UNIVERSITI PUTRA MALAYSIA

TRANSFORMER T-JOINT OPTIMIZATION USING PARTICLE SWARM OPTIMIZATION AND HEMISPHERE-SHAPE DESIGN OF THE CORE

OMAR SHARAF AL-DEEN YEHYA

TRANSFORMER T-JOINT OPTIMIZATION USING PARTICLE SWARM OPTIMIZATION AND HEMISPHERE-SHAPE DESIGN OF THE CORE

By

OMAR SHARAF AL-DEEN YEHYA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

August 2017

DEDICATION

This thesis is dedicated to my parents

For their endless love, support and encouragement

And

To my beloved family (my wife and my children)

Especially my wife who leads me through the valley of the darkness with light of hope and support

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Doctor of Philosophy

TRANSFORMER T-JOINT OPTIMIZATION USING PARTICLE SWARM OPTIMIZATION AND HEMISPHERE-SHAPE DESIGN OF THE CORE

By

OMAR SHARAF AL-DEEN YEHYA

August 2017

Chairman : Professor Mohd Zainal Abidin Ab. Kadir, PhD, PEng
Faculty : Engineering

Transformers are considered as a key in the transmission and distribution of electrical energy. The increases for electricity have encouraged the manufacturers to produce huge numbers of transformers for different sizes and ratings to work on the electric grid in order to meet market demands. The electrical power engineering and transformer experts seek to achieve the best economic and practical operation of electrical power system transformers, which include minimizing losses that are generated inside the transformers. The losses in transformers can be significantly reduced, especially in the core by improving the performance of the joint design. Several factors and parameters contribute to core losses such as shape of joint, gaps in between the joint parts, thickness of laminations, overlapping, orientation and number of laminations per stack.

In this study, an intelligent algorithm was carried out using the particle swarm optimization technique (PSO) to propose the optimum design of T-joints for the core in three-phase distribution transformers. This technique was applied to design a new geometry of joint to get the minimum losses and to reduce the temperature in three-phase transformers. The smart algorithm proposed in this study presents the following advantages: (i) the correlation between the angles of the T-joint and gaps, (ii) the core loss profiles with temperature were considered, and (iii) the system was examined under different operational conditions.

The transformer was simulated on the basis of real dimensions obtained from the transformer manufacture's data. Furthermore, a 3D finite element analysis software model for transformer coupling with particle swarm optimization (PSO) technique was used and is validated by corresponding experiments. The simulation results have been validated with the manufacturer's data of transformer rated at 1000 KVA.

Practically, good agreements were obtained between the simulation results and the experimental data. The important parameters in the core joint design were emphasized through a comparison of the losses in various types of T-joint designs. The core losses, total losses were reduced for the new proposed model.

The core and oil temperature underwent a good reduction as compared with the conventional T-joint designs. The core losses in the proposed design reduced more than 11% and 7% when using material M5 and M4 respectively. While more than 25% of the core loss reduction occurred when using material M6. The total owing cost for energy saving for different materials in the different T-joint designs indicated a life cycle, saving of RM 1297 for the M5 material and RM 1971 for the M6 material per transformer when compared to a conventional T-joint design of the same rating. Moreover, the proposed intelligent algorithm in this work can improve the transformer core design as well as can be applied to various power and distribution transformers.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

OPTIMISASI PENGUBAH T-JOINT MENGGUNAKAN TEKNIK PENGOPTIMUMAN KELOMPOK ZARAH (PSO) DAN REKA BENTUK TERAS SEPARA SFERA

Oleh

OMAR SHARAF AL-DEEN YEHYA

Ogos 2017

Pengerusi : Profesor Mohd Zainal Abidin Ab. Kadir, PhD, PEng
Fakulti : Kejuruteraan

Pengubah adalah dianggap terpenting dalam penghantaran dan pengagihan tenaga elektrik. Peningkatan tenaga elektrik telah menggalakkan pengilang untuk menghasilkan pengubah dengan pelbagai saiz dan kadaran untuk beroperasi di grid elektrik untuk memenuhi permintaan pasaran. Pada masa ini, kejuruteraan kuasa elektrik dan pakar pemindahan berusaha untuk mencapai operasi ekonomi dan praktikal yang terbaik untuk pengubah sistem kuasa elektrik, termasuk meminimumkan kerugian yang dijana di dalam pengubah. Kerugian-kerugian di dalam pengubah tiga-fasa boleh dikurangkan dengan ketara terutamanya di teras dengan menambahbaikan prestasi reka bentuk sambungan. Beberapa faktor dan parameter menyumbang kepada kerugian teras seperti bentuk sambungan, jurang di antara bahagian-bahagian sambungan, ketebalan pelapisan, pertindihan, orientasi dan bilangan pelapisan setiap timbunan.

Di dalam kajian ini, suatu algoritma pintar telah dijalankan dengan menggunakan teknik pengoptimuman sekelompok zarah (PSO) bagi mencadangkan reka bentuk optimum sambungan-T untuk teras dalam pengubah pengedaran tiga-fasa. Teknik ini telah digunakan untuk mereka bentuk geometri baru sambungan untuk mendapatkan kerugian minimum (tanpa-beban dan dengan beban) dan untuk mengurangkan suhu minyak di dalam pengubah tiga-fasa. Algoritma pintar yang dicadangkan di dalam kajian ini membentangkan kelebihan berikut: (i) korelasi antara sudut sambungan-T dan jurang, (ii) profil kerugian teras dengan suhu telah dipertimbangkan, dan (iii) sistem itu diperiksa di bawah keadaan operasi berbeza (dengan beban dan tanpa-beban).

Pengubah itu disimulasi berdasarkan dimensi sebenar yang diperolehi daripada data pengilang pengubah. Untuk mencapai sasaran ini, suatu model perisian analisis berunsur 3D untuk gandingan pengubah dengan teknik pengoptimuman sekelompok zarah (PSO) digunakan dan disahkan oleh eksperimen yang sepadan. Selain itu, tiga jenis bahan-bahan teras yang penting telah digunakan untuk model-model yang dicadangkan. Alat perisian yang telah digunakan di dalam kajian ini adalah Ansys Workbench, dan juga untuk pra dan pasca pemprosesan termasuk antara muka dengan MATLAB. Keputusan simulasi telah disahkan dengan data pengilang bagi pengubah pengedaran tiga-kaki tiga-fasa berkadaran 1000 KVA dan persetujuan yang agak baik telah diperolehi antara simulasi dan kerja eksperimen. Parameter penting di dalam reka bentuk sambungan teras telah diberi penekanan melalui perbandingan antara kerugian dalam pelbagai reka bentuk sambungan-T. Menurut keputusan simulasi dan eksperimen, kerugian teras dan jumlah kerugian telah dikurangkan untuk model baru yang dicadangkan.

