The Reliability Effects of Transient-Induced Degradation on the Performance of Large Power Transformers

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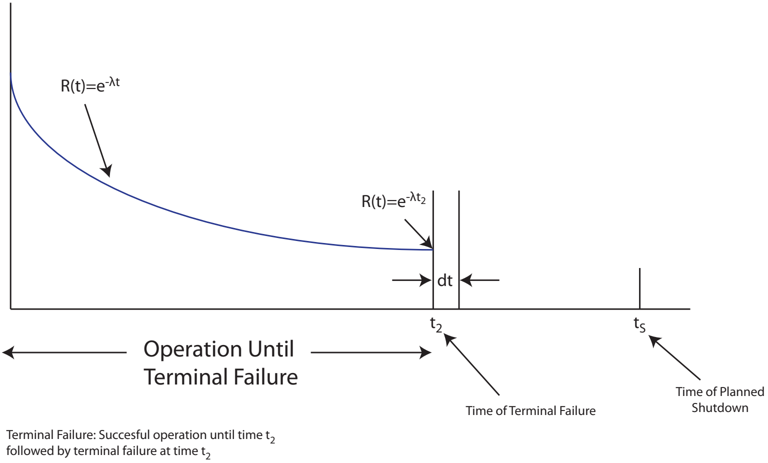
Motivation

- Traditional component reliability models are incomplete.
  - Time-dependent degradation is not the only important mode of degradation.
- Event-induced degradation could **also** affect component performance and thus should be included in reliability models.
- Accurate modeling of aging component reliability improves effectiveness of a nuclear power plant's asset management.

Traditional Component Reliability Model

- Failure frequency is constant, or a function of time-dependent mechanistic degradation (ex. radiation embrittlement, water chemistry)



Transient-Induced Degradation Reliability Model

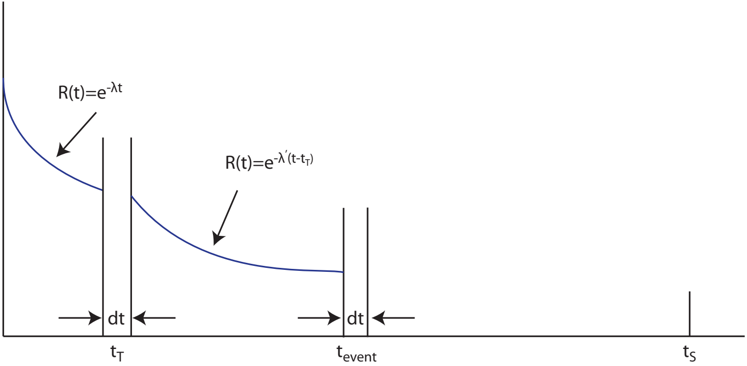


Figure 1 : Reliability diagram indicating the relationship of transient, t_t, and time of failure event, t_{event}

- Tranisent increases the random failure frequency

$$\lambda' = \lambda_R + \Delta\lambda_R \quad (1)$$

Seeking an Example for Model Demonstration

- Criteria for Component Selection:
  - High capital cost
  - Long lead-time for replacement
  - Failure leads to unplanned shutdown
  - Failure has occurred prematurely
  - Record of component experiencing strong transients

Seeking an Example for Model Demonstration

- Criteria for Component Selection:
  - High capital cost
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  - Record of component experiencing strong transients
- Selection: **Large Power Transformers**

Plant-Specific Data: *Fault Evaluation*

- Model demonstration requires component-specific event history
- A utility partner was identified who had experienced unanticipated transformer failures
  - 7 Large power transformers at site
  - Event-history: 25 years, 17 events affecting transformers
- Impact codes assigned to each transformer for each event

Code	*Severity*
0	None
1	Low
2	Low/Medium
3	Medium
4	Medium/High
5	High

Plant-Specific Data: *Fault Evaluation Data*

Table 1 : Lifetime Impact Codes from Plant Data Set

Transformer Name	MT1A	MT1B	UAT1	MT2A	MT2B	UAT2	Spare
Lifetime Impact Code Sum	2	20	11	20	26	20	13

