Artificial Intelligence Applications in the Diagnosis of Power Transformer Incipient Faults

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To

My lovely wife, Tong Wang
And my to-be-born baby girl, Lucia Wang
ABSTRACT

This dissertation is a systematic study of artificial intelligence (AI) applications for the diagnosis of power transformer incipient fault. The AI techniques include artificial neural networks (ANN, or briefly neural networks - NN), expert systems, fuzzy systems and multivariate regression.

The fault diagnosis is based on dissolved gas-in-oil analysis (DGA). A literature review showed that the conventional fault diagnosis methods, i.e. the ratio methods (Rogers, Dornenburg and IEC) and the key gas method, have limitations such as the “no decision” problem. Various AI techniques may help solve the problems and present a better solution.

Based on the IEC 599 standard and industrial experiences, a knowledge-based inference engine for fault detection was developed. Using historical transformer failure data from an industrial partner, a multi-layer perceptron (MLP) modular neural network was identified as the best choice among several neural network architectures. Subsequently, the concept of a hybrid diagnosis was proposed and implemented, resulting in a combined neural network and expert system tool (the ANNEPS system) for power transformer incipient diagnosis. The abnormal condition screening process, as well as the principle and algorithms of combining the outputs of knowledge based and neural network based diagnosis, were proposed and implemented in the ANNEPS. Methods of fuzzy logic based transformer oil/paper insulation condition assessment, and estimation of oil sampling interval and maintenance recommendations, were also proposed and implemented.

Several methods of power transformer incipient fault location were investigated, and a 7×21×5 MLP network was identified as the best choice. Several methods for on-load tap changer (OLTC) coking diagnosis were also investigated, and a MLP based modular network was identified as the best choice. Logistic regression analysis was identified as a good auditor in neural network input pattern selection processes.

