Smart Transformer for Smart Grid – Intelligent Framework and Techniques for Power Transformer Asset Management

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Presentation Outline

1. Introduction
2. Research and Development Works
3. SmartBox – A Reconfigurable Platform for Smart Transformer
4. Conclusions

Introduction

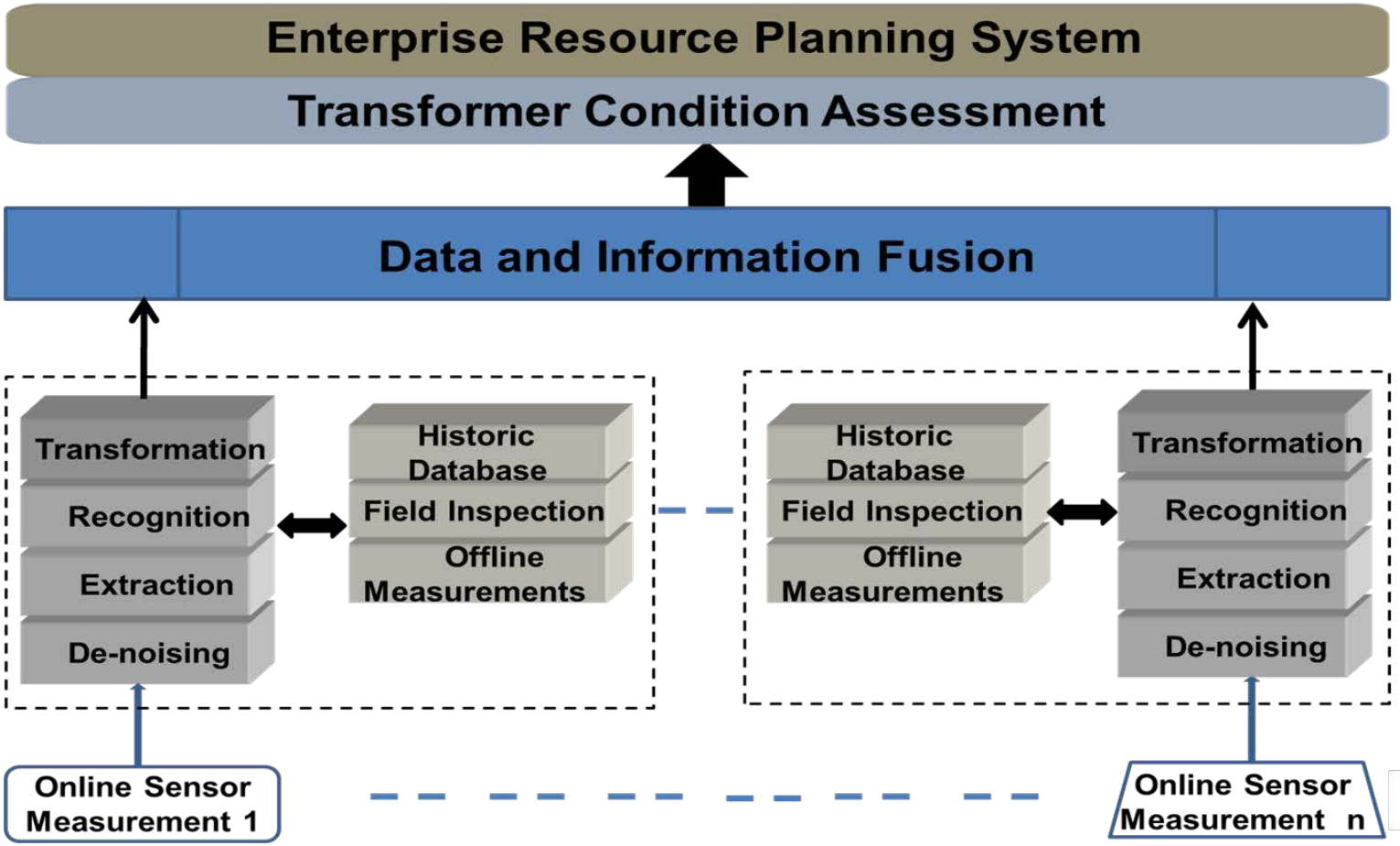
Key Objectives:

- To develop online sensor based monitoring techniques to provide total visibility of transformer health condition.

- To develop data centric and machine learning techniques for automatic data processing, information extraction for transformer asset management.

Introduction

System Architecture:

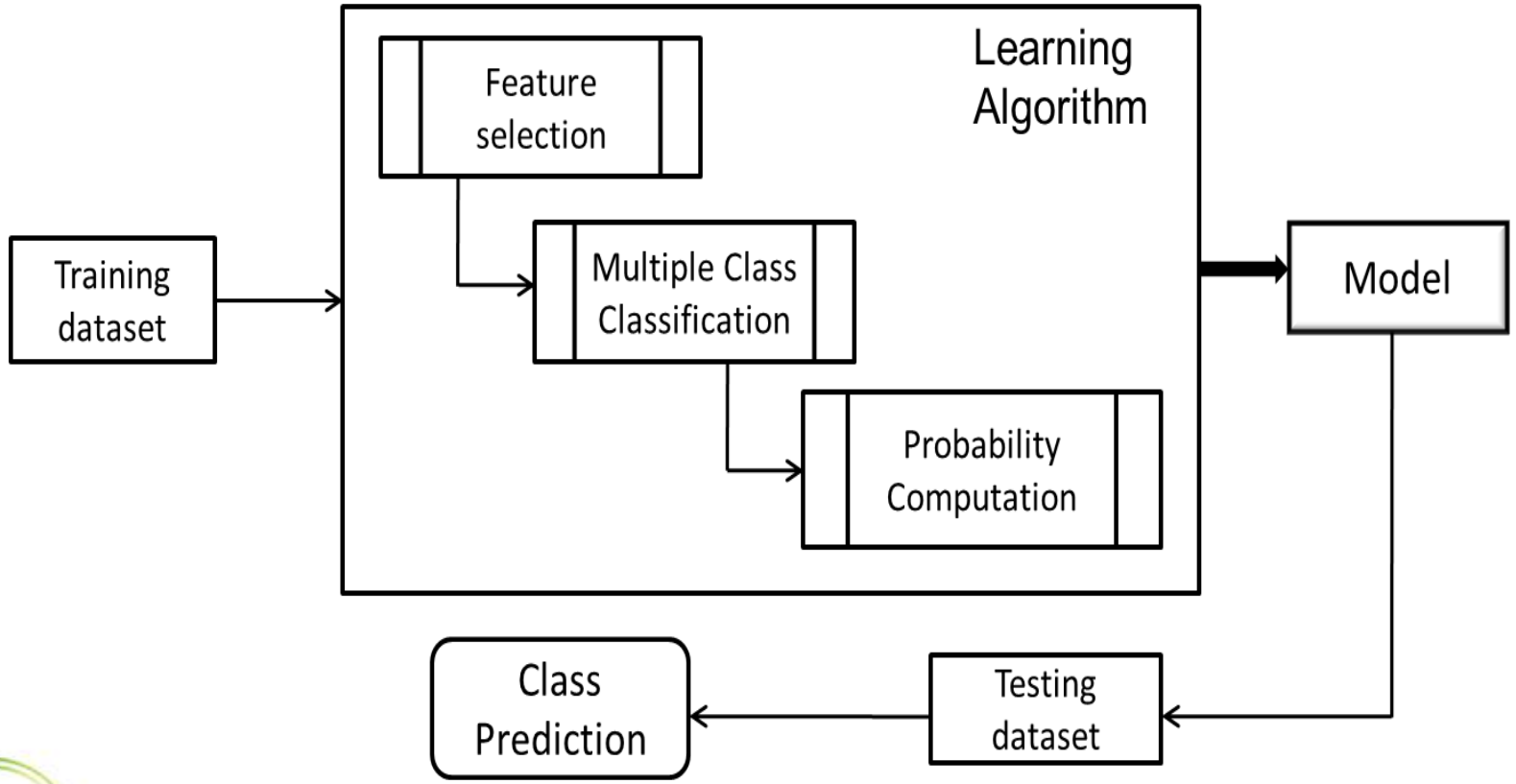


Research & Development

- Statistical learning techniques for transformer condition assessment
- Signal processing techniques for online monitoring of transformers
- Paper insulation remaining life estimation
- Moisture estimation in transformer insulation
- Dielectric response measurement
- Field testing

Exploits the dependency between transformers' conditions and measurements (DGA, PD, PDC, FDS) using historic datasets; and then evaluates the condition of transformer under investigation.

