Transformer Lifetime Prediction

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Introduction

- Cost of a blackout is astronomical. Reliability of electric grid is of paramount economic importance
- With grid becoming smarter, we can effectively monitor the state of the power grid and its components
- Goal is to make the expected performance quantifiable, make risks and costs predictable and controllable
Reliability of Transformers

![Graph showing the relationship between stress and time, indicating stress events and the end of life.](image)

Courtesy: Presentation by Alex Rojas, GE in EE392N
Project Goals

Inputs:
- Transformer performance model
- History of unpredictable events

Outputs:
- Expected lifetime of the transformer
- Probability of failure at any given point in time
- Expected cost of failure
Transformer Failure Modes

Failure of a transformer is usually a failure of a component
- Paper-Oil Insulation Degradation
- Bushing Failure
- Tap Changers:
  Asynchronous operation or carbon layer formation
Paper Degradation Model

\[ DP = \text{Degree of Polymerization} \]
\[ R_g = \text{Universal Gas Constant} \]
\[ A = \text{Process Constant} \]
\[ E_a = \text{Activation Energy} \]
\[ k(t) = \text{Reaction Rate} \]
\[ t_0 = \text{Initial Time} \]

\[ \frac{d DP(t)}{dt} = -k(t) [DP(t)]^2, \]

\[ DP(t) = \frac{DP(t_0)}{1 + DP(t_0) \int_{t_0}^{t} k(\tau) \, d\tau}, \]

\[ k(t) = A \exp \left( -\frac{E_a}{R_g \, T(t)} \right), \]
Simulation Outline

- **Generate Input Data**
  - Generate the ideal transformer curve based on the model
  - Generate transformer history curve by superimposing unpredictable events using a Generalized Extreme Value Value distribution

- **Process Input Data**
  - Estimate GEV distribution looking at the history curve and comparing it against model
  - Predict probability of failure in some set number of days using a monte-carlo simulation
Ideal Transformer Curve

DP(t₀) = 1200
Threshold DP = 250
Ideal transformer lifetime ~ 6000 days ~ 16 years
Generate History Curve

Ideal and Actual Transformer History Curves

Threshold DP = 250
Generate History Curve

Example of a highly unlikely catastrophic event expediting transformer failure
Compute the deviations at each step using interpolation techniques
Fitting data to the GEV distribution,

\[ \mu \sim 0 \]
\[ \sigma \sim 0.05 \]
\[ \text{shape} \sim -3 \]
Probability of Failure

Graph produced by a Monte-Carlo simulation

Computes probability of transformer failure in next 30 days
Cost of Failure

- We assume most systems are N-1 reliable
- In which case, cost of failure is nothing but the cost of replacing a transformer
- Cost of a transformer ~ $500,000
- Cost of Failure curve is nothing but 500,000-times scaled version of failure probability curve!
Future Work

- Multiple failure modes
  - Bushing failure
  - Tap chargers
  - Dependence of these modes on one another

- Multiple component failure
  - Independent failures
  - Dependent failures

- Cost structure
  - Cost of component(s) failure
  - Cost of a blackout
  - Cost of maintenance
References

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4. Power Transformer Reliability Modeling - Arjan Schijndel