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DECLARATION

The work submitted in this dissertation is the result of my own investigation, except where otherwise stated.

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CONTENTS

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Abstract

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Accelerated ageing occurs in transformers when loads exceed nameplate ratings or ambient temperature exceeds the design value. A software package has been developed by the authors based on IEC 354: *Loading guide for oil immersed power transformers*. It identifies the risks involved and indicates how transformers may be loaded in excess of the nameplate rating (abnormal loading) without adverse effects for specific load curves.

A matrix formulation of top oil temperature allows a near continuous load curve simulation. The relative ageing rate is calculated using Simpson's rule. Results of the package agree exactly with the two step approach specified in the Loading guide for two step load curves. However, it is shown that the two step approximation gives somewhat inaccurate results for certain practical complex load curves. Thus use of the package could minimize unexpected future damages to transformers.

Calculations have been done based on practically obtained data to determine the excess voltage regulation introduced by the abnormal loading and the variation of efficiency of a practical induction motor within this range of voltages. These show that there is no adverse effect on motor efficiency. In addition other general effects of voltage regulation on induction motor characteristics were also considered with the guidance of IEEE standard 141:1993. This shows that while there is no significant change in the full load speed and efficiency the starting and running torque varies as the square of the voltage and can drop to about 81% at a maximum possible voltage drop of 10%.

Acknowledgement

Thanks are due first to my supervisor, Professor Name, for his great insights, perspectives, guidance and sense of humor. My sincere thanks go to the officers in Post Graduate Office, Faculty of Engineering, University of Moratuwa, Sri Lanka for helping in various ways to clarify the things related to my academic works in time with excellent cooperation and guidance. Sincere gratitude is also extended to the people who serve in the Department of Electrical Engineering office.

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Chapter 1

Introduction

It is well known that accelerated ageing occurs when a transformer is overloaded and when the ambient

temperature increases above normal. The standard *IEC 354: Loading guide for oil immersed power transformers*[1] indicates how transformers may be loaded in excess of the nameplate rating (abnormal loading) for load curves with a two step approximation. Based on this guide, a software package [2] has already been developed to provide guidance for daily cyclic loading of ONAN type distribution transformers without on-load tap changing complying with IEC 76: Power Transformers. This package indicates how transformers, with a maximum rating of 2500 kVA three phase and high voltage 33 kV, may be loaded in excess of their nameplate rating, within limitations. It can also be used to select a transformer of optimum capacity for a given loading condition and to check the utilization of an existing transformer.

A distribution transformer is usually rated for continuous operation at that value. However, extraordinary events, such as over-voltages, short-circuits in the system and emergency loading can affect the life of a transformer to a high degree. It has been identified that the consequences [3,4] of loading a transformer beyond name-plate rating are (i) the temperatures of windings, insulation, oil etc. increase and can reach unacceptable levels, (ii) the leakage flux density outside the core increases, causing additional eddy current heating in metallic parts linked by the flux, (iii) the moisture and gas content in the insulation and in the oil increase with the temperature increase, and (iv) bushings, tap-changers, cable-end connections and current transformers are exposed to higher stresses.

Sample Chapter Start

Chapter 2

Concept of Switching Computed Torque Method (SCTM)

In recent past, there is a considerable interest in employing switching controllers to control nonlinear systems, for which conventional controllers cannot especially meet the demand [47]–[53]. Basically, there are two kinds of switching schemes: Direct switching: the choice of when to switch to the next controller, in predetermined sequence, is based directly on the output of the plant. Indirect switching: multiple models are used to determine both when and to which controller one should switch.