Dissolved Gas Analysis (DGA) Results Interpretation



Statistical Learning Techniques

CLASSIFICATION RESULTS: IEEE/IEC SCHEME VS. BAYESIAN CLASSIFIER

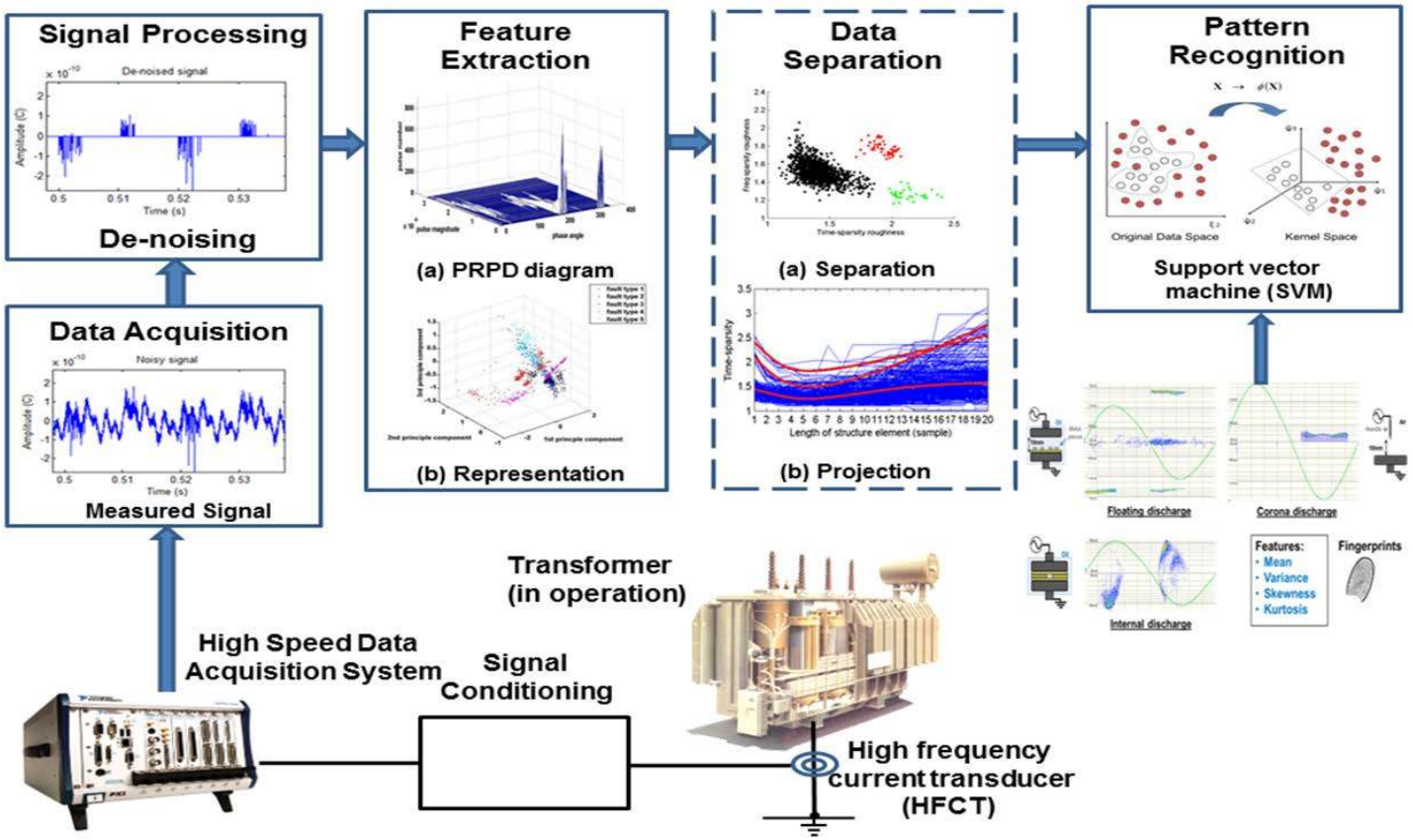
	IEEE /IEC Results	Probability of Each Class	Bayesian Classifier Results	On-site Inspection
T1	NA*	[**1.0**, 0, 0, 0, 0]	Normal	**Normal**
T2	NA*	[**1.0**, 0, 0, 0, 0]	Normal	**Normal**
T3	NA*	[0, **0.85**, 0.15, 0, 0]	MT	**DS**
T4	NA*	[0.06, 0, **0.87**, 0, 0.07]	MT	**MT**
T5	NA*	[0.01, 0, **0.57**, 0.42, 0]	HT	**HT**
T6	NA*	[0, 0, 0.01, 0, **0.99**]	PD	**PD**
T7	Normal	[**1.0**, 0, 0, 0, 0]	Normal	**Normal**
T8	Normal	[**1.0**, 0, 0, 0, 0]	Normal	**Normal**
T9	DS	[0, **0.75**, 0, 0.25, 0]	DS	**DS**
T10	MT	[0.49, 0, **0.51**, 0, 0]	MT	**MT**
T11	PD	[0, 0, 0.01, 0, **0.99**]	PD	**PD**
T12	HT	[**1.0**, 0, 0, 0, 0]	Normal	**Normal**
T13	Normal	[0, 0.06, 0.01, **0.93**, 0]	HT	**MT**
T14	MT	[0, 0, **1**, 0, 0]	MT	**HT**
T15	Normal	[0, 0, 0.01, 0.25, **0.74**]	PD	**PD**

NA* refers no classification of IEEE/IEC due to missing code.
[Normal DS MT HT PD] is the probability of each class, DS - discharge, MT- lower/medium thermal fault, HT- high thermal fault, and PD - partial discharge.

Probability output : a certain degree of inaccuracy and uncertainty in data interpretation.

T15: high temperature thermal fault - 25% chance; PD – 74% chance.

