Artificial Intelligence Applications in the Diagnosis of Power Transformer Incipient Faults

Zhenyuan Wang

Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
In partial fulfillment of the requirement for the degree of

Doctor of Philosophy
In
Electrical Engineering

Dr. Yilu Liu, Chair
Dr. Robert Broadwater
Dr. Hugh VanLandingham
Dr. Jaime De La Ree Lopez
Dr. Maury Nussbaum

August 8, 2000
Blacksburg, Virginia

Keywords:
Artificial Intelligence, Neural Network, Expert System, Fuzzy System,
Power Transformer, Fault Diagnosis, Dissolved Gas-in-oil Analysis (DGA)

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 $7\times21\times5$ 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.

CONTENTS

FIGURES

TABLES

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
$\Phi(\bullet)$:	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
H_2:	Hydrogen
CH_4:	Ethane
C_2H_6:	Methane
C_2H_4:	Ethylene
C_2H_2:	Acetylene
CO:	Carbon monoxide
CO_2:	Carbon dioxide
O_2:	Oxygen
N_2:	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 CH_4/H_2
R2:	Ratio C_2H_2/C_2H_4
R3:	Ratio C_2H_2/CH_4
R4:	Ratio C_2H_6/C_2H_2
R5:	Ratio C_2H_4/C_2H_6

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