The above results can help developing better power transformer maintenance strategies, and serve as the basis of on-line DGA transformer monitors.
<table>
<thead>
<tr>
<th>CONTENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 1  Introduction .......................................................... 1</td>
</tr>
<tr>
<td>1.1 Importance of power transformer incipient fault diagnosis ........................................... 1</td>
</tr>
<tr>
<td>1.2 Methodology of incipient fault diagnosis .......................................................... 1</td>
</tr>
<tr>
<td>1.2.1 Insulation condition assessment test .......................................................... 1</td>
</tr>
<tr>
<td>1.2.2 On-line partial discharge monitoring .......................................................... 2</td>
</tr>
<tr>
<td>1.2.3 Dissolved gas-in-oil analysis (DGA) .......................................................... 3</td>
</tr>
<tr>
<td>1.2.4 Combination of DGA and acoustic method .......................................................... 4</td>
</tr>
<tr>
<td>1.3 The scope of this dissertation ............................................................. 5</td>
</tr>
<tr>
<td>1.3.1 Areas of interest ......................................................................................... 5</td>
</tr>
<tr>
<td>1.3.2 Contributions through the research ........................................................................ 5</td>
</tr>
<tr>
<td>1.3.3 Arrangement of this dissertation ............................................................. 5</td>
</tr>
<tr>
<td>Chapter 2  DGA based Power Transformer Incipient Fault Diagnosis ........................................... 6</td>
</tr>
<tr>
<td>2.1 Gassing characteristic study for faulty transformers ......................................................... 6</td>
</tr>
<tr>
<td>2.2 Transformer incipient faults ............................................................. 7</td>
</tr>
<tr>
<td>2.3 The study and application of ratio methods ..................................................................... 9</td>
</tr>
<tr>
<td>2.4 The study and application of key gas method .......................................................... 11</td>
</tr>
<tr>
<td>2.5 The artificial intelligence based methods ..................................................................... 12</td>
</tr>
<tr>
<td>2.6 Other diagnostic methods and industrial expertise ........................................................... 14</td>
</tr>
<tr>
<td>2.6.1 Leakage diagnosis ................................................................................. 14</td>
</tr>
<tr>
<td>2.6.2 Paper degradation diagnosis ............................................................................. 15</td>
</tr>
<tr>
<td>2.7 Future development ......................................................................................... 15</td>
</tr>
<tr>
<td>2.8 Summaries ................................................................................. 16</td>
</tr>
<tr>
<td>Chapter 3  Rule based Transformer Fault Diagnosis .......................................................... 17</td>
</tr>
<tr>
<td>3.1 Assumptions ......................................................................................... 17</td>
</tr>
<tr>
<td>3.2 Basis of rules – the IEC guidelines .................................................. 17</td>
</tr>
<tr>
<td>3.3 Interpretation and modification of the guideline rules ......................................................... 18</td>
</tr>
<tr>
<td>3.4 Special fault diagnosis rules ........................................................................ 21</td>
</tr>
<tr>
<td>3.4.1 OH and OHO diagnosis ........................................................................ 21</td>
</tr>
<tr>
<td>3.4.2 Ratio CO/CO₂ based diagnosis ......................................................... 22</td>
</tr>
<tr>
<td>3.4.3 Additional CD and OHC diagnosis rule .................................................. 22</td>
</tr>
<tr>
<td>3.4.4 NR diagnosis ............................................................................. 22</td>
</tr>
<tr>
<td>3.5 The inference engine and fuzzy fault representation ......................................................... 22</td>
</tr>
<tr>
<td>3.6 Summary and discussions .............................................................................. 22</td>
</tr>
<tr>
<td>Chapter 4  Neural Network Based Transformer Fault Diagnosis .................................................. 24</td>
</tr>
<tr>
<td>4.1 The mechanism of neural network based diagnosis ......................................................... 24</td>
</tr>
<tr>
<td>4.2 The multi-layer perceptron (MLP) neural network ......................................................... 25</td>
</tr>
<tr>
<td>4.3 The learning vector quantization (LVQ) neural network ....................................................... 27</td>
</tr>
<tr>
<td>4.4 The modular neural network ........................................................................ 29</td>
</tr>
<tr>
<td>4.5 Optimization of input vectors ........................................................................... 30</td>
</tr>
<tr>
<td>4.6 Neural network optimization ...................................................................... 33</td>
</tr>
<tr>
<td>4.6.1 Optimal MLP topology identification ........................................................................ 33</td>
</tr>
<tr>
<td>4.6.2 LVQ network study ............................................................................. 35</td>
</tr>
<tr>
<td>4.6.3 MVG classifier study ........................................................................ 37</td>
</tr>
<tr>
<td>4.6.4 Selection of the best fault diagnosis tool ..................................................................... 38</td>
</tr>
</tbody>
</table>
4.7 MLP applications issues......................................................................................................39
  4.7.1 Selection of the training data set ..................................................................................39
  4.7.2 MLP training ................................................................................................................39
  4.7.3 MLP topology optimization .........................................................................................40
4.8 Summaries...........................................................................................................................41

Chapter 5  Hybrid Diagnosis......................................................................................................... 43
  5.1 The basis of hybrid diagnosis.............................................................................................. 43
  5.2 The topology of hybrid diagnosis ....................................................................................... 44
  5.3 The abnormal detectors .......................................................................................................45
    5.3.1 Neural network based abnormal detector.....................................................................45
    5.3.2 Rule based abnormal detectors.....................................................................................46
  5.4 Artificial neural network (ANN) and rule based fault detectors .........................................47
    5.4.1 ANN based fault detectors ...........................................................................................47
    5.4.2 Rule based fault detector..............................................................................................47
  5.5 Combined fault diagnosis................................................................................................48
  5.6 Performance improvement via hybrid diagnosis.................................................................49
    5.6.1 Overall fault diagnosis performance of the ANNEPS system .....................................49
    5.6.2 Case discussions for fault diagnosis .............................................................................50
    5.6.3 Fault diagnosis capability comparisons with the Rogers ratio method........................52
    5.6.4 Overall performance comparison between ratio methods and ANNEPS ....................53
  5.7 Summary and discussions ...................................................................................................53