Signal Processing Techniques

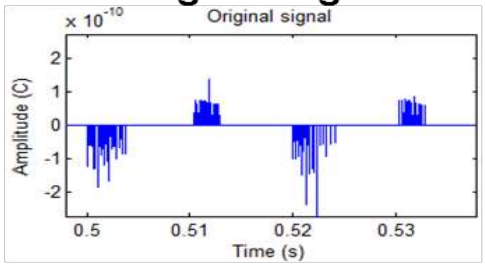


Advanced Signal Processing and Pattern Recognition Technique for Partial Discharge (PD) Monitoring and Diagnosis

Signal Processing Techniques

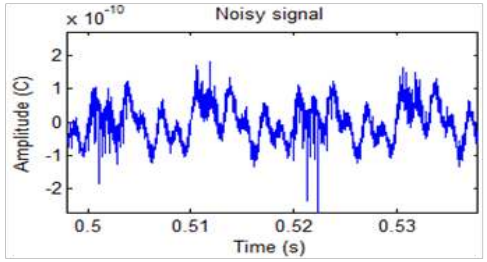
Signal Processing: PD signals de-noising

Original signals



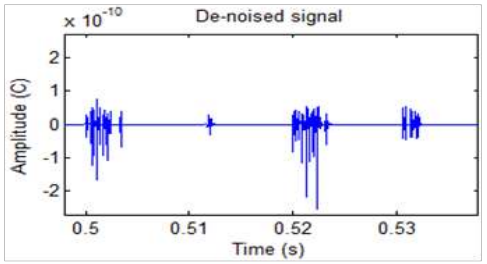
(a)

Noise corrupted signals
(original signals + noise, SNR = -5 dB)



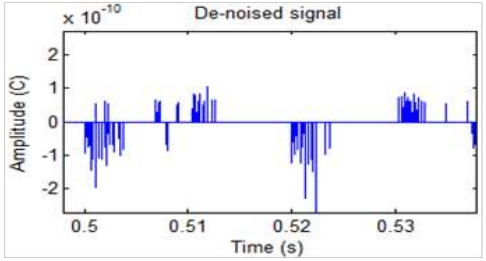
(b)

De-noised signal of DWT (db5)



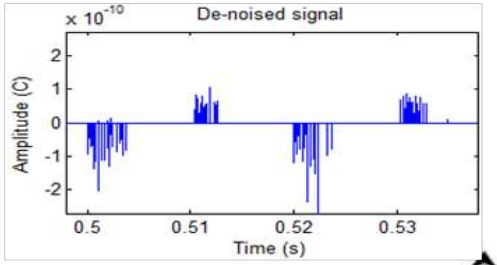
(c)

De-noised signal of EMD



(d)

De-noised signal of EEMD

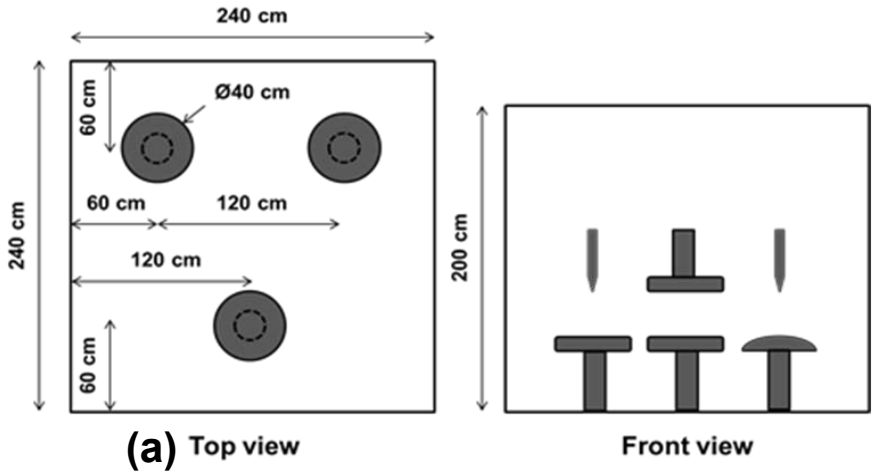


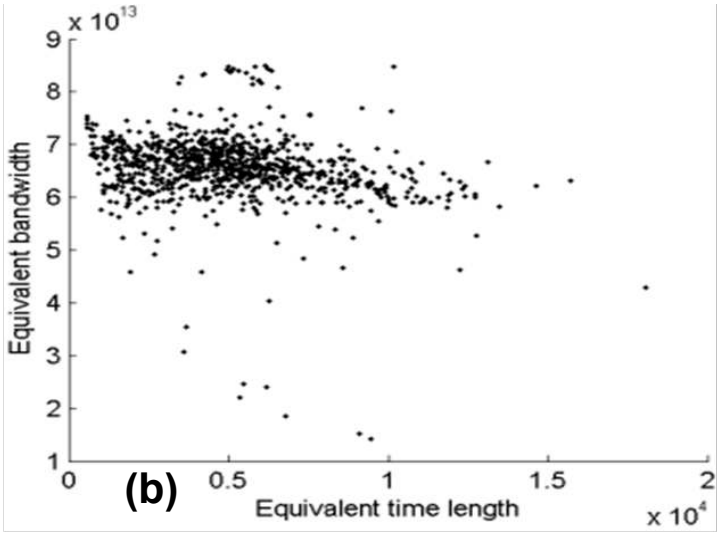
(e)

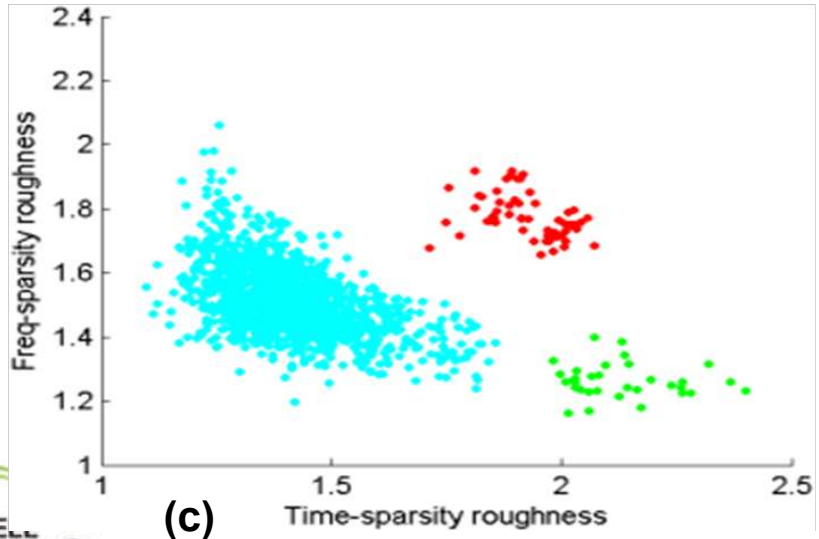
DWT – discrete wavelet transform
EMD – empirical mode decomposition
EEMD – ensemble EMD

