TOWARDS COST-EFFECTIVE MAINTENANCE OF POWER TRANSFORMER BY ACCURATELY PREDICTING ITS INSULATION CONDITION

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INTRODUCTION

- Transformer asset management has been a priority to power utilities:
  - Improving condition monitoring and diagnosis methods
  - Preparing solid asset maintenance plans
    - Maintenance costs are found to be heavy burden on utilities
  - Developing a well constructed determining process for transformer health index
**Megger Test**

- A classical time-based preventive maintenance test
- Easy, fast, and inexpensive test to be conducted
- Indicates insulation deterioration
- Efficient tool for developing trend analysis
- A diagnostic tool in unplanned outages
MEGGER TEST DRAWBACKS

- Temperature effect
  - Rule in practice: factor of two is attributed to megger test readings for every 10 degrees change

- Moisture Content effects
  - Accelerating deterioration
  - Reducing the dielectric strength

- Faults are not detected by the insulation resistance parameter
Traditional Maintenance Practices

- Reducing the unplanned outage cost and period for tripped transformer insulation inspection
  - Rule-of-thumb: if the transformer trips due to the operation of differential, restricted earth fault and Buchholz relays, insulation inspection must be conducted before reconnecting to the network
  - Megger test clearance of abnormal situation is not reliable for reconnecting the transformer
  - Supportive tests should be conducted
Supportive Tests

- Other tests are conducted to enhance the diagnosis reliability of the megger test:
  - Oil Breakdown Voltage (BDV)

- Oil water content
  - Temperature correction should be considered
    - Due to equilibrium process in the oil-paper system

- Dissolved-gas analysis (DGA):
  - CO2/CO ratio
  - Total Dissolved Combustible Gases (TDCG)

- BUT, costly ($200/sample) and time consuming (few days)
TOWARDS COST-EFFECTIVE MAINTENANCE

- Optimizing the number of time-based maintenance tests
  - Predicting oil quality and dissolved gases parameters informs about the critical tests that should be taken
  - Developing well constructed asset maintenance plans with optimized number of tests and periods between them
## The Literature

<table>
<thead>
<tr>
<th>Year(s)</th>
<th>Authors</th>
<th>Model</th>
<th>Predictors</th>
<th>Output</th>
<th>Accuracy</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009&amp;2008</td>
<td>Khaled Shaban, A. H. El-Hag, and Andrei Matveev and Khaled Assaleh &amp; Ayman El-Hag</td>
<td>Artificial Neural Network (ANN) &amp; Polynomial Network</td>
<td>Megger</td>
<td>Breakdown voltage (BDV), oil water content, interfacial tension (IF) and acidity &amp; BDV &amp; Water content</td>
<td>BDV: 84% Water content: 60% IF: 95% Acidity: 75% &amp; Water content: could not be estimated IF: 93% BDV: 84%</td>
<td>BDV and IF are indication for oil contamination only</td>
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<td>2004&amp;1999</td>
<td>Mohamed Ahmed Abdel Wahab &amp; Mohamed A.A. Wahab, M.M. Hamada, and A.G. Zeitoun, G. Ismail</td>
<td>ANN &amp; Polynomial Regression models</td>
<td>Oil acidity, oil water content and transformer age &amp; Service period</td>
<td>BDV &amp; BDV, oil water content and acidity</td>
<td>More than 90% for both</td>
<td>BDV is not comprehensive and No. of data is very small</td>
</tr>
<tr>
<td>2009&amp;2008</td>
<td>Sheng-wei Fei, Cheng-Liang Liu, and Yu-Bin Miao &amp; Sheng-Wei Fei, and Yu Sun</td>
<td>Support vector machine with genetic algorithm</td>
<td>DGA</td>
<td>DGA trend</td>
<td>Less than 90% &amp; More than 90%</td>
<td>It is not practical</td>
</tr>
<tr>
<td>2000&amp;2003</td>
<td>I N da Silva, A N de Souza, R M C Hosssi, and J H C Hosssi &amp; J.S. Navamany, and P.S. Ghosh</td>
<td>ANN</td>
<td>furan, volume of carbon monoxide (CO), Interfacial tension and acidity &amp; CO, CO2 and furfural</td>
<td>Aging Degree</td>
<td>N/A &amp; Around 90%</td>
<td>It is not cost-effective</td>
</tr>
<tr>
<td>2009</td>
<td>Ali Naderian Jahromi, Ray Piercy, Stephen Cress, Jim R. R. Service and Wang Fan</td>
<td>Weighted average</td>
<td>All standard transformer tests</td>
<td>Transformer health index</td>
<td>N/A</td>
<td>The weights are not assigned based on quantities correlations &amp; Relatively hard to be practiced</td>
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</table>
**ANN for Prediction**