Chapter 6 Power Transformer Insulation Condition Assessment and Maintenance
Recommendation........................................................................................................................... 54
  6.1 Why these are important .....................................................................................................54
  6.2 Transformer condition assessment ......................................................................................54
    6.2.1 Oil condition assessment..............................................................................................55
    6.2.2 Solid Insulation Condition Assessment .......................................................................58
  6.3 Index of oil sampling intervals............................................................................................ 60
    6.3.1 $T_i$ Estimation Scheme 1: Based on Present TDCG concentrations and TDCG Gassing
         Rate ............................................................................................................................. 61
    6.3.2 $T_i$ Estimation Scheme 2: Based on Present TDHG and $C_2H_2$ concentrations........61
    6.3.3 $T_i$ Estimation Scheme 3: Based on Present TCG percentage and TCG Gassing Rate 61
    6.3.4 $T_i$ Estimation Scheme 4: Based on Gassing Rate of $H_2$ .......................................63
    6.3.5 $T_i$ Estimation Scheme 5: Based on Present Gas-in-oil Concentrations .......................63
  6.4 Combination of the oil sampling interval indices ...............................................................63
  6.5 Adjustment of the overall oil sampling interval index ........................................................64
  6.6 Maintenance recommendations based on overall oil sampling interval index ....................65
  6.7 Summary and discussions ...................................................................................................65

Chapter 7  Power Transformer Fault Location.............................................................................. 66
  7.1 Why Fault Location.............................................................................................................66
  7.2 The Basis of Fault Location ................................................................................................66
  7.3 Logistic Regression Based Fault Location .........................................................................68
  7.4 Pattern Representation For Fault Location.........................................................................69
  7.5 Fuzzy Combination of Logistic Regression Based Fault Location ....................................71
  7.6 ANN based Fault Location ..................................................................................................71
  7.7 Summary and discussion .....................................................................................................72
# Chapter 8  Load Tap Changer Fault Diagnosis

8.1 Why treat load tap changer separately ......................................................... 74
8.2 The data sets for studying OLTC “coking” diagnosis........................................ 75
8.3 Logistic regression based OLTC “coking” diagnosis ........................................... 76
8.4 MLP based OLTC “coking” diagnosis ............................................................ 77
   8.4.1 Neural Network Specifications ................................................................. 78
   8.4.2 Neural Network Training Evaluation Parameters ........................................... 79
   8.4.3 Data Scaling Studies ................................................................................. 80
   8.4.4 Activation Function Studies ....................................................................... 82
   8.4.5 Modular Network Studies ......................................................................... 82
   8.4.6 Discussions ............................................................................................... 83
8.5 Apply the techniques to the testing data sets..................................................... 84
8.6 Summaries ....................................................................................................... 85

# Chapter 9 Conclusions

9.1 Conclusions .................................................................................................... 87
9.2 Contributions .................................................................................................. 88
9.3 Future work .................................................................................................... 89

Related Publications ............................................................................................ 91
Acknowledgements ............................................................................................. 92
Resume .................................................................................................................. 93
References ............................................................................................................ 94

Appendix 1 DGA Analysis Based on IEC 599-1978 ................................................. 102
Appendix 2 DGA Analysis Flow Chart of IEC 599 Revision Draft .......................... 103
Appendix 3 Editing and Condensing Algorithms for NNR Classifiers .................. 104
Appendix 4 Multivariate Gaussian Classifier .......................................................... 105
FIGURES