Teras dan suhu minyak menjalani pengurangan yang baik berbanding dengan reka bentuk sambungan-T konvensional. Keputusan simulasi menunjukkan bahawa kerugian teras dalam reka bentuk yang dicadangkan dikurangkan lebih daripada 11% dan 7% apabila menggunakan bahan M5 dan M4 masing-masing. Manakala lebih daripada 25% daripada pengurangan kerugian teras telah diwujudkan oleh penggunaan bahan M6. Jumlah kos terhutang untuk penjimatan tenaga bagi bahan-bahan yang berbeza dalam reka bentuk sambungan-T yang berbeza menunjukkan penjimatan sepanjang kitaran hidup sebanyak RM 1297 untuk bahan M5 dan RM 1971 untuk bahan M6 bagi setiap pengubah berbanding reka bentuk sambungan-T konvensional yang sama kadarnya. Selain itu, algoritma pintar dalam kajian ini boleh meningkatkan reka bentuk teras pengubah dan juga boleh digunakan untuk pelbagai pengubah kuasa dan pengagihan dengan kadaran yang berbeza.

ACKNOWLEDGEMENTS

First and foremost, great thanks, glories and praises devoted to God (Allah), the Supreme Ruler of the universe who created us, for giving us ability to think and power to perform our duties.

Profound and sincere gratitude is extended to my supervisor Professor Mohd Zainal Abidin Ab. Kadir for his great advice, encouragement, valuable guidance, and foresight throughout the years. This thesis would have never been completed without his assistance. He has helped me in providing all facilities required to do this work. It is my pleasure also to thank the active members of my supervisory committee, Dr. Mahdi Izadi, Prof Chandima Gomes, Dr. Norhafiz Azis and Dr. Maryam Mohd. Isa, for their suggestions, assistance and support during my research.

I would like also to express my deepest appreciation and thanks to Iraqi Government represented by Ministry of Higher Education and Scientific Research, Scholarship and Cultural Relations Directorate, Iraqi Embassy and Cultural Attaché in Kuala Lumpur, for the opportunity to given in pursuing the PhD degree at Universiti Putra Malaysia. I would like to thank Malaysia Transformer Manufactory for experimental transformer data.

Last but not least, I acknowledgment my family (my parents, brothers, sisters, and my wife) and my friends for their support, help and encouragement.

I certify that a Thesis Examination Committee has met on 21 August 2017 to conduct the final examination of Omar Sharaf Al-Deen Yehya on his thesis entitled "Transformer T-Joint Optimization using Particle Swarm Optimization and Hemisphere-Shape Design of the Core" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Mohd Nizar bin Hamidon, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Jasronita binti Jasni, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Mohd Amran bin Mohd Radzi, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Jinliang He, PhD
Professor
Tsinghua University
China
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 28 September 2017

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Mohd Zainal Abidin Ab. Kadir, PhD, PEng
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Chandima Gomes, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mahdi Izadi, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Norhafiz Azis, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software

Signature: ____________________________ Date: __________________

Name and Matric No.: Omar Sharaf Al-Deen Yehya , GS38680

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature: ____________________
Name of Chairman of Supervisory Committee: Professor Dr. Mohd Zainal Abidin Ab. Kadir

Signature: ____________________
Name of Member of Supervisory Committee: Professor Dr. Chandima Gomes

Signature: ____________________
Name of Member of Supervisory Committee: Dr. Mahdi Izadi

Signature: ____________________
Name of Member of Supervisory Committee: Dr. Norhafiz Azis

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

A	core cross-section area
B	Magnetic Flux density
B_m	Maximum flux density
BIL	Impulse insulation level
C	Temperature
c_1	Cognitive
c_2	Acceleration factors
CRGO	Cold-Rolled Grain-Oriented Silicon Steel
D	Diameter of core transformer
E	Electric field intensity
F	frequency
FEM	Finite Element Method
g	Velocity
Hi-B	High-permeability, cold rolled grain oriented
HRGO	Hot rolled grain oriented
HV	High-voltage
H	Magnetic field intensity
I	Current
J	Current density
K_e	Co-efficient of eddy current
K_h	Hysteresis or Steinmetz's constant
L	length of flux path
LV	Low voltage

M4	Core material grade M4
M5	Core material grade M5
M6	Core material grade M6
N1	Number of primary windings
N2	Number of secondary windings
p	Position
Pa	Stray losses
P_e	Eddy current losses
P_h	Hysteresis loss
PSO	Particle Swarm Optimization
R	Resistance
Ř	Reluctance
SASI	Swanson as Swanson Analysis Systems
TOC	Total owning cost
V1	Primary voltage
V2	Secondary voltage
w	Initial inertia weights
μ	Permeability of the material
μ_o	Permeability of the air
μ_r	relative permeability of steel
α_1	Angle of the T-joint
γ	Conductivity
Φ	Magnetic flux

CHAPTER 1

INTRODUCTION

1.1 Background

Three-phase are essential components in electrical power systems which transfer electrical energy from the power plants to the loads. Distribution transformers have intrinsically high efficiencies in comparison with other electrical equipment, especially as they are in constant operation and have a comparatively long lifespan. They are utilised in great numbers to enable and provide electricity distribution to the customers and end users (Lutchman, 2012). A huge number of distribution transformers have been working steadily and continuously in electrical network grids.

Nevertheless, the efficiency of transformers is not 100% as there are electrical losses associated with them. Although transformer efficiency during operation at full load is very high, but the losses are always present even with no load. In spite of operating with high efficiencies, the loss issue still attracts the attention of researchers. The power efficiency in transformers has been often greater than 98 % at its highest level (Ilo et al., 2000). The core loss represents about 70 % of the total losses of the transformer whereas the operating efficiency is 93.38 %.

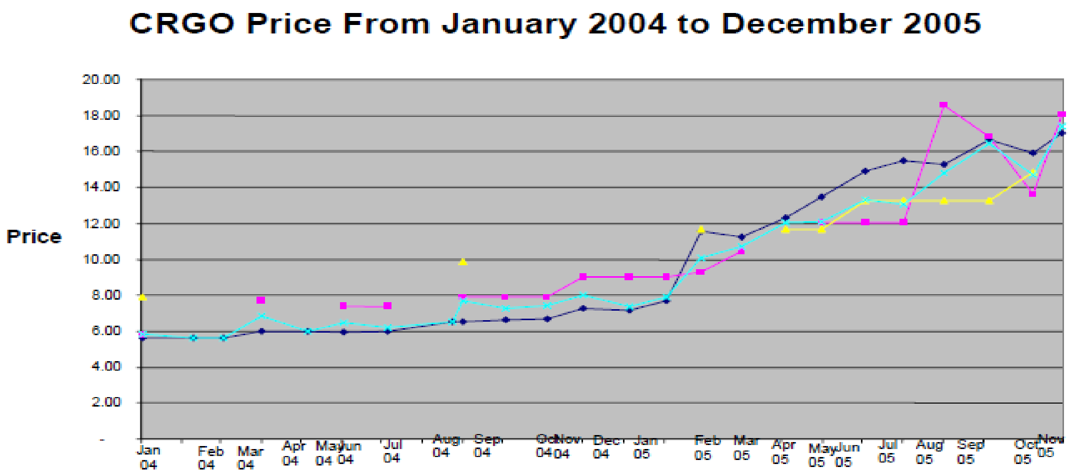
In twenty five European Union countries (EU-25) and generally around the world, there is anxiety about the no-load losses that should be minimized as much as possible (Targosz and Topalis 2007).

