techniques for K-FACTOR transformers are discussed. In designing of K-FACTOR transformers different design techniques like parallel conductor arrangement for windings, lower flux density & introduction of static shields are discussed & the estimated results are compared with actual implemented results.

DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge and behalf, it contains no material previously published or written by another person nor material, which to substantial extent, has been accepted for the award of any other academic qualification of an university or institute of higher learning except where acknowledgement is made in text.

N.R.Jayasinghe
December 2003

UOM Verified Signature

Professor J.R. Lucas
Project Supervisor
December 2003

UOM Verified Signature

K.B.I.M Perera
Project Supervisor
December 2003

Acknowledgement

I express my sincere gratitude to Prof. Rohan Lucas and Mr. Manjula Perera For all the encouragement, guidance and support given throughout to make this task a success.

I also would like to thank Mr. Kosala Gunawardana, Factory Manager, Lanka Transformers Ltd, Transformer plant and Dr. Sarath Perera and Dr. Lalith Wickramaratne for the support given in numerous ways.

Finally A big thank goes to my wife Chamari for finding me free time to do the research and baby Rumeth for being a quite and nice during that period.

CONTENTS

LIST OF SYMBOLS

θ_a = Ambient temperature (°C)

θ_g = Hottest-spot conductor rise over top-oil temperature (°C)

θ_{g-R} = Hottest-spot conductor rise over top-oil temperature under rated conditions (°C)

θ_{g1} = Hottest-spot HV conductor rise over top-oil temperature (°C)

θ_{g1-R} = Hottest-spot HV conductor rise over top-oil temperature under rated conditions °C)

θ_h = Ultimate (steady state) hot spot temperature (°C)

θ_{TO} = Top-oil rise over ambient temperature (°C)

θ_{TO-R} = Top-oil rise over ambient temperature under rated conditions (°C)

ϕ_2 = Power factor angle

$\Delta\theta_{oi}$ = Initial top oil temperature rise

$\Delta\theta_{on}$ = Top oil temp. rise at end of n^{th} interval

$\Delta\theta_{o(n-1)}$ = Top oil temp. rise at end of $(n-1)^{th}$ interval

$\Delta\theta_{or}$ = Top oil rise at rated current

$\Delta\theta_{ot}$ = Top oil temp. rise after time t

$\Delta\theta_{ou}$ = Ultimate top oil temp. rise corresponding to load during time t

$\Delta\theta_{oun}$ = Ultimate top oil temp. rise in n^{th} interval

$\Delta\theta_{our}$ = Ultimate top oil temp. rise corresponding to rated current

$\Delta\theta_{td}$ = Temperature difference between hot spot and top oil

$\Delta\theta_{tdr}$ = Temperature difference between hot spot and top oil at rated current

ρ = Number of wound legs

a_{rad} = Thickness of conductor in radial direction

B_m = Peak Flux density

c_{st} = Axial saray loss constant for the winding material at 75 °C

F_{HL} = Harmonic loss factor for winding eddy currents

F_{HL-STR} = Harmonic loss factor for other stray losses

F_{IR} = Harmonic loss factor for winding I^2R loss

f = Frequency

f_a = Fill factor in axial direction

h = Harmonic order

I = RMS load current

I_1 = RMS fundamental load current (ampere)

I_h = RMS current at harmonic "h" (ampere)

I_R = RMS fundamental current under rated frequency and rated load conditions (ampere)

I_{H-R} = High voltage (HV) rms fundamental line current under rated frequency and rated load conditions (amperes)

I_{L-R} = Low voltage (LV) rms fundamental line current under rated frequency and rated load conditions (amperes)

I_T = Sum of HV and LV line currents

K_h = hysterisis constant

K_e = eddy current constant

K_f = Form factor

L = Loss of Life in per unit days

N_2 = No. of turns in LV coil

n_{rad} = Number of layers in radial direction

P = I^2R loss portion of the load loss (watts)

P_{EC} = Winding eddy-current loss (watts)

P_{EC-R} = Winding eddy-current loss under rated conditions (watts)

P_{EC-O} = Winding eddy-current loss at the measured current and the power frequency (watts)

P_K = nominal load losses

P_{LL} = Load loss (watts)

P_{LL-R} = Load loss under rated condition (watts)

P_{NL} = No load loss (watts)

P_0 = idle losses

P_{OSL} = Other stray loss (watts)

P_{OSL-R} = Other stray loss under rated conditions (watts)

P_{TSL-R} = Total stray loss under rated conditions (watts)

P_V = Losses at actual loading

LR = Loss ratio = $\frac{\text{Load loss at rated current}}{\text{No load loss}}$

R = DC resistance (ohms)

R_1 = DC resistance measured between two HV terminals (ohms)

R_2 = DC resistance measured between two LV terminals (ohms)

S = Rating of the transformer

t = time interval of application of specific load

$t_2 - t_1$ = period under consideration T

T_p = Peak duration

τ_o = Oil time constant

V_r = % resistance voltage at full load

V_x = % leakage reactance voltage at full load

V_R = % voltage regulation

x = Oil exponent

y = Winding exponent

Z = Impedance voltage