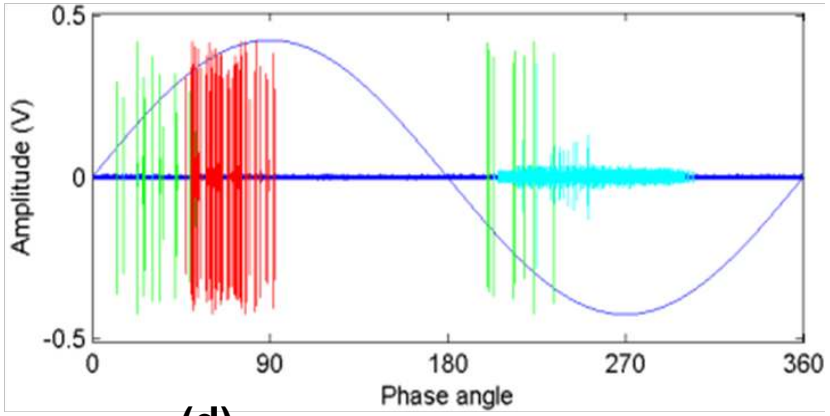
Signal Processing Techniques

Multiple PD Sources Separation



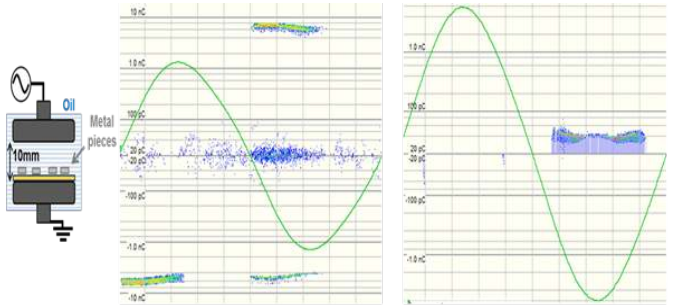






Signal Processing Techniques

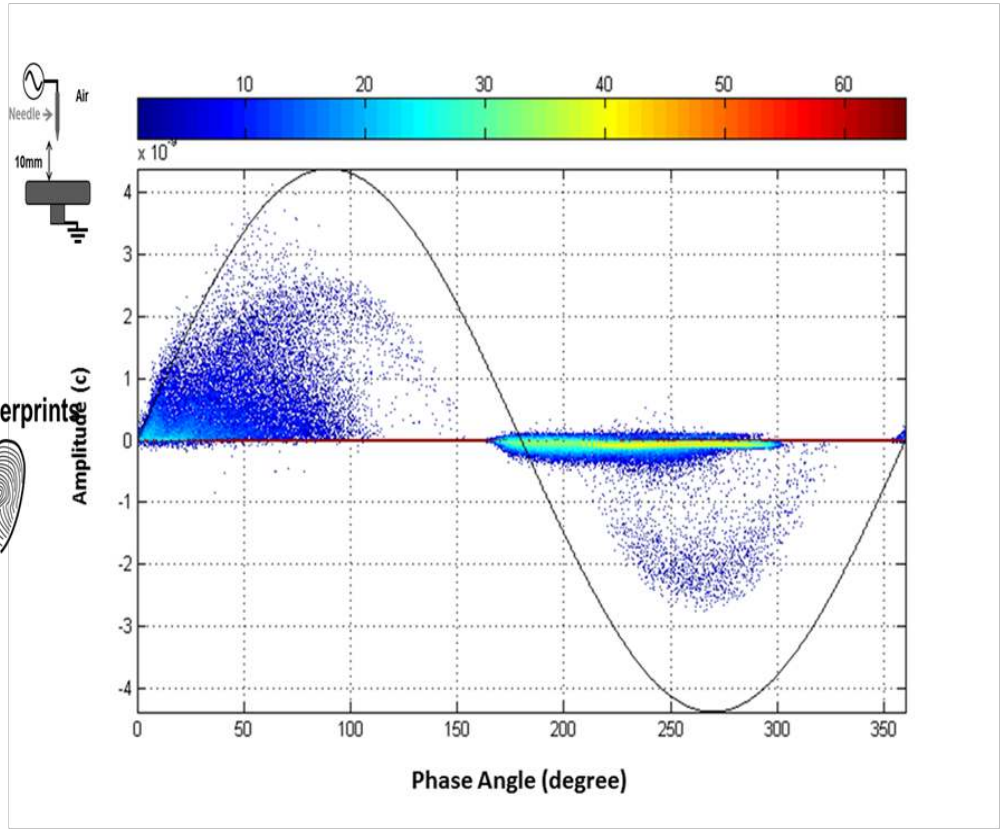
PD Sources Classification



Features:
- Mean
- Variance
- Skewness
- Kurtosis

Fingerprints

(a)



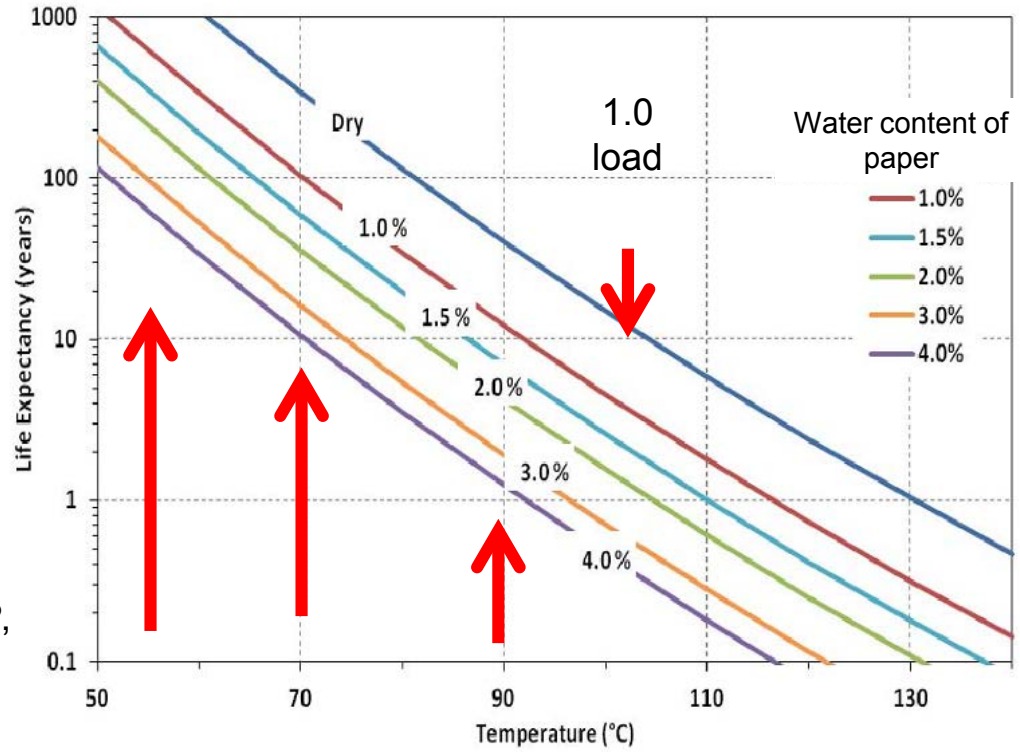
54% - internal discharge, 32% - surface discharge, 14% - corona

(b)

PREDICTING THE LIFE REMAINING OF TRANSFORMER PAPER INSULATION

We are focussing on the Kraft paper insulation within a transformer.

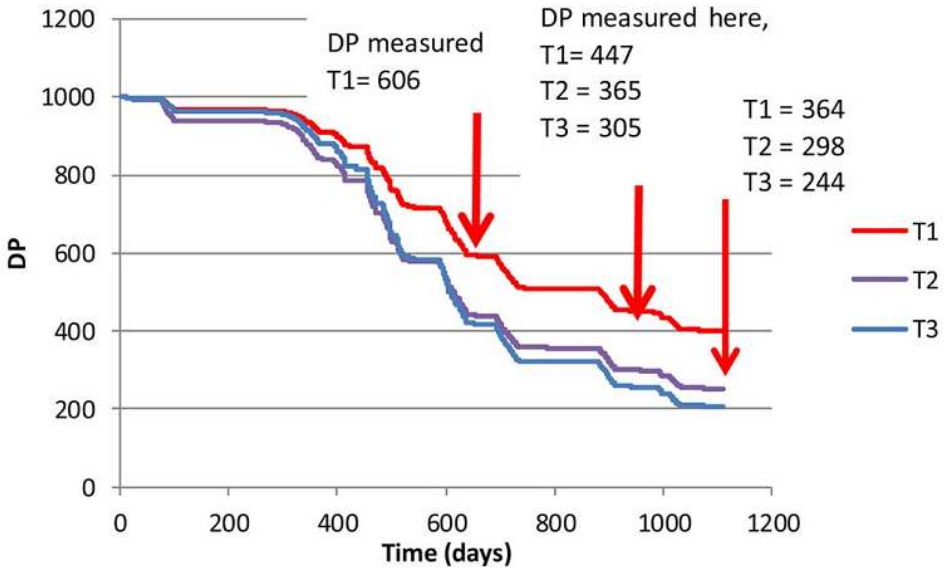
During operation this paper slowly degrades to a point when it has reached its end of life.