Moreover, there are three important solutions to reduction the losses in transformer. One of them is to use better material. Another way is to improve the cooling medium and methods. The third one is to improve the distribution of flux by changing the geometry of the core design. For the first one, the economic factor is present here which means, can get a good performance for transformer if used high quality core materials but the cost is very high. In the recent years, cost of cold-rolled grain-oriented steel (CRGO) increase. Silicon iron for cores of transformers is supplied by a few factories which are quite renowned for this material. Major manufacturers are Posco of Korea, Nippon and Kawasaki of Japan, and manufacturers from East Europe, Russia and American continental nations.

The most prevalent CRGO electrical steel utilised is M5 which was at RM5.60 per/kg in January 2004; the cost in December 2005 was about RM17.04 per/kg, a price upsurge of 304 %. Figure 1.1 shows the average cold-rolled grain-orientated (CRGO) steel price graph which reveals that the highest price level was from February 2005 to December 2005 for each of the CRGO grades (Daut and Uthman

2006). For the second solution which can be used to reduction the losses in transformer is related to the cooling technique, but for this solution, the economic factor is very high because should be known about the heat distribution inside the core, windings and oil.

Furthermore, more information about oil properties and which type of oil should be used in the different rated of transformers. Therefore, as a result, any saving or minor increase in efficacy can amount to considerable savings over the lifetime of the transformer (Leonardo, 2010).



	Jan 04	Feb 04	Mar 04	Apr 04	May 04	Jun 04	Jul 04	Aug 04	Sep 04	Oct 04	Nov 04	Dec 04
Slit Coil, M5	5.60	5.60	5.60	6.00	5.97	5.97	5.97	6.50	6.53	6.63	6.68	7.27
Slit Coil, MOH	5.80			7.68		7.40	7.40		7.90	7.90	7.90	9.00
Slit Coil, ZDKH	7.90								9.85			
Average of Price	5.82	5.60	5.60	6.86	5.97	6.48	6.22	6.50	7.71	7.28	7.40	8.03

	Jan 05	Feb 05	Mar 05	Apr 05	May 05	Jun 05	Jul 05	Aug 05	Sep 05	Oct 05	Nov 05	Dec 05
Slit Coil, M5	7.18	7.67	11.55	11.27	12.29	13.47	14.91	15.50	15.29	16.65	15.89	17.04
Slit Coil, MOH	9.00	9.00	9.27	10.44		12.04	12.04	12.04	18.55	16.81	13.64	18.06
Slit Coil, ZDKH			11.65		11.65	11.65	13.25	13.25	13.25	13.25	14.85	
Average of Price	7.37	7.90	10.06	10.73	12.02	12.09	13.32	13.04	14.82	16.44	14.70	17.42

Month

Slit Coil, M5 — Slit Coil, MOH — Slit Coil, ZDKH — Average of Price

Figure 1.1 : Price of CRGO material (Daut and Uthman 2006)

For the third solution (related to the geometry of joints) which effect to the losses profiles because any change of the core design has effect to the performance of the core. The central limb is linked to the base yoke and the top yoke and this joint is known as a T-joint. The T-joint is regarded as the spine of the transformer core since it affords a mechanical support for the core and a large amount of the magnetic flux is routed through the T-joint connection. Efficiency of any type of transformer depends on numerous factors, one of these factors is the joint design of the core (corner and T-joints). The relationship between the losses profiles with different geometries of the core T-joint is very complex. The core of a transformer is built from assembled numerous packages which have different thicknesses. The semi-circular yokes tend to be joint with circular limbs so the features of a core joint are considered to be a complex 3D system. In a transformer, core losses and the behaviour of the magnetic flux are crucial for its design (Høidalen et al., 2016; Lotfi and Rahimpour 2013). As a very rough guide, increasing the flux density by 1 %

causes an increase in losses by about 2 % (Pfützner et al., 2014). On the other word, most of the losses inside the transformers followed by a rise of temperature which means any reduce of losses, the temperature reduces and vice versa. Hence there is an urgent need to find a suitable way in the design of the transformer core to reduce the losses.

1.2 Problem Statement

The majority of these researches have focused on flux behaviour and localize losses in the T-joint area. However, there are many subjects in this matter has not been addressed in the previous studies. Currently, power transformer core joints generally use 45° mitred overlap joints (Bengtsson et al., 1989). Moreover, for laboratory studies, most of researcher have used few laminations to build the core of transformer to measure the localize losses and flux but this method does not give a real impression of the behaviour of core. From all the investigation in the literature, it is obvious that the main problem in the core design, it is coming from the joints. Although the above has been researched, so far there have been very few studies suggesting a new shape of T-joint design to reduce core loss and to achieve efficient flux behaviour in the core transformer. Thus, it is essential to find the optimum design of T-joint for core in three-phase transformer. There are many significant points which can be highlighted from previous studies and the research gaps brought to light as follows:

1. There is a lack of technique and justification to evaluate the T-joint parts and most studies are based on trial and error methods, whereas the angle should be evaluated based on the transformer conditions by considering other parameters at the same time.
2. No significant available concerning the correlation between T-joint angles, length of flux path (L) and the gaps in the joint area.
3. Lack of consideration on the T-joint design and the gaps between the joints under different load conditions as most studies consider only the no load condition whereas by increasing I, then B increased and losses increased.
4. No significant study focused on both aspects of the design of the core parameters in the presence of oil and considered the thermal profiles at the same time as the losses. This is significant because the gaps in the joints inside the transformer are filled using oil and the thermal behaviour of the oil is therefore very significant, especially in the ageing of a newly designed transformer.
5. The correlation between the joint design with the gaps and temperature profiles has not been addressed in previous studies.

1.3 Research Objectives

The main aim of this study is to propose a new model of the T-joint in a distribution transformer in order to improve the behaviour of the core and reduction the losses within the transformer. To attain this objective, it is essential to conduct several tasks in the area of transformer core prototyping, materials, measurement, and analysing the correlation among them. Furthermore, the model must have the ability to be applied using finite element methods by using ANSYS Software. Distribution transformers have complex three-dimensional geometry with nonlinear materials in the core. This makes it necessary to use powerful and accurate numerical methods like the finite element method to analyse and understand its behaviour. The overall gains from this study will have significance both for the end users and for the producers of transformers and related materials.

The key objectives and expected tasks and accomplishments of the current study were achieved under the below specific goals:

1. **To present** a new T- joint design of transformer core using proposed PSO base intelligent algorithm by considering on the power loss reduction under different load conditions.
2. **To develop** a new T-joint design called (hemisphere) for the transformer core.
3. **To evaluate** the proposed designs under different core materials and loads and also comparison between the electrical and economical indices of proposed designs and conventional ones from industry.