Figure 2-1 Gases Generated During Breakdown of Dielectric Oil ................................................. 7
Figure 3-1 Fault classification zones based on IEC 599 ................................................................. 19
Figure 3-2 Classification zone of the final rule base ................................................................. 20
Figure 3-3 Flow chart of the inference engine of rule-based fault diagnosis .............................. 23
Figure 4-1 Topology of a two hidden layer MLP ...................................................................... 25
Figure 4-2 Topology of the LVQ networks .............................................................................. 28
Figure 4-3 A committee machine type modular network .......................................................... 29
Figure 4-4 The modular network used for transformer fault diagnosis .................................... 30
Figure 5-1 Flow chart of the ANNEPS .................................................................................. 45
Figure 5-2 Rule based abnormal detector .................................................................................. 46
Figure 5-3 ANN based fault detector ....................................................................................... 47
Figure 5-4 Rule based fault detector ....................................................................................... 48
Figure 5-5 Combined fault diagnosis ...................................................................................... 48
Figure 6-1 Transformer Oil Condition Assessment Indices ....................................................... 57
Figure 6-2 Transformer Oil Power Factor Correction Factor .................................................. 57
Figure 6-3 Transformer Paper Insulation Condition Assessment Indices ................................. 60
Figure 6-4 Scheme 1 $T_{S1}$ Definition .................................................................................. 61
Figure 6-5 Scheme 2 $T_{S2}$ Definition .................................................................................. 62
Figure 6-6 Scheme 3 $T_{S3}$ Definition .................................................................................. 62
Figure 6-7 Membership Functions of Oil Sampling Interval Indices ........................................ 64
Figure 6-8 Overall Oil Sampling Index Adjustment Functions ............................................... 65
Figure 8-1 Modular network topology ...................................................................................... 79
Figure 8-2 AI Based OLTC “Coking” Diagnosis .................................................................... 84
TABLES

Table 2-1 Correlation between Power Transformer Incipient Faults and Causes........................... 8
Table 2-2 Ratio definition of ratio methods .................................................................................. 9
Table 2-3 Dornenburg’s ratio method .......................................................................................... 9
Table 2-4 Dornenburg’s L1 limit .................................................................................................. 9
Table 2-5 Original diagnosis table of Rogers ratio method ......................................................... 10
Table 2-6 Code definition of Rogers refined ratio method ........................................................... 11
Table 2-7 Diagnosis of Rogers refined ratio method ..................................................................... 11
Table 2-8 Diagnostic criteria of key gas method ......................................................................... 12
Table 2-9 Expert systems for power transformer fault diagnosis ............................................... 13
Table 3-1 Draft Revision Table of IEC 599 .................................................................................. 18
Table 3-2 Meanings of fault type abbreviations in Figure 3-1 and 3-2 ......................................... 21
Table 4-1 Testing accuracy (%) of 3-output MLPs with/without CO, CO₂ concentrations in the input vectors ......................................................................................................................... 32
Table 4-2 Testing accuracy (%) of single-output MLPs with/without CO, CO₂ concentrations in the input vectors ........................................................................................................................................... 32
Table 4-3 MLP based condition classification accuracy (%) of data set TST_IPO ................. 34
Table 4-4 Testing accuracy (%) of MLP based cellulose degradation diagnosis for data set TST_IPO ......................................................................................................................................................... 34
Table 4-5 Average testing accuracy (%) of studied LVQ networks ....................................... 35
Table 4-6 Standard deviation (%) of testing accuracies for the studied LVQ networks ............. 36
Table 4-7 Testing accuracy (%) of studied MVG classifiers ..................................................... 37
Table 4-8 Testing accuracy (%) of three tools on data set TRN_DBL1 and TST_DBL1 ............ 38
Table 5-1 The L1 norms of gases-in-oil from different sources ............................................... 46
Table 5-2 Test accuracy (%) of the training and testing data sets ............................................. 50
Table 5-3 Close up of some test examples ................................................................................. 51
Table 5-4 The testing results of ANNEPS and the Rogers ratio method .................................. 52
Table 5-5 Testing accuracy (%) of some popular ratio methods on the 210 data samples ....... 53
Table 6-1 Power Transformer Oil Condition Assessment Tests ............................................. 55
Table 6-2 Tests for Power Transformer Solid Insulation Assessment ...................................... 58
Table 6-3 Index of Transformer Oil Sampling Intervals ............................................................. 60
Table 6-4 Scheme 4 $T_{54}$ Definition ....................................................................................... 63
Table 6-5 Scheme 5 $T_{55}$ Definition ....................................................................................... 63
Table 6-6 Overall Oil Sampling Interval Index and Maintenance Recommendations ............. 65
Table 7-1 Test Accuracy (%) of Logistic Regression Based Fault Location Classifiers .......... 70
Table 7-2 Test Accuracy (%) of the ANN Based Fault Location Classifier .............................. 72
Table 8-1 Testing success rates of logistic regression based OLTC “coking” diagnosis .......... 77
Table 8-2 SR Definition for Single Output Neural Networks ................................................. 79
Table 8-3 Informative Index IFID Definition for Single Output Neural Networks .................. 80
Table 8-4 Comparison of Training Performance for Different Data Scaling Schemes ............. 81
Table 8-5 Comparison of Training Performance for a Single .................................................. 82
Table 8-6 Comparison of Training Performance for Different Activation Function Combinations ................................................................. 82
Table 8-7 Comparison of Training Performance for Different Modular Networks .............. 83
Table 8-8 “Coking” Diagnosis When MLP and LOGIT Function Fail to Agree ....................... 85
ABBREVIATIONS