Lelekakis, Martin, Wijaya, *Ageing rate of paper insulation used in power transformers, Parts 1 and 2*, *IEEE Transactions on Dielectrics and Electrical Insulation*, 2012.

Testing

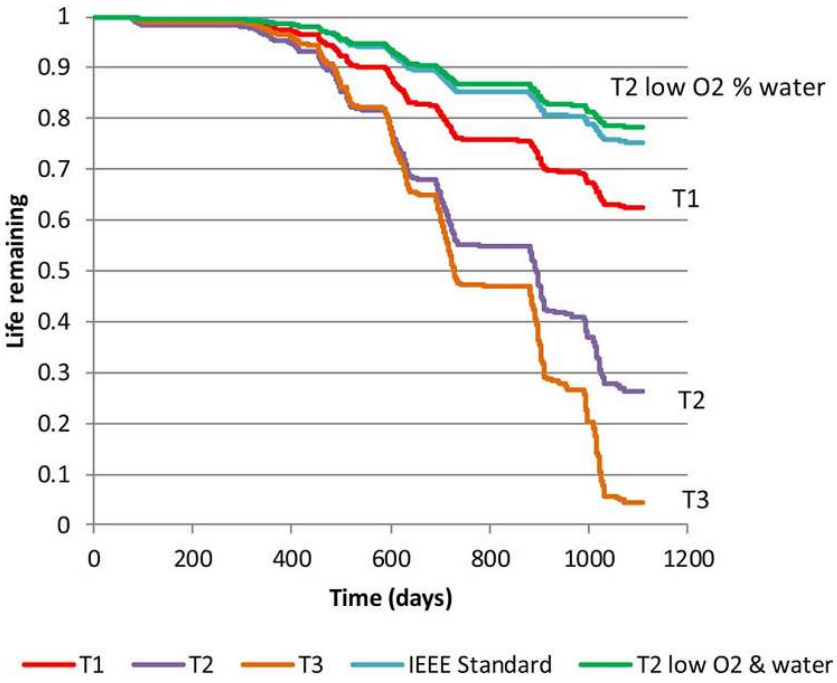
Three test transformers were set up. Using temperature and WCP their fall in paper DP was modelled, and can be seen to closely match measured values



Life remaining

The fall in DP can also be plotted as life remaining (where end of life is DP=200).

Blue and trace is using the existing IEEE standard. Insulation can be see to degrade far faster when oxygen and water are present. Setting oxygen and water to low values in our model gives close alignment with the IEEE one.

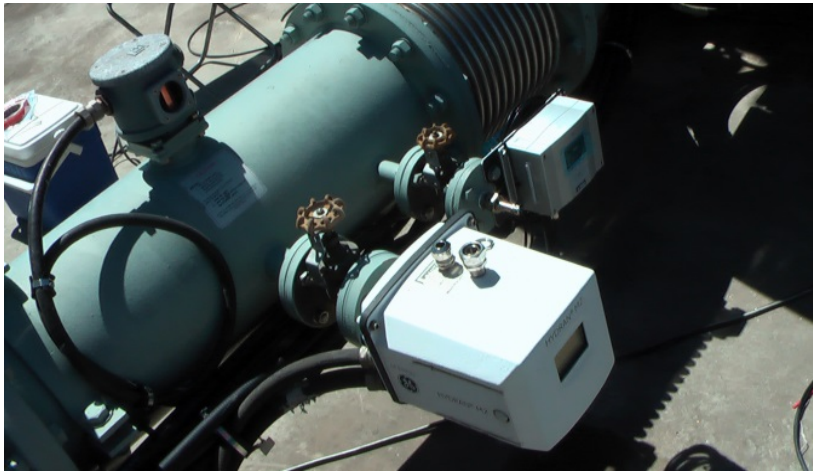


Insulation water content

- Because the life expectancy model needs water content of paper, techniques to measure this were investigated.

EXISTING METHODs

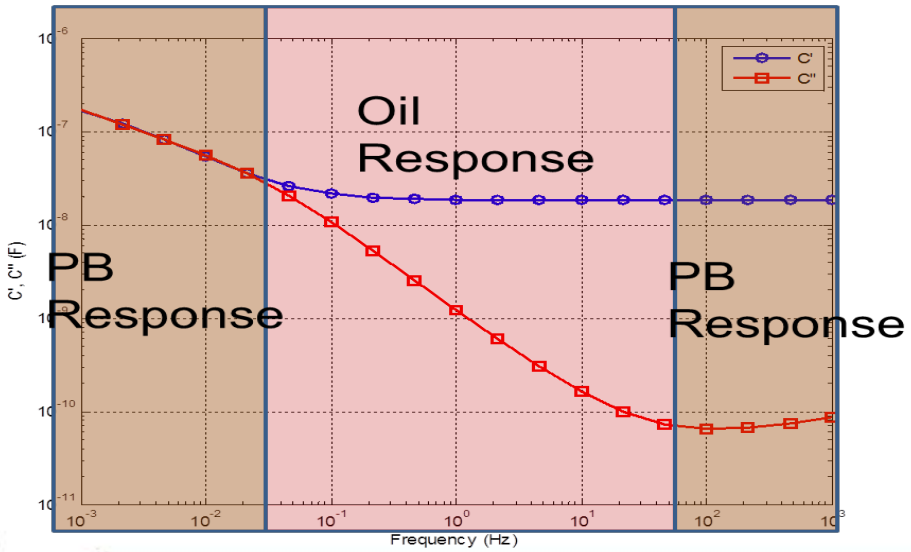
- Sensors mounted in pipe at bottom
- Hard to see how the water content of paper can be calculated if the temperature of the paper is not known. A probe mounted at the top is better because there will be a smaller temperature gradient.
- Some devices give water content of oil in ppm, which brings inaccuracy because the equation used does not reflect all oils or all ages.