1.4 Scope and Limitations

In this study, the influence of redesign the form of T-joint to the losses and thermal profiles in three-phase transformer was studied in the different operation conditions. To achieve this target, the current study involved many points but the main ones can be summarized as follows:

1. Studying the effect of changing the design of T-joint shape to the performance of the core for three phase transformer via using different core materials.
2. In this study, intelligent algorithm proposed to find the optimum dimensions of T-joint parameters.
3. Using the commercial ANSYS Software to build all the 3D proposed models for transformer core.
4. Proposed a new T-joint model which called hemisphere that gives a good performance as compare with the conventional models.

1.5 Research Contributions

The contributions of this study can be brief as follows:

1- New information of the core design of three phase transformer under different types of materials and geometries.
2- Using an intelligent algorithm to determine the optimum design T-joint geometers by considering the important parameters which effect to the design.

3- The current proposed model (hemisphere) T-joint design is different from previous models in the literature in terms of form and content.
4- The relationship between the power loss and the oil temperature was considered.
5- The effect of changing the form of the T-joint design for a core transformer was presented to demonstration the relationship between the shapes of the design with the losses.

1.6 Organization of the Thesis

In order to accomplish the targeted objectives mentioned earlier, the thesis consists of five chapters and each is elaborated with further details below:

Chapter One provides an overview of this thesis and this chapter also discusses a briefly the research problem, objectives, scope and limitations of the study, research contributions and also discussed.

Chapter Two presents a literature review is given concerning the losses in transformers as well as a concise theory of transformers and their structures. There are different transformer variants and designs. In this chapter emphasis on the core-type of power transformers. All the selected past research and references were discussed briefly in this chapter.

Chapter Three discusses the details of methodology for the new algorithm, transformer parameters and graphs. A brief explanation is given of the algorithm which is proposed in this project. In addition, this chapter includes a description of the configuration of the transformer core design which is incorporated into this work that allows the study of losses and thermal profile of the transformer. Further, the modelling of a power transformer is discussed, including models of the transformer core and the windings. A discussion is also given concerning the finite element method (FEM) with a description of the Ansys software model for a three-phase transformer.

Chapter Four presents the simulation results of the three-phase transformer and an analysis of the developed model is discussed. It covers the new design modelling of the T-joint design in the different core materials.

Chapter Five concludes with emphasis on the final discussion and a summary of the conclusions. Possible future works are discussed in brief in this research area.

REFERENCES

A. A. Aram Bonyar, & Basak, A. (1989). Flux and loss distribution in a split-core five -limb transformer. *IEEE Transactions on Magnetics*, *25*(5), 3961–3963.

Adly, A. A. (1995). Determination of total transformer losses resulting from semirotating flux excitation. *IEEE Transactions on Magnetics*, *31*(6 pt 2), 4253–4255.

Ahmad, D. M. M. (2010). Evaluation of the Localised Loss Transformer Core Lamination. *Journal of Applied Sciences*, *10*(22), 2917–2922.

Ahmad, D. M. M., & Fauzi, F. (2010). Influence of the Mix 60 o - 23 o T-joint of Three Phase Transformer Core Longitudinal Direction of Flux Distribution. *The 4th International Power Engineering and Optimization Conf. (PEOCO2010), Shah Alam, Selangor, MALAYSIA:23-24 June 2010*, (June), 23–24.

Akçay, H., & Ece, D. G. (2003). Modeling of hysteresis and power losses in transformer laminations. *IEEE Transactions on Power Delivery*, *18*(2), 487–492.

Amoiralis, E. I., Tsili, M. A., & Georgilakis, P. S. (2008). The state of the art in engineering methods for transformer design and optimization: A survey. *Journal of Optoelectronics and Advanced Materials*, *10*(5), 1149–1158.

Amoiralis, E. I., Tsili, M. a., & Kladas, A. G. (2009). Transformer design and optimization: A literature survey. *IEEE Transactions on Power Delivery*, *24*(4), 1999–2024.

Andjelic, Z., Fazlagic, A., & Girgis, R. S. (2006). Applications of 3D Simulation to Solutions of Field Problems and Peformance Upgrades of Large Power Transformers. *Transmission and Distribution Conference and Exhibition, 2005/2006 IEEE PES*, 62–68.

Ansys.com. (2016). ANSYS Maxwell - Low Frequency Electromagnetic Field Simulation. http://www.ansys.com/Products/Electronics/ANSYS-Maxwell

Anthony J.Moses. (2003). Prediction of core losses of three phase transformers from estimation of the components contributing to the building factor. *Journal of Magnetism and Magnetic Materials*, 615–617.

Arslan, E., S.Sakar, & E.Balci, A. (2014). On the No- Load Loss of Power Transformers under Voltage with Sub-Harmonics. In *Conference Energycon 2014. May 13-16 , 2014 Dubrovnik , Croatia* (pp. 228–233).

Ashbahani, N., Daut, I., & Halim, N. . (2011). Measurement of Overall Power Loss for Different Three Phase 100kVA Transformer Core Material. In *The 4th international Power Engineering and Optimization Conf. (PEOCO2011), Shah Alam, Selangor, MALAYSIA:6-7 June 2011* (pp. 208–210).

Ashbahani, N., Daut, I., & Md. Reza Md. Mohyin. (2010). Measurement of Overall Power Loss and Flux Leakage in M4 Grain-Oriented Silicon Iron Assembled with 45 o T-Joint of Three Phase Transformer Core. In *The 4th international Power Engineering and Optimization Conf. (PEOCO2010), Shah Alam, MALAYSIA:23-24 June* (pp. 122–125).

Azizah, N., Yusoff, M., Karim, K. A., Ghani, S. A., Sutikno, T., & Jidin, A. (2015). Multiphase Transformer Modelling using Finite Element Method. *International Journal of Power Electronics and Drive System*, *6*(1), 56–64.

Basak, A., & Higgs, C. (1982). Flux distribution in three phase transformer cores with various T-joint geometries. *IEEE Transactions on Magnetics*, *18*(2), 670–673.

Basak, A., Moses, A. J., & Al-Bir, R. (1990). Effect of clamping stress on power loss in POWERCORE strip and Si-Fe transformer cores. *IEEE Transactions on Magnetics*, *26*(5), 1999–2001.

Bastos, J. P. A., & N., S. (2003). *Electromagnetic Modeling by Finite Element Methods*. New York.: Basel: Marcel. Dekker, Inc., 2003.

Behrang, M. A., Assareh, E., Noghrehabadi, A. R., & Ghanbarzadeh, A. (2011). New sunshine-based models for predicting global solar radiation using PSO (particle swarm optimization) technique. *Energy*, *36*(5), 3036–3049.

Bengtsson, C., Pfützner, H., & Schönhuber, P. (1989). On the optimization of mitred overlaps in transformer cores. *Physica Scripta*, *39*, 629–632.

Bengtsson, C., & Sundén, S. (1989). Control of local flux distortion in single phase cores by corner joints with non-constant overlap length. *Physica Scripta*, *39*, 633–635.

Bernard, Y., Mendes, E., & Bouillault, F. (2002). Dynamic Hysteresis Modeling Based on Preisache Model.pdf. *IEEE Transactions on Magnetics*, *38*(2), 885–888.

