

# **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  $7 \times 21 \times 5$  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.

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## 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 <sub>2</sub> :	Hydrogen	
CH <sub>4</sub> :	Ethane	
C <sub>2</sub> H <sub>6</sub> :	Methane	
C <sub>2</sub> H <sub>4</sub> :	Ethylene	
C <sub>2</sub> H <sub>2</sub> :	Acetylene	
CO:	Carbon monoxide	
CO <sub>2</sub> :	Carbon dioxide	
O <sub>2</sub> :	Oxygen	
N <sub>2</sub> :	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 <sub>4</sub> /H <sub>2</sub>	
R2:	Ratio C <sub>2</sub> H <sub>2</sub> /C <sub>2</sub> H <sub>4</sub>	
R3:	Ratio C <sub>2</sub> H <sub>2</sub> /CH <sub>4</sub>	
R4:	Ratio C <sub>2</sub> H <sub>6</sub> /C <sub>2</sub> H <sub>2</sub>	
R5:	Ratio C <sub>2</sub> H <sub>4</sub> /C <sub>2</sub> H <sub>6</sub>	

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