Dielectric Response Measurement

Frequency Domain Spectroscopy (FDS) Measurements

- Measures capacitance and dielectric losses of transformer insulation at different frequencies
- Condition monitoring of transformers
  - ➢ *Estimating moisture content in transformer insulation*
  - ➢ *Estimating oil conductivity*

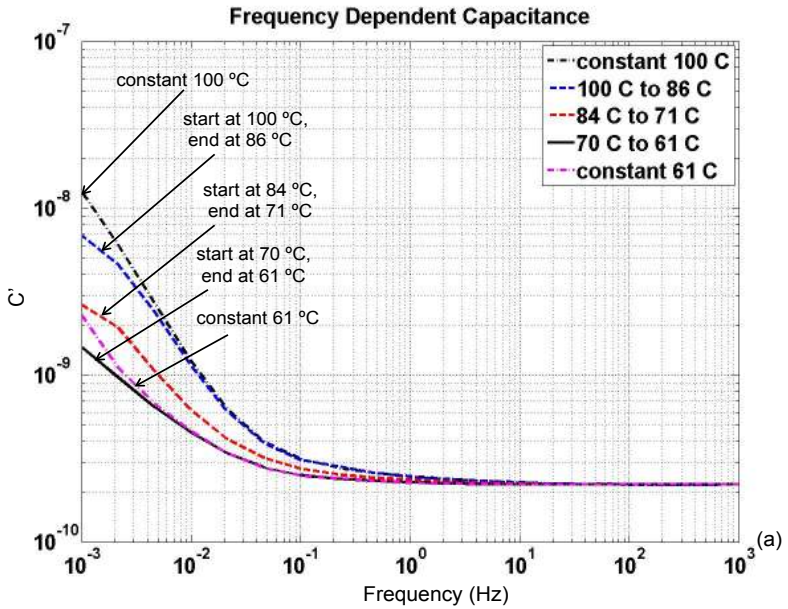


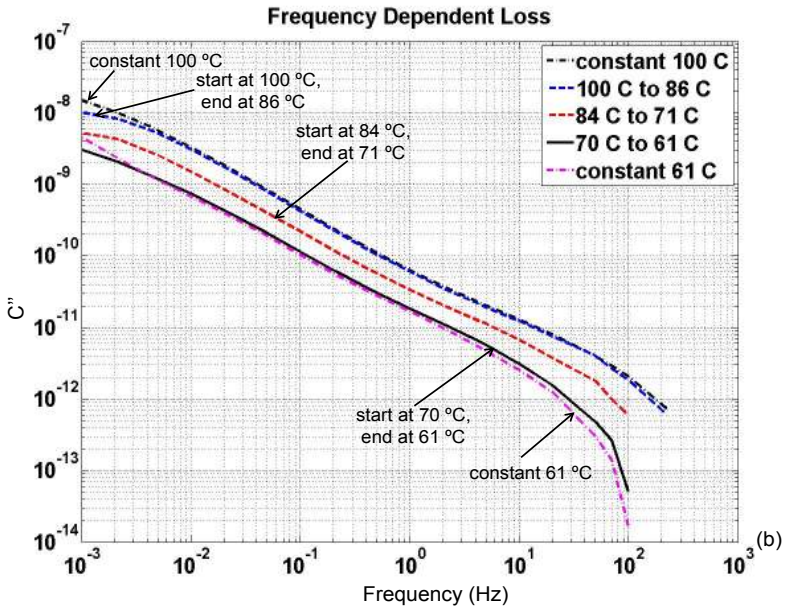
Typical FDS response of oil-paper insulation system in of transformer.

Dielectric Response Measurement

Frequency Domain Spectroscopy (FDS) Measurements

Thermal transient effect needs to be considered for properly interpreting dielectric response measurement.

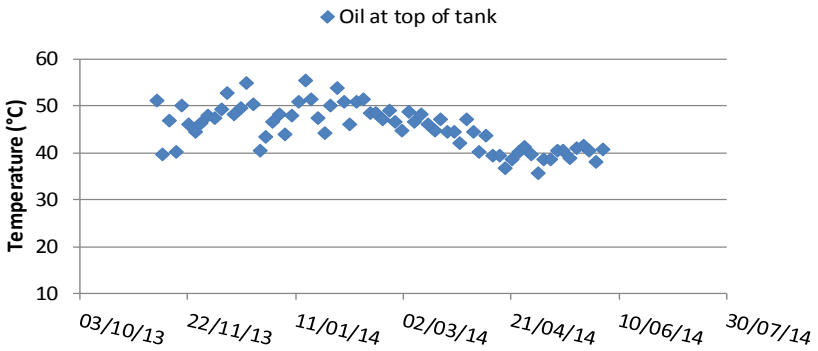




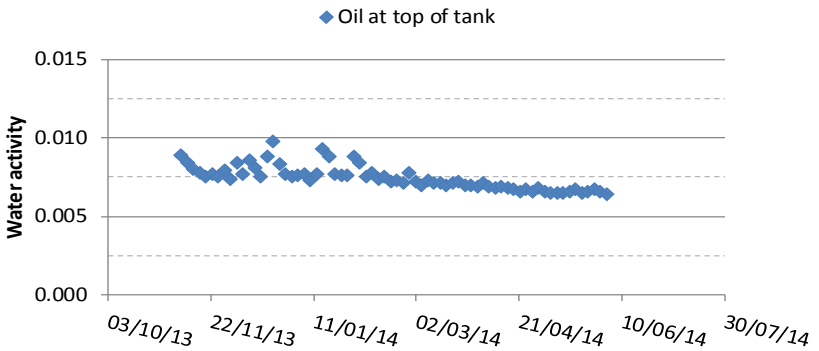
FIELD TESTING: THE FOLLOWING TRANSFORMERS WERE USED

EXAMPLE OUTPUT OF MODEL

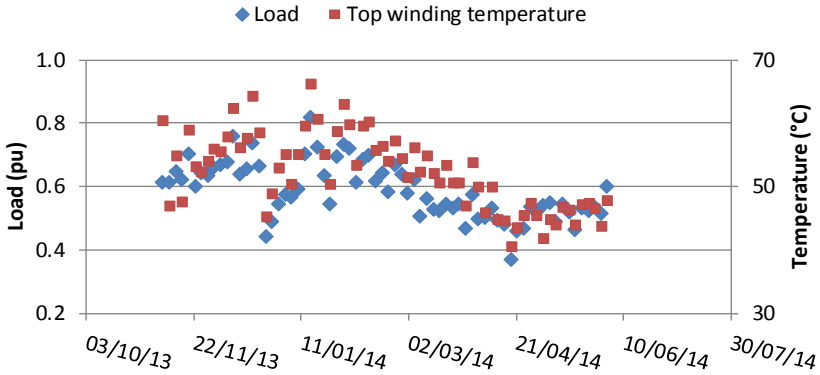
Temperature measured by water activity probes



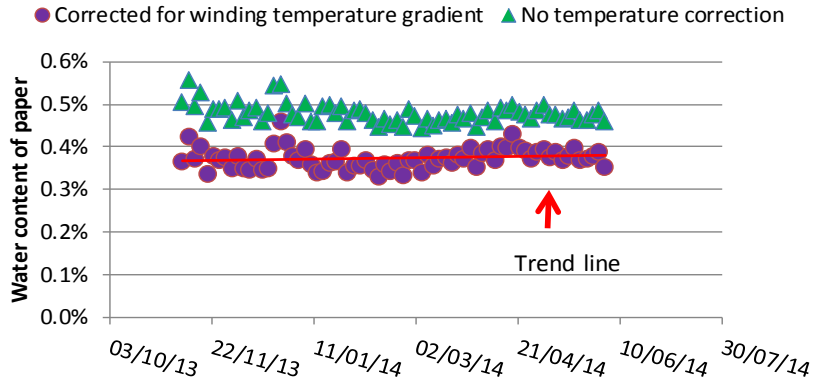
Measured water activity



Winding temperature calculated from load



Calculated water content of paper insulation



Results

	Tr1	Tr2	Tr3	Tr4
Unit description (MVA)	12.5	12.5	25	225/375
Age on test (years)	33	33	29	7
Water content measured using dielectric response (%)	3.9	3.0[1] – 3.6[2]	3.7	0.3
Water content measured using UQ algorithm and water activity sensor (%)	3.8	3.7	2.7 – 2.9	0.4

Paper water and life remaining calculator

Version 3

1) Make sure that your csv data file is in the proper format

- (•) No temperature correction
- ( ) Use load and modeling
- ( ) Use hotspot temperature

2) Load this datafile — Open csv file

3) Is your transformer sealed or free-breathing?