Biro, O., Buchgraber, G., Leber, G., & Preis, K. (2008). Prediction of Magnetizing Current Wave-Forms in a Three-Phase Power Transformer Under DC Bias. *IEEE Transactions on Magnetics*, *44*(6), 1554–1557.

Bjerkan, E. (2005). *High Frequency Modeling of Power Transformers*. (NTNU). https://brage.bibsys.no/xmlui/handle/11250/256420

Blanco Alonso, P. E., Meana-Fernández, A., & Fernández Oro, J. M. (2017). Thermal Response and Failure Mode Evaluation of a Dry-Type Transformer. *Applied Thermal Engineering*.

Bonyar, A. A., & Basak, A. (1989). Loss Distribution in Five-Limb Transformer Cores with Split and Non-Split Limbs. *Physica Scripta*, *40*, 499–501.

Bruckner, F., Abert, C., Vogler, C., Heinrichs, F., Satz, A., Ausserlechner, U., … Suess, D. (2016). Macroscopic simulation of isotropic permanent magnets. *Journal of Magnetism and Magnetic Materials*, *401*, 875–879.

Cabanas, M. F., Pedrayes, F., Melero, M. G., Orcajo, C. H. R. G. A., Cano, J. M., & Norniella, J. G. (2011). Insulation Fault Diagnosis in High Voltage Power Transformers By Means of Leakage Flux Analysis. *Progress In Electromagnetics Research*, *114*(January), 211–234.

Caeai.com. (2016). ansys-benefits. https://caeai.com/ansys-software-support/ansys-benefits

Canonsburg, T. D., Information, G., & Support, T. (2010). Getting Started with Maxwell : Transient Problem. *ANSYS, Inc.*, (November).

Chapman, S. (2005). *Electric machinery fundamentals*. McGraw-Hill, New York.

Chen, W., Ma, J., Huang, X., & Fang, Y. (2015). Predicting Iron Losses in Laminated Steel with Given Non-Sinusoidal Waveforms of Flux Density. *Energies*, (November), 13726–13740.

Cinar, M. A., Alboyaci, B., & Sengul, M. (2014). Comparison of Power Loss and Magnetic Flux Distribution in Octagonal Wound Transformer Core Configurations. *Journal Electr Eng Technol*, *9*(4), 1290–1295.

Colonel WM. T. Mclyman. (2004). *TRANSFORMER AND INDUCTOR DESIGN HANDBOOK Third Edition , Revised and Expanded*. Idyllwild , California: Marcel Dekker, Inc. All Rights Reserved.

Connell, S. A. H. G. P. O., Holland, S., O'Connell, G. P., & Haydock, L. (1992). Calculating stray losses in power transformers using surface impedance with finite elements. *Magnetics, IEEE Transactions on*, *28*(2), 1355–1358.

Cougo, B., & Saint-exupéry, I. D. R. T. (2015). Optimal Cross Section Shape of Tape Wound Cores Keywords. *Power Electronics and Applications*.

Cullity, B. D., & Graham, C. D. (2009). *Introduction to Magnetic Materials (2nd Edition)*. *Materials Today* (Vol. 12).

Dasgupta, I. (2011). *Design of Transformers*. New Delhi, India: Tata McGraw Hill.

Daut, I., Ahmad, D. M. M., Zakaria, S., & Taib, S. (2007). Comparison on Losses and Flux Distribution Between Two 3-Phase Distribution Transformers 1000KVA Assembled With Air Gap and Without Air Gap of Transformer Core Lamination. In *Asia-Pacific Conference on Applied Electromagnetics Proceedings, APACE2007* (pp. 5–8).

Daut, I., Ahmad, D. M. M., Zakaria, S., Uthman, S., & Taib, S. (2006). Comparison of Losses and Flux Distribution in 3 Phase 100 kVA Distribution Transformers Assembled from Various Type of T-Joint Geometry. *American Journal of Application Sciences*, *3*(9), 1990–1992.

Daut, I., & Uthman, S. (2006). *Transformer Manufacturers in Malaysia: Perspective In Manufacturing And Performance Status*. *KUKUM Engineering Research Seminar 2006*.

Difference-between-power-transformer-and-distribution- transformer. (2016). http://electrical-engineering-portal.com/difference-between-power-transformer-and-distribution-transformer

Digalovski, M., Najdenkoski, K., & Rafajlovski, G. (2013). Impact of current high order harmonic to core losses of three-phase distribution transformer. *IEEE EuroCon 2013*, (March), 1531–1535.

Du, Y., Cheng, Z., Zhao, Z., Fan, Y., Liu, L., Zhang, J., & Wang, J. (2010). Magnetic flux and iron loss modeling at laminated core joints in power transformers. *IEEE Transactions on Applied Superconductivity*, *20*(3), 1878–1882.

Edwards, K. R. (1996). *Transformer*. American Technical Publishers, Incorporated, Technology & Engineering.

Enokizono, M., & Soda, N. (1999). Core loss analysis of transformer by improved FEM. *Journal of Magnetism and Magnetic Materials*, *196*, 910–912.

Faiz, J., Ebrahimi, B., & Noori, T. (2008). Three- and Two-Dimensional Finite-Element Computation of Inrush Current and Short-Circuit Electromagnetic Forces on Windings of a Three-Phase Core-Type Power Transformer. *IEEE Transactions on Magnetics*, *44*(5), 590–597.

Fauzi, F., & Ahmad, D. M. M. (2010). Normal direction of flux distribution in the mix 60 - 23 T-joint of three phase transformer core. *PEOCO 2010 - 4th International Power Engineering and Optimization Conference, Program and Abstracts*, (June), 570–572.

Fiorillo, F. (2010). Measurements of magnetic materials. *Metrologia*, *47*(2), S114–S142.

Fiorillo, F., Dupré, L. R., Appino, C., & Rietto, A. M. (2002). Comprehensive model of magnetization curve, hysteresis loops, and losses in any direction in grain-oriented Fe-Si. *IEEE Transactions on Magnetics*, *38*(3), 1467–1476.

Francisco de Leon, & Semlyen, A. (1994). Complete Transformer Model for Electromagnetic Transients. *IEEE Transactions on Power Delivery*, *9*(1).

Georgilakis, P. S. (2007). Decision support system for evaluating transformer investments in the industrial sector. *Journal of Materials Processing Technology*, *181*, 307–312.

Georgilakis, P. S. (2009). Differential evolution solution to transformer no-load loss reduction problem. *IET Generation, Transmission & Distribution*, *3*(10), 960.

Georgilakis, P. S. (2009). *Spotlight on Modern Transformer Design*. Springer.

Girgis, R. S., te Nijenhuis, E. G., Gramm, K., & Wrethag, J.-E. (1998). Experimental investigations on effect of core production attributes on transformer core loss performance. *IEEE Transactions on Power Delivery*, *13*(2), 526–531.

Group, H. R. and T. S. (2005). *Transformers : Basics , Maintenance , and Diagnostics*. Denver, Colorado: Hydroelectric Research and Technical Services Group.