ANNEPS: The combined Artificial Neural Network and ExPert System tool for power transformer incipient fault diagnosis

COC: Combined Output Confidence

DGA: Dissolved Gas-in_oil Analysis

AI: Artificial Intelligence

ANN: Artificial Neural Network

LVQ: Learning Vector Quantization neural network

NN: Neural Network

NNR: Nearest Neighbor Rule

MLP: Multi-Layer Perceptron

MVQ: MultiVariate Gaussian classifier

Φ(●): Activation function of MLP

NR: NoRmal condition

OH: OverHeating

OHO: OverHeating of Oil

CD: Cellulose Degradation

OHC: OverHeating of Cellulose

PDL, PD, LED: Partial discharge

PDH, DL, HEDA_1, HEDA_2: Low energy discharge

ARC, DH, HEDA, HEDA_3, HEDA_4: High Energy Discharge

H₂: Hydrogen

CH₄: Ethane

C₂H₆: Methane

C₂H₄: Ethylene

C₂H₂: Acetylene

CO: Carbon monoxide

CO₂: Carbon dioxide

O₂: Oxygen

N₂: Nitrogen

TDCG: Total Dissolved Combustible Gases

TCG: Total Combustible Gases

TDHG: Total Dissolved Hydrocarbon Gases

L1: Critical gas-in-oil levels for abnormal screening

R1: Ratio CH₄/H₂

R2: Ratio C₂H₂/C₂H₄

R3: Ratio C₂H₂/CH₄

R4: Ratio C₂H₆/C₂H₂

R5: Ratio C₂H₄/C₂H₆
AE: Acoustic Emission
DP: Degree of Polymerization
ECT: Electrostatic Charging Tendency
FUR: 2-Furfural
HPLC: High Performance Liquid Chromatography
HFCT: High Frequency Current Transformer
IFT: InterFacial Tension
IR: Insulation Resistance
KOH: acid number
LTC: Load Tap Changer
OLTC: On-Load Tap Changer
PD: Partial Discharge
PF: Power Factor
PI: Polarization Index
RIV: Radio Induced Voltage
SFL: oxidation stability
WNDG: Windings

IFID: InFormative InDex
PRM: Pattern Representation Method
SR: Success Rate
Ts: oil sampling interval index
TA: Test Accuracy

DBL: Doble Engineering Company
LOC: Location
TRN: Training
TST: Testing