- Artificial neural network (ANN) is used as a modeling technique.
- Multi-layer feed forward ANN with Back propagation algorithm.
THE EXPERIMENT

- Data from transformer maintenance records of 19 power transformers in Abu Dhabi Transmission and Despatch Company (TRANSCO) are used

- Voltage rating of 220/33/11KV

- Rating is in the range of 50-140MVA

- Range of 7-15 years into service

- 54 samples are used to predict oil BDV

- 31 samples are used to predict oil water content

- 32 samples are used to predict TCG

- 33 samples are used to predict CO2/CO ratio

- All the samples are used for training and testing to predict all the available data
### Sample of the Dataset

<table>
<thead>
<tr>
<th>Insulation Resistance (MΩ)</th>
<th>Parameters</th>
</tr>
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<tbody>
<tr>
<td>HV/E</td>
<td>LV/E</td>
</tr>
<tr>
<td>------</td>
<td>-------</td>
</tr>
<tr>
<td>1</td>
<td>300</td>
</tr>
<tr>
<td>2</td>
<td>820</td>
</tr>
<tr>
<td>3</td>
<td>280</td>
</tr>
<tr>
<td>4</td>
<td>560</td>
</tr>
<tr>
<td>5</td>
<td>270</td>
</tr>
</tbody>
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RESULTS

- 4 ANNs:
  - 3 neurons in the input layer (HV/E, LV/E and TV/E)
  - 2 hidden layers with three neurons at the first hidden layer and 10 neurons at the second hidden layer
  - 1 neuron at the output layer (BDV, water content, TDCG and CO2/CO)

- Prediction rate:
  - Oil BDV - 96%
  - Oil water content - 84%
  - CO2/CO ratio - 91%
  - TDCG - 88%
“This result agrees with the results of the models proposed in [1] and [2]. Transformer oil breakdown voltage gives an indication about the dielectric capability of transformer oil to withstand high electrical stresses. Also, BDV can be an indication about the deterioration state of the insulation system in the transformer. This is because the contamination particles resulted from the insulation deterioration in the transformer oil decrease the BDV value. This explains the high correlation presented between IR and oil BDV.”
RESULTS

"compared to BDV the prediction accuracy has been reduced between 10-15%. This can be attributed to the relatively wider scatter of the data of water content (17-32 ppm) compared to BDV (63.6-78.8 kV) and the relatively small size of the training set (31 vs. 54). Moreover, the oil temperature effect in altering the value of the measured oil water content was not completely considered as the oil sample was taken between 60-65 °C. Such narrow band of temperature variation may still influence the accuracy of the water content measurement. The proposed model to predict oil water content in this study can be considered superior to other proposed models [1-2] where the effect of temperature variation on measured samples was normalized."
RESULTS

“Although CO\textsubscript{2}/CO ratio is more effective in diagnosing cellulose involvement in incipient faults rather than indicating the deterioration of cellulose, the proposed model shows an acceptable reliability. This agrees with the practice in utilities to use CO\textsubscript{2}/CO ratio with other insulation quality parameters as indicators for cellulose thermal degradation.”
“Insulation resistance is affected by the deterioration and the abnormal excess of degradation, thus, IR can be an indicative parameter to the TDCG. Although TDCG as a parameter is a reflection of incipient faults rather than a parameter for aging index, an acceptable and reliable correlation is verified in the proposed model.”
CONCLUSIONS

- Prediction techniques can improve transformer insulation diagnosis and reduce the predictive and corrective maintenance costs.

- The proposed models suggests a decent potential for predicting oil BDV, water content, TDCG and CO$_2$/CO ratio.

- It can be more efficient to test the correlations of the transformer insulation parameters in different conditions (wide temperature ranges, service ages and voltage levels, etc.)

- Increasing data size can enhance the generalization capability of the model