Haidar, A. M. A., & Al-Dabbagh, and M. (2013). The Influences of T-Joint Core Design on No-Load Losses in Transformers. *IEEE Potentials*, *32*(3), 40–48.

Haidar, A. M. A., Taib, S., Daut, I., & Uthman, S. (2006). Evaluation of Transformer Magnetizing Core Loss. *Journal of Applied Sciences*, *6*(12), 2579–2585.

Hamzehbahmani, H., Moses, A. J., & Anayi, F. J. (2013). Opportunities and Precautions in Measurement of Power Loss in Electrical Steel Laminations Using the Initial Rate of Rise of Temperature Method. *IEEE Transactions on Magnetics*, *49*(3), 1264–1273.

Hanoon, A. N., Jaafar, M. S., Hejazi, F., & Abdul Aziz, F. N. A. (2016). Energy absorption evaluation of reinforced concrete beams under various loading rates based on particle swarm optimization technique. *Engineering Optimization*, *0*(0), 1–19.

Heathcote J., M. (2007). *J & P Transformer Book*. Elsevier Ltd.

Hernandez, I., de Leon, F., Canedo, J. M., & Olivares-Galvan, J. C. (2010). Modelling transformer core joints using Gaussian models for the magnetic flux density and permeability. *IET Electric Power Applications*, *4*(9), 761–771.

Hernandez, I., Olivares-Galvan, J. C., Georgilakis, P. S., & Cañedo, J. M. (2012). Core loss and excitation current model for wound core distribution transformer. *International Transsaction on Electrical Energy Systems*, *24*, 30–42.

Higgs, C., & Moses, A. J. (1984). Flux Distribution in Five-Limb Transformer Cores. *Journal of Magnetism and Magnetic Materials*, *41*(1), 1–5.

Hihat, N., Komęza, K., Napieralska-Juszczak, E., Lecointe, J., & Niewierowicz, T. (2010). Simplified models including eddy currents for laminated structures. *COMPEL - The International Journal for Computation and Mathematics in Electrical and Electronic Engineering*, *29*(4), 1033–1046.

Hihat, N., Napieralska-Juszczak, E., Lecointe, J. P., Sykulski, J. K., & Komeza, K. (2011). Equivalent permeability of step-lap joints of transformer cores: Computational and experimental considerations. *IEEE Transactions on Magnetics*, *47*(1 PART 2), 244–251.

Høidalen, H. K., Lotfi, A., Zirka, S., Moroz, Y., Chiesa, N., & Mork, B. A. (2016). Benchmarking of hysteretic elements in topological transformer model. *Electric Power Systems Research*, *138*, 33–40.

IEEE Guide for Loading Mineral-oil-immersed Transformer, IEEE Std C57.91. (2002).

Igarashi, H., Watanabe, K., & Kost, A. (2006). A Reduced Model for Finite Element Analysis of Steel Laminations. *IEEE Transactions on Magnetics*, *42*(4), 739–742.

Ilo, A., Pfutzner, H., & Nakata, T. (2000). Critical induction - a key quantity for the optimisation of transformer core operation. *Journal of Magnetism and Magnetic Materials*, *216*, 637–640.

Inc., A. (2014). Ansys Electromagnetics Suite, Release 15.0, ANSYS Maxwell.

Jamali, S., Ardebili, M., & Abbaszadeh, K. (2005). Calculation of short circuit reactance and electromagnetic forces in three phase transformer by finite element method. In *ICEMS*.

Jensen, B. B., Guest, E. D., & Mecrow, B. C. (2015). Modeling Overlapping Laminations in Magnetic Core Materials Using 2-D Finite-Element Analysis. *IEEE Transactions on Magnetics*, *51*(6).

Jez, R., & Polit, A. (2014). Influence of air-gap length and cross-section on magnetic circuit parameters. In *Excerpt from the proceeding of the 2014 COMSOL Conference in Cambridge*.

Kang, Y., Bai, B., Xin, Z., Guo, Y., Jian, W., & Wang, J. (2013). Analysis of Magnetic field and loss of the large compress yoke transformer. In *International Conference on Electrical Machines and Systems, Oct. 26-29, 2013, Busan, Korea* (pp. 847–850).

Kefalas, T. D., Kladas, A. G., & Member, S. (2014). Reduction of Cost and Losses of Transformers by Using Composite Magnetic Cores, 2257–2263.

Kefalas, T., Tsili, M., & Kladas, A. (2008). Unification of anisotropy and FEM-BE models for distribution transformer optimization. *Journal of Optoelectronics and Advanced Materials*, *10*(5), 1143–1148.

Keiichiro Ooka, Kajiwara, T., Aihara, S., & Enokizono, M. (2014). Control of Rotating Magnetic Flux Distribution in a Transformer Model Core by Laser Irradiation. *IEEE Transactions on Magnetics*, *50*(4), 8400204.

Kennedy, B. (1998). *Energy efficient transformers*. McGraw-Hill, New York.

Khelil, M., & Elleuch, M. (2010). Finite element method analysis of three phase transformer core accounting for anisotropy and air gaps. In *2010 7th International Multi-Conference on Systems, Signals and Devices* (pp. 1–6).

Kralj, L., & Miljavec, D. (2010). Stray losses in power transformer tank walls and construction parts. In *Electrical Machines (ICEM), 2010 XIX , IEEE International Conference on*.

Kulkami, S. V., & Khaparde, S. A. (2000). Stray Loss Evaluation in Power Transformers - A Review. In *IEEE conf* (pp. 2269–2274).

Kulkarni, S. V., & A, K. S. (2012). *Transformer Engineering: Design, Technology, and Diagnostics*. CRC Press.

Kulkarni, S. V., & Khaparde, S. A. (2004). *Transformer Engineering: Design and Practice*. Marcel Dekker, Inc.

Lee, C., & Jung, H. K. (2000). Nonlinear analysis of the three-phase transformer considering the anisotropy with voltage source. *IEEE Transactions on Magnetics*, *36*(2), 491–499.

Lee, H., Park, J. M., Hur, K., & Kang, Y. C. (2015). Development of a compensation scheme for a measurement voltage transformer using the hysteresis characteristics of a core. *Energies*, *8*(4), 3245–3257.

Leite, J. V., Benabou, A., Sadowski, N., Clénet, S., Bastos, J. P. A., & Piriou, F. (2008). Implementation of an anisotropic vector hysteresis model in a 3-D finite-element code. *IEEE Transactions on Magnetics*, *44*(6), 918–921.

Leite, J. V., Benabou, A., Sadowski, N., & Da Luz, M. V. F. (2009). Finite element three-phase transformer modeling taking into account a vector hysteresis model. *IEEE Transactions on Magnetics*, *45*(3), 1716–1719.

Leonardo. (2010). Energy efficient distribution transformers, (January).

Li, Y., Sun, X., Jing, Y., & Li, J. (2011). Calculation and analysis of 3-D nonlinear eddy current field and structure losses in transformer. *2011 International Conference on Electrical Machines and Systems*, 1–4.