- ( ) Sealed
- (•) Free breathing

4) How do you wish to calculate initial paper conditions?

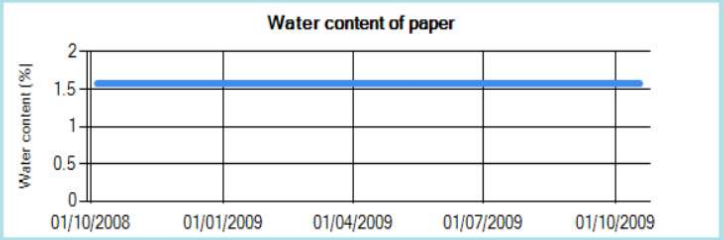
- ( ) New transformer
- (•) Enter DP value — 600
- ( ) Calculate from data

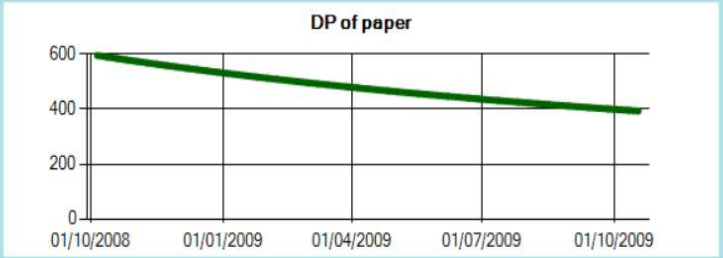
4) Click on process button — Process

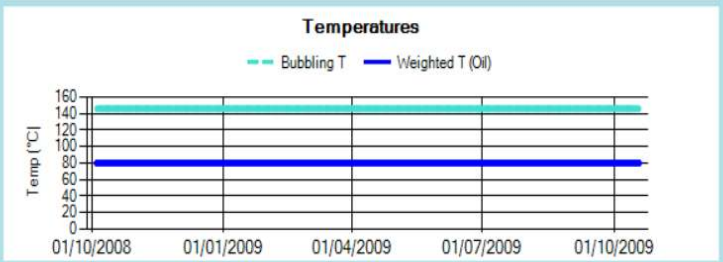
5) Click to export — Export to Excel

Time	Temperature	Water activity
05/10/2008 ...	80	0.08
05/10/2008 ...	80	0.08
05/10/2008 ...	80	0.08
05/10/2008 ...	80	0.08
05/10/2008 ...	80	0.08
05/10/2008 ...	80	0.08

Week beginning	Bubbling T	Weighted T	V
05/10/2008 ...	145.847943...	80.0000000...	0
12/10/2008 ...	145.847943...	80.0000000...	0
19/10/2008 ...	145.847943...	80.0000000...	0
26/10/2008 ...	145.847943...	80.0000000...	0
02/11/2008 ...	145.847943...	80.0000000...	0