Plant-Specific Data: *Fault Evaluation Data*

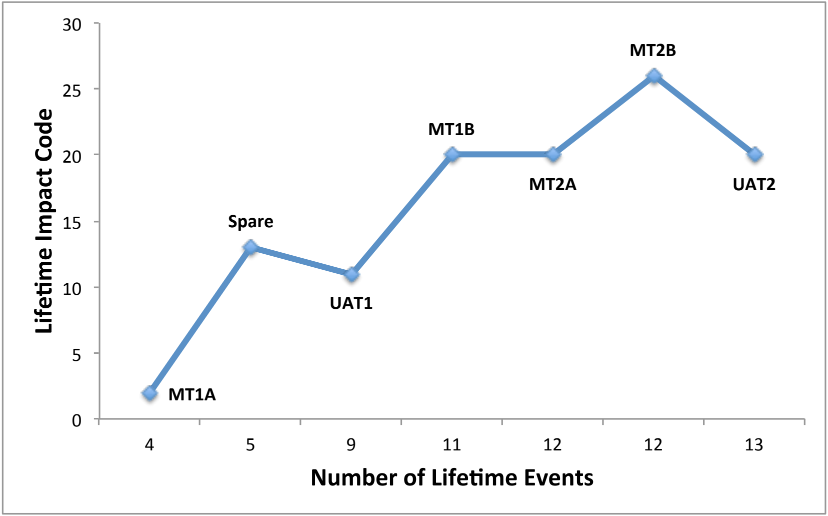

Figure 2 : Comparison of the Lifetime Severity and Number of Events Experienced by Each Transformer

Plant-Specific Data: *Classification of Internal and External Events*

- **Internal Events**: Events occurring due to the malfunctioning of components internal to the transformer
- **External Events**: Events that degrade the transformer, but were initiated by a component external to the transformer

- We want to predict more accurately the occurrence of **internal events** – these events are most relevant to asset management

Plant-Specific Data: *Comparison of Internal and External Events*

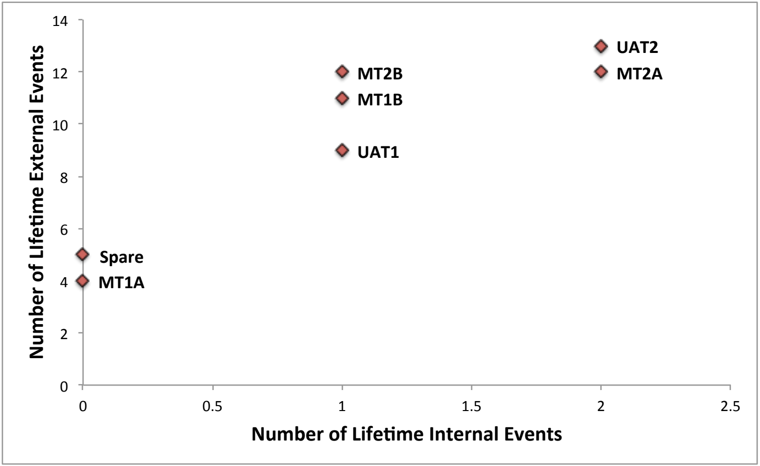

Figure 3 : Comparison of Internal and External Events for Transformers Examined

Strategy for Developing a Physics-of-Failure Predictive Model

- **Model goal**: Accurately predict transformer downtime
- Worst case scenario: catastrophic failures
  - Model will focus on life-limiting failure modes
- Perform a fragility analysis
  - Identify most life-limiting components
  - Identify most important degradation modes
  - Characterize degradation by fragility factor

Strategy for Developing a Physics-of-Failure Predictive Model

- Development of Fragility Factor
  - Requires relationship between transient-event data and physical models of degradation
  - Requires the definition of a failure limit
- Fragility Factor:

$$F = \frac{\sum_{i=1}^{n} [\% \ Component \ Degradation]_n}{n} \tag{2}$$

- Percent Degration:

$$P_D = MAX \left[\frac{Degradation}{Degradation \ Limit} \right]_m \tag{3}$$

Use of the Fragility Factor for Reliability Predictions

- We seek improved asset management strategies through better reliability modeling
- Use the external event data for reliability predictions
  - Event frequencies
  - Characteristic induced degradation
  - Combine with age-related degradation models
- Result: Prediction of reliability(time) – better information for decision-making

Summary

- Traditional age-related models of degradation yield incomplete future reliability predictions.
- Event-based, component-specific reliability predictions can provide more accurate reliability predictions.
- We propose development of physics-of-failure based fragility factor to represent state of component degradation.
- Improved component monitoring strategies could be developed from more accurate mechanistic failure modeling.