Li, Y., Yang, Q., Zhu, J., Zhao, Z., Liu, X., & Zhang, C. (2014). Design and analysis of a novel 3-d magnetization structure for laminated silicon steel. *IEEE Transactions on Magnetics*, *50*(2), 1–4.

Lin, L., & Xiang, C. (1998). Losses Calculation in Transformer Tie Plate Using the Finite Element Method. *IEEE Transactions on Magnetics*, *34*(5), 3644–3647.

Liu, R., Mi, C. C., & Gao, D. W. (2008). Modeling of eddy-current loss of electrical machines and transformers operated by pulsewidth-modulated inverters. *IEEE Transactions on Magnetics*, *44*(8), 2021–2028.

Loffler, F., Pfützner, H., Booth, T., Bengtsson, C., & Gramm, K. (1994). Influence of air gaps in stacked transformer cores consisting of several packages. *IEEE Transactions on Magnetics*, *30*(2 pt 2), 913–915.

Loizos, G., Kefalas, T. D., Kladas, A. G., & Souflaris, A. T. (2010). Flux distribution analysis in three-phase Si-Fe wound transformer cores. *IEEE Transactions on Magnetics*, *46*(2), 594–597.

Lotfi, A., & Rahimpour, E. (2013). Optimum design of core blocks and analyzing the fringing effect in shunt reactors with distributed gapped-core. *Electric Power Systems Research*, *101*, 63–70.

Lundmark, S., Serdyuk, Y. V., Gubanski, S. M., & Lärking, B. (2008). Comparison between hexa- and conventional E-type core three-phase transformers. *Proceedings of the 2008 International Conference on Electrical Machines, ICEM'08*, 1–6.

Lutchman, P. (2012). *Evaluation of an Efficiencent Transformer Core Design*.

Luz, F. da, Valencia, M., Dular, P., Leite, J. V., & Kuo-peng, P. (2014). Modeling of Transformer Core Joints via a Subproblem FEM and a Homogenization Technique. *IEEE Transactions on Magnetics*, *50*(2), 1009–1012.

Maizana, D. (2013). Analysis eddy Current Loss in the Three Phase 100 KVA Transformer Core with the Mix 60-0 joint core. *Asian Journal of Scientific Research*, *6*(1), 122–128.

Maloberti, O., Mazauric, V., Meunier, G., Kedous-Lebouc, A., & Geoffroy, O. (2006). An Energy-Based formulation for dynamic hysteresis and extra-losses. *IEEE Transactions on Magnetics*, *42*(4), 895–898.

Marketos, P., & Meydan, T. (2006). Novel transformer core design using consolidated stacks of electrical steel. *INTERMAG 2006 - IEEE International Magnetics Conference*, *42*(10), 127.

Martinez, J. a., & Mork, B. a. (2005). Transformer Modeling for Low and Mid Frequency Transients A Review. *IEEE Transactions on Power Delivery*, *20*(2), 1625–1632.

Mechler, G. F., & Girgis, R. S. (1998). Calculation of Spatial Loss Distribution in Stacked Power and Distribution transformer Cores. *IEEE Transactions on Power Delivery*, *13*(2), 532–537.

Mechler, G. F., & Girgis, R. S. (2000). Magnetic flux distributions in transformer core joints. *IEEE Transactions on Power Delivery*, *15*(1), 198–203.

Meunier, G. (2008). *The Finite Element Method for Electromagnetic Modeling*. Wily.

Milagre, A. M., Ferreira Da Luz, M. V., Cangane, G. M., Komar, A., & Avelino, P. A. (2012). 3D calculation and modeling of eddy current losses in a large power transformer. *Proceedings - 2012 20th International Conference on Electrical Machines, ICEM 2012*, *i*, 2282–2286.

Moses, A. J., & Thomas, B. (1973). The spatial variation of localized power loss in two practical transformer T-joints. *IEEE Transactions on Magnetics*, *9*(4), 655–659.

Moses, A. J., & Thomas, B. (1974). Problems in the design of power transformers. *IEEE Transactions on Magnetics*, *10*(2), 148–150.

Moses, A. J., Thomas, B., & Thompson, E. (1972). Power Loss and Flux Density Distributions in the T-Joint of a Three Phase Transformer Core. *IEEE Transactions on Magnetics*, *MAG-8*(4), 785–790.

Mousavi, S. A. (2012). *Electromagnetic Modelling of Power Transformers with DC Magnetization*. Royal Institute of Technology (KTH).

MTM. (2015). Malaysia Transformer Manufacturing Sdn.Bhd.

Najafi, A., Dokmetas, B., & Iskender, I. (2015). Estimation of stray loss and leakage flux in the structural Component of 3-phase distribution transformer under unbalanced voltage based on numerical analysis. *6th International Conference on Modeling, Simulation, and Applied Optimization, ICMSAO 2015 - Dedicated to the Memory of Late Ibrahim El-Sadek*.

Najafi, A., & Iskender, I. (2015). Thermal Modeling and Electromagnetic Analysis of 1000 kVA Distribution Transformer Based on Electric _ Thermal Equivalent Circuit and TSFEM. *Global Advanced Research Journal of Engineering*, *4*(2), 24–30.

Najafi, A., & Iskender, I. (2016). An improved thermal model for distribution transformer under unbalanced voltage conditions. *International Journal of Thermal Sciences*, *104*, 373–385.

Nippon Steel Corporation. (2004). Nippon Steel Catlogue, Grain -Oriented electrical steel sheets. Japan.

Olivares-Galvan, J. C., Georgilakis, P. S., Campero-Littlewood, E., & Escarela-Perez, R. (2013). Core lamination selection for distribution transformers based on sensitivity analysis. *Electrical Engineering*, *95*(1), 33–42.

Olivares-Galván, J. C., Georgilakis, P. S., & Ocon-Valdez, R. (2009). A Review of Transformer Losses. *Electric Power Components and Systems*, *37*(9), 1046–1062.

Pavlik, D., Johnsor, D. C., & Girgis, R. S. (1993). Calculation and reduction of stray and eddy losses in core-form transformers using a highly accurate finite element modelling technique. *IEEE Transactions on Power Delivery*, *8*(1), 239–245.

Petkovska, L., Member, S., Digalovski, M., & Ieee, M. (2014). A Novel Approach to Multi-objective Efficiency Optimisation for a Distribution Transformer Based on the Taguchi Method. In *International Conference Electrical Machines (ICEM)* (pp. 2228–2234).

Pfützner, H., Shilyashki, G., Hamberger, P., Aigner, M., Hofbauer, F., Palkovits, M., … Galabov, V. (2014). Automatic 3-D Building Factor Analyses of a Grain-Oriented Model Transformer Core. *IEEE Transactions on Magnetics*, *50*(4), 3–6.

Pietruszka, M., & Juszczak, E. N. (1996). Lamination of T-joints in the transformer core. *IEEE Transactions on Magnetics*, *32*(3), 1180–1183.