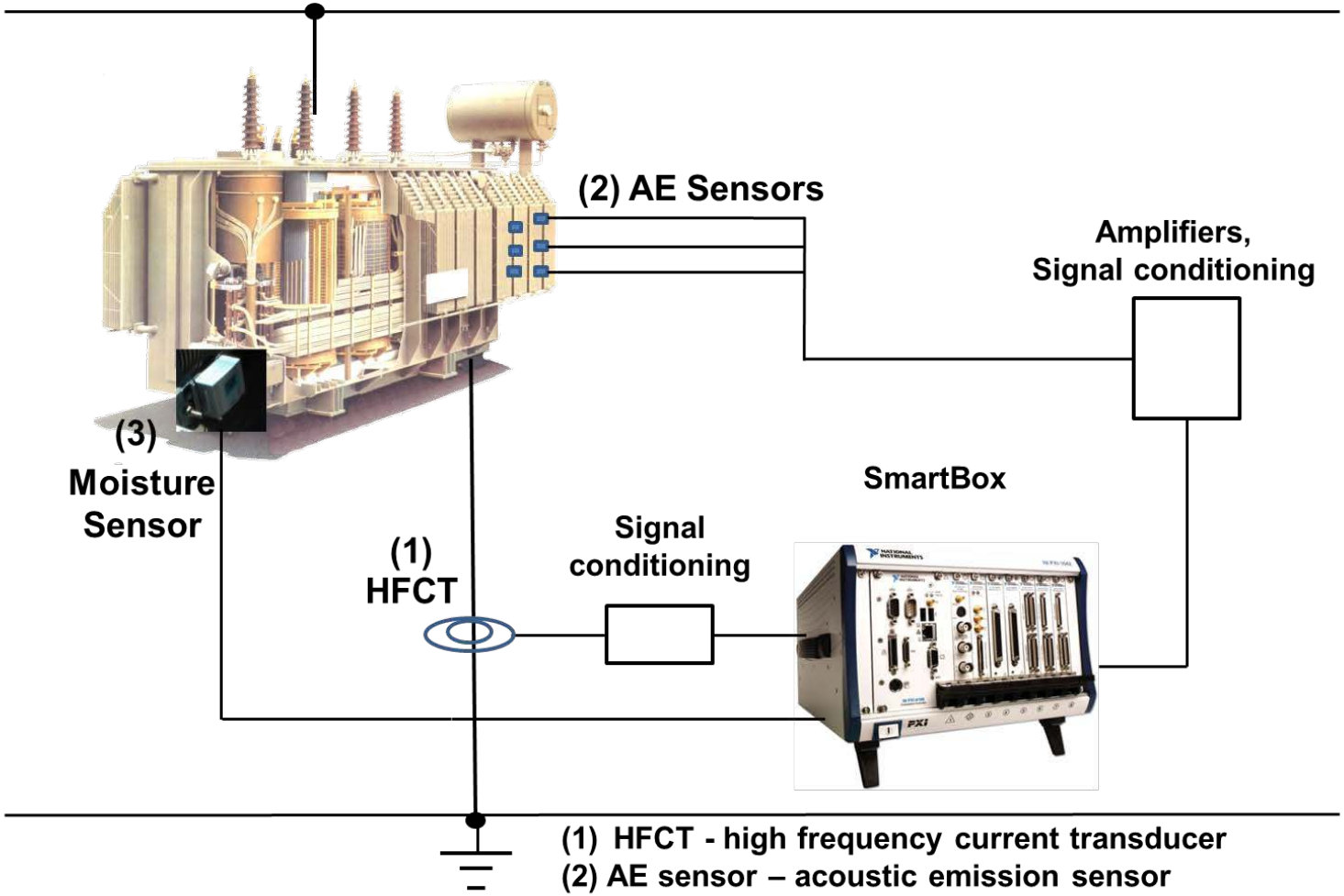






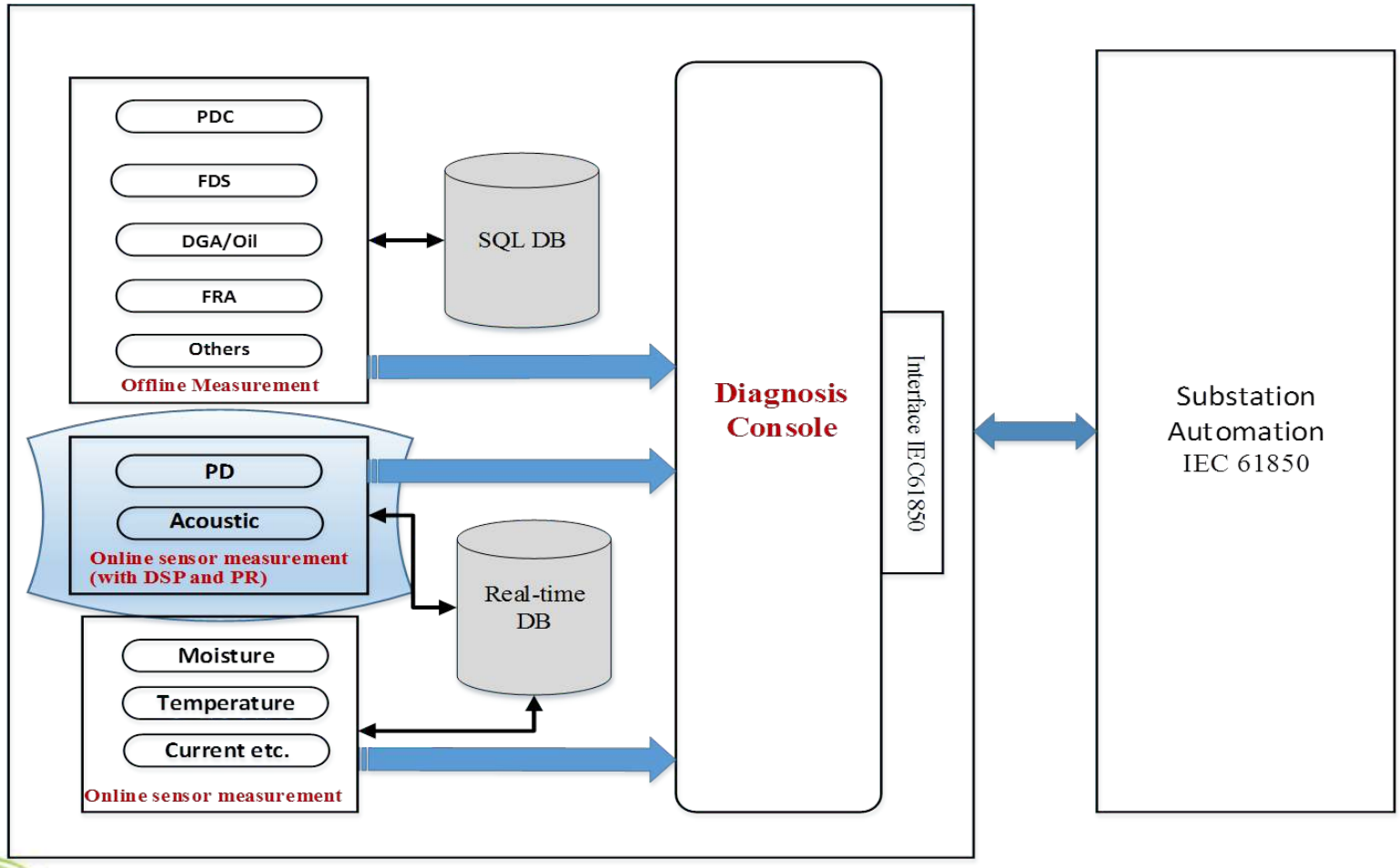
SmartBox Development

SmartBox: reconfigurable hardware/software platform



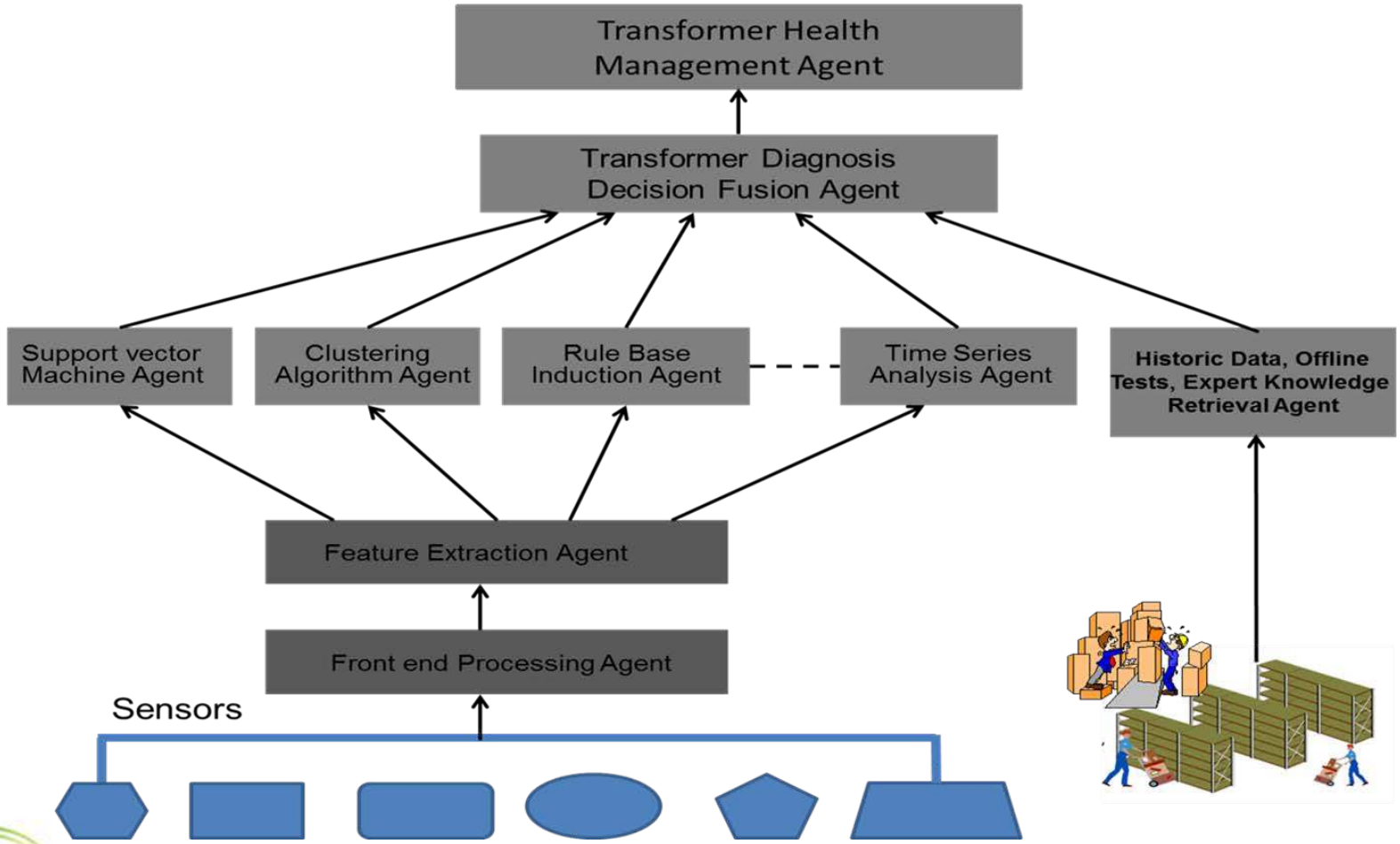
SmartBox Development

SmartBox: Functional Components



SmartBox Development

SmartBox: Software Platform - Multi-Agent System



Conclusions

- Transformer is a complex system requires a comprehensive solution of condition monitoring and assessment.
- Developed a number of techniques for condition monitoring and assessment of transformers.
- Developed a re-configurable hardware and software platform (SmartBox) for deploying various techniques for condition assessment.

Thank you!

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