Figure 2.1 - Faraday's first transformer

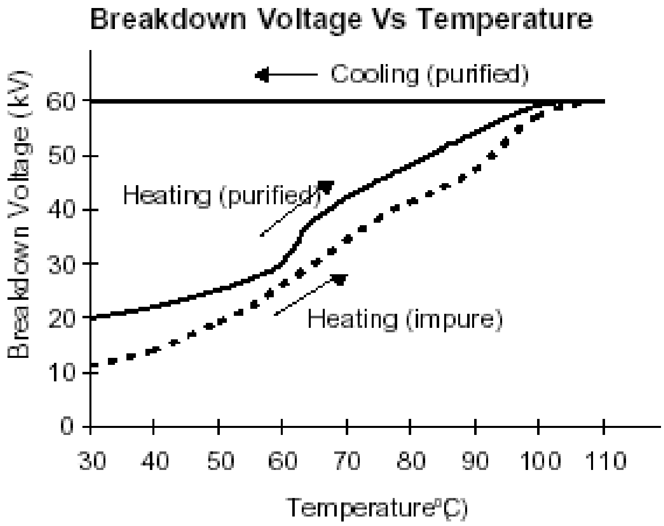

Figure 1 - Heating/Cooling Curve of Coconut Oil

State of solidification	Breakdown voltage (kV) of 2.5 mm gap
liquid	60.00, 60.21, 60.07, 60.07, 60.00
partially solid	59.65, 59.79, 60.07, 60.21, 60.21
solid	60.00, 58.33, 60.00, 60.00, 60.07

Table 1 - Breakdown strength of Coconut Oil

$$\Delta\theta_{ou} = \Delta\theta_{or}\left[\frac{1 + RK^2}{1+R}\right]^X \tag{2.1}$$

$$\begin{bmatrix} 1 & 0 & 0 & --- & 0 & (C-1) \\ (C-1) & 1 & 0 & --- & 0 & 0 \\ 0 & (C-1) & 1 & --- & 0 & 0 \\ : & : & : & :\ :\ : & : & : \\ 0 & 0 & 0 & --- & (C-1) & 1 \end{bmatrix} \begin{bmatrix} \Delta\theta_{o1} \\ \Delta\theta_{o2} \\ \Delta\theta_{o3} \\ : \\ \Delta\theta_{on} \end{bmatrix} = \boldsymbol{C} \begin{bmatrix} \Delta\theta_{ou1} \\ \Delta\theta_{ou2} \\ \Delta\theta_{ou3} \\ : \\ \Delta\theta_{oun} \end{bmatrix} \tag{2.2}$$

Chapter 7

Conclusions

The software package is developed based on the standard equations given in IEC 354 guide. The software package can be applied to any complex shape of load curve. Hence this package gives a solution to the tedious manual calculations involved with complex load profiles found in reality.

The studies made shows that the results obtained for loss of life is more precise with the software package, than with manual two step approximation. This will help to reduce unexpected damage to the transformer in the future.

The practical results obtained for transformer voltage regulation shows that it has no significant effect on the

distribution network at acceptable loading conditions above nameplate rating.

With regard to industrial loads such as induction motors, again the test results show that the voltage drops caused by loading transformers above nameplate rating has no major effect on its performance other than for the reduction in the starting and maximum running torque.

Thus it is recommended that maximum utilisation of the transformer be made allowing loading beyond nameplate rating within specified limits.

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APPENDIX – A : Definitions for Economic Evaluation

A.1 Time Value of Money

Two sums of money at different points in time are difficult to compare directly [16] due to change in value with time. Value changes due to two basic reasons

- Economic forces such as inflation changing buying power of money
- Possibility of investing money for a real return, independent of inflation

All monetary values need to be equated to a common point in time. Rs. 100 today is worth more than Rs. 100 a year from now if money can be invested to produce a return on investment. This discount rate used in project evaluations reflects the time value of money. Thus a future sum of money F, at the end of *n* periods is given by equation (B 1)

$$F = P(1+r)^n \qquad (B1)$$

where, P = initial amount
r = percentage discount rate

B.2 The Annuity

The capital cost of an investment in certain equipment should be distributed over a specific number of years, i.e. the *economic lifetime* of the equipment. The annuity of annual cost of an investment is then given by equation (B2),

$$A = r(1+r)^N/[(1+r)N - 1] \qquad (B2)$$

where, N = economic life time