Poulin, R. M. D. V. and B. (2010). *Transformer Design Principles: With Applications to Core-Form Power Transformers* (Second Edi). CRC Press, 2010.

Ren, L., Zeng, S., & Zhang, Y. (2015). Magnetic field characteristics analysis of a single assembled magnetic medium using ANSYS software. *International Journal of Mining Science and Technology*, *25*(3), 479–487.

Resource.ansys.com. (2016). ANSYS+Maxwell.

Rezaei-Zare, A., Sanaye-Pasand, M., Mohseni, H., Farhangi, S., & Iravani, R. (2007). Analysis of ferroresonance modes in power transformers using Preisach-type hysteretic magnetizing inductance. *IEEE Transactions on Power Delivery*, *22*(2), 919–929.

Schmidt, E., & Hamberger, P. (2004). Design Optimization of Power Transformers, Part 2 - Eddy Current Analyses for Tank Wall and Core Clamping Parts. In *2004 International IEEE conference on power System Technology - Powercon 2004* (pp. 21–24).

Shilyashki, G., Pfutzner, H., Anger, J., Gramm, K., Hofbauer, F., Galabov, V., & Mulasalihovic, E. (2014). Magnetostriction of transformer core steel considering rotational magnetization. *IEEE Transactions on Magnetics*, *50*(1).

Shilyashki, G., Pfützner, H., Gerstbauer, E., Trenner, G., Hamberger, P., & Aigner, M. (2016). Numerical Prediction of Rhombic Rotational Magnetization patterns in a Transformer Core Package. *IEEE Transactions on Magnetics*, *52*(1).

Shilyashki, G., Pfützner, H., Hamberger, P., Aigner, M., Hofbauer, F., Matkovic, I., & Kenov, A. (2014). The impact of off-plane flux on losses and magnetostriction of transformer core steel. *IEEE Transactions on Magnetics*, *50*(11), 1–4.

Sim, H. J., & Scott Digby, H. (2004). Elecrric Power Transformer Engineering. In *USA*. CRC Press LLC.

So, E., Arseneau, R., & Hanique, E. (2004). Measurement and correction of no-load losses of power transformers. *CPEM Digest (Conference on Precision Electromagnetic Measurements)*, *54*(2), 570.

Soda, N., & Enokizono, M. (2000). Improvement of T-joint part constructions in three-phase transformer cores by using direct loss analysis with E&S model. *IEEE Transactions on Magnetics*, *36*(4), 1285–1288.

Sumathi, S., & Surekha, P. (2010). *Computational Intelligence Paradigms Theory and Applications Using Matlab*.

Susa, D., Lehtonen, M., & Nordman, H. (2005). Dynamic thermal modelling of power transformers. *IEEE Power Engineering Society General Meeting, 2005.*, *20*(1), 197–204.

Susnjic, L., Haznadar, Z., & Valkovic, Z. (2008). 3D finite-element determination of stray losses in power transformer. *Electric Power Systems Research*, *78*(10), 1814–1818.

Tang, Q., Guo, S., & Wang, Z. (2015). Magnetic flux distribution in power transformer core with mitred joints. *Journal of Applied Physics*, *117*(17), 2–6.

Targosz, R., & Topalis, F. V. (2007). Energy efficiency of distribution transformers in Europe. In *2007 9th International Conference on Electrical Power Quality and Utilisation, EPQU*.

TeNyenhuis, E. G., Girgis, R. S., & Mechler, G. F. (2001). Other factors contributing to the core loss performance of power and distribution transformers. *IEEE Transactions on Power Delivery*, *16*(4), 648–653.

TeNyenhuis, E. G., Mechler, G. F., & Girgis, R. S. (2000). Flux distribution and core loss calculation for single phase and five limb three phase transformer core designs. *IEEE Transactions on Power Delivery*, *15*(1), 204–209.

Thomas, B. (1975). Flux Paths and Flux Transfer Mechanism in the T Joints of Three Phase Transformer Cores. *IEEE Transactions on Magnetics*, *MAG-11*(1), 65–71.

Tomczuk, B., & Koteras, D. (2011). Magnetic flux distribution in the amorphous modular transformers. *Journal of Magnetism and Magnetic Materials*, *323*(12), 1611–1615.

Tsili, M. A., Amoiralis, E. I., Kladas, A. G., & Souflaris, A. T. (2012). Optimal design of multi-winding transformer using combined FEM, taguchi and stochastic-deterministic approach. *IET,Electric Power Applications*, *6*(7), 437–454.

Valkovic, Z. (1982). Influence of transformer core design on power losses. *IEEE Transactions on Magnetics*, *18*(2), 801–804.

Van Mier, J. B. M. (1984). *Strain-softening of Concrete under Multiaxial Loading Conditions*.

Vecchio, R. M. Del, Poulin, B., Feghali, P. T., Shah, D. M., & Ahuja, R. (2002). *Tranformer Design Principles with Applications to Core-form Power Transformers*. *New York*. CRC Press.

Wada, S., Yagisawa, T., & Asai, N. (1989). Building factors of transformer cores made from low loss Si-steel sheets. *Physica Scripta*, *39*, 403–405.

Wang, Z. Q., Yin, Z. D., Zhou, L. X., Wang, Z. J., & Ma Key, L. R. (2009). Study on controllable reactor magnetic structure and loss based on ANSYS. *2009 4th IEEE Conference on Industrial Electronics and Applications, ICIEA 2009*, 201–205.

Winders. John J., J. (2002). *Power Transformers Principles and Applications*. *World Wide Web Internet And Web Information Systems*. New York . Basel: Marcel Dekker, Inc. All Rights Reserved.

Witczak, P. (2014). Magnetostriction force spectrum in power transformer. *Proceedings - 2014 International Conference on Electrical Machines, ICEM 2014*, (3), 2246–2251.

X. M. Lopez-Fernandez, Penabad-Duran, P., & Turowski, J. (2012). Three-Dimensional Methodology for the Overheating Hazard Assessment on Transformer Covers. *IEEE Transactions on Industry Applications*, *48*(5), 1549–1555.

Yu, C. H., & Basak, A. (1993). Optimum Design of Transformer Cores by Analysing Flux and Iron Loss with the Aid of a Novel Software. *IEEE Transactions on Magnetics*, *29*(2), 1446–1449.

Zhang, X., Yang, Q., Cheng, Z., Xing, J., Du, Y., & Zhang, J. (2008). An Engineering Practical method for Simulation of Anisotropic Laminated Core Joints and Validation. In *International Conference on Electrical Machines and Systems, ICEMS 2008.* (pp. 4489–4492).

Zhang, Y., Xu, C., Xie, D., Yoon, H. S., & Koh, C. S. (2009). Analysis of magnetic characteristic in the three-phase transformer core considering two-dimensional magnetic anisotropic property. *Proceedings - The 12th International Conference on Electrical Machines and Systems, ICEMS 2009*.

Zhao, L., Qian, F., Yang, Y., Zeng, Y., & Su, H. (2010). Automatically extracting T–S fuzzy models using cooperative random learning particle swarm optimization. *Applied Soft Computing*, *10*(3), 938–944.