Transformer Lifetime Prediction

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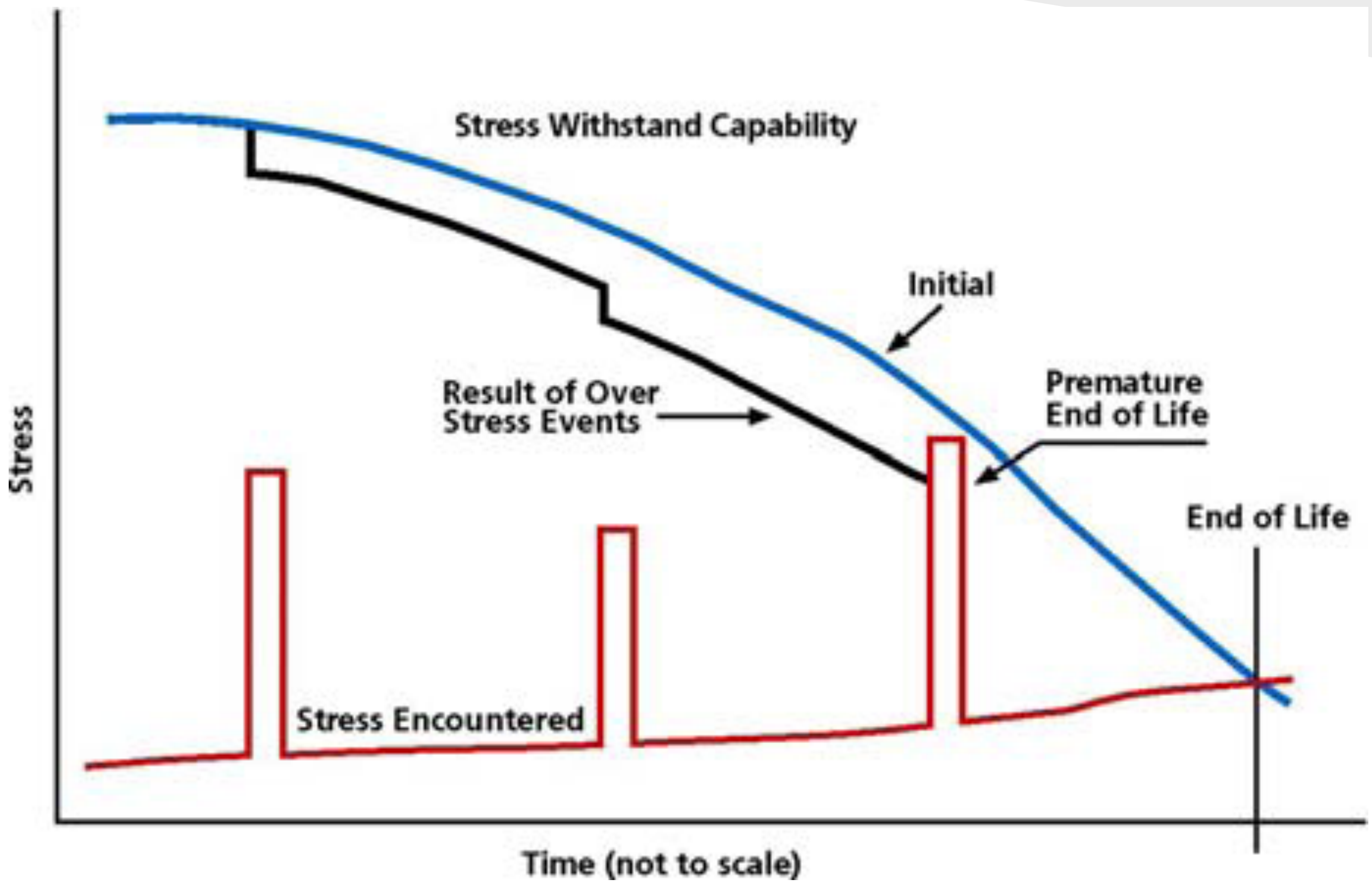
Introduction

- 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



Courtesy: Presentation by Alex Rojas, GE in EE392N

Project Goals

Inputs:

- Transformer performance model
- History of unpredictable events

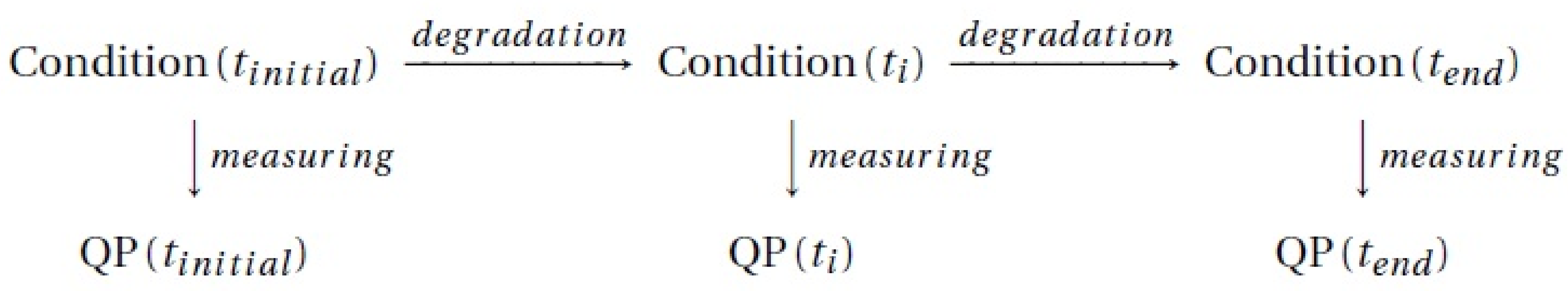
Outputs:

- 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 = Degree of Polymerization

Rg = Universal Gas Constant

A = Process Constant

Ea = Activation Energy

k(t) = Reaction Rate

t_o = Initial Time

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

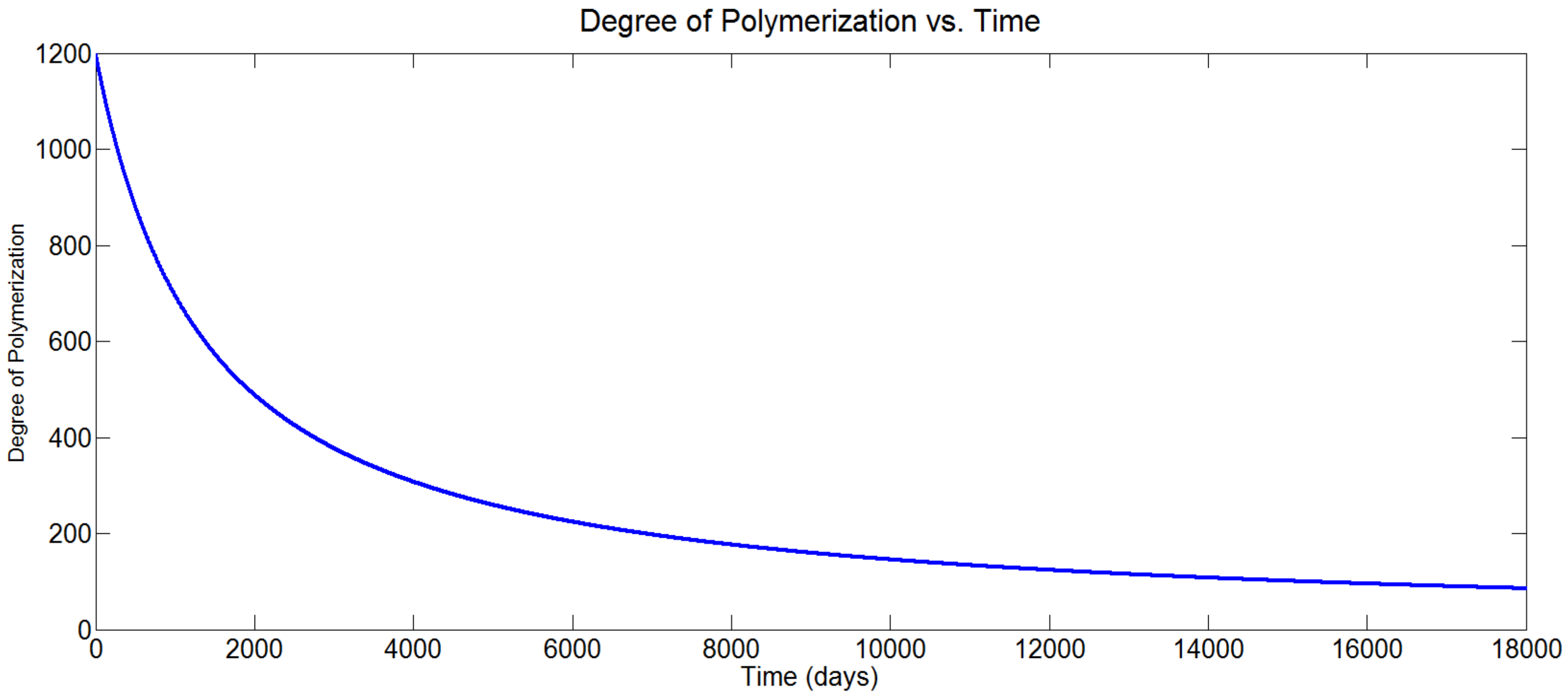
$$DP(t) = \frac{DP(t_0)}{1 + DP(t_0)\int_{t_0}^{t} k(\tau)\; d\tau},$$

$$k(t) = A\exp\left(-\frac{E_a}{R_g\, T(t)}\right),$$

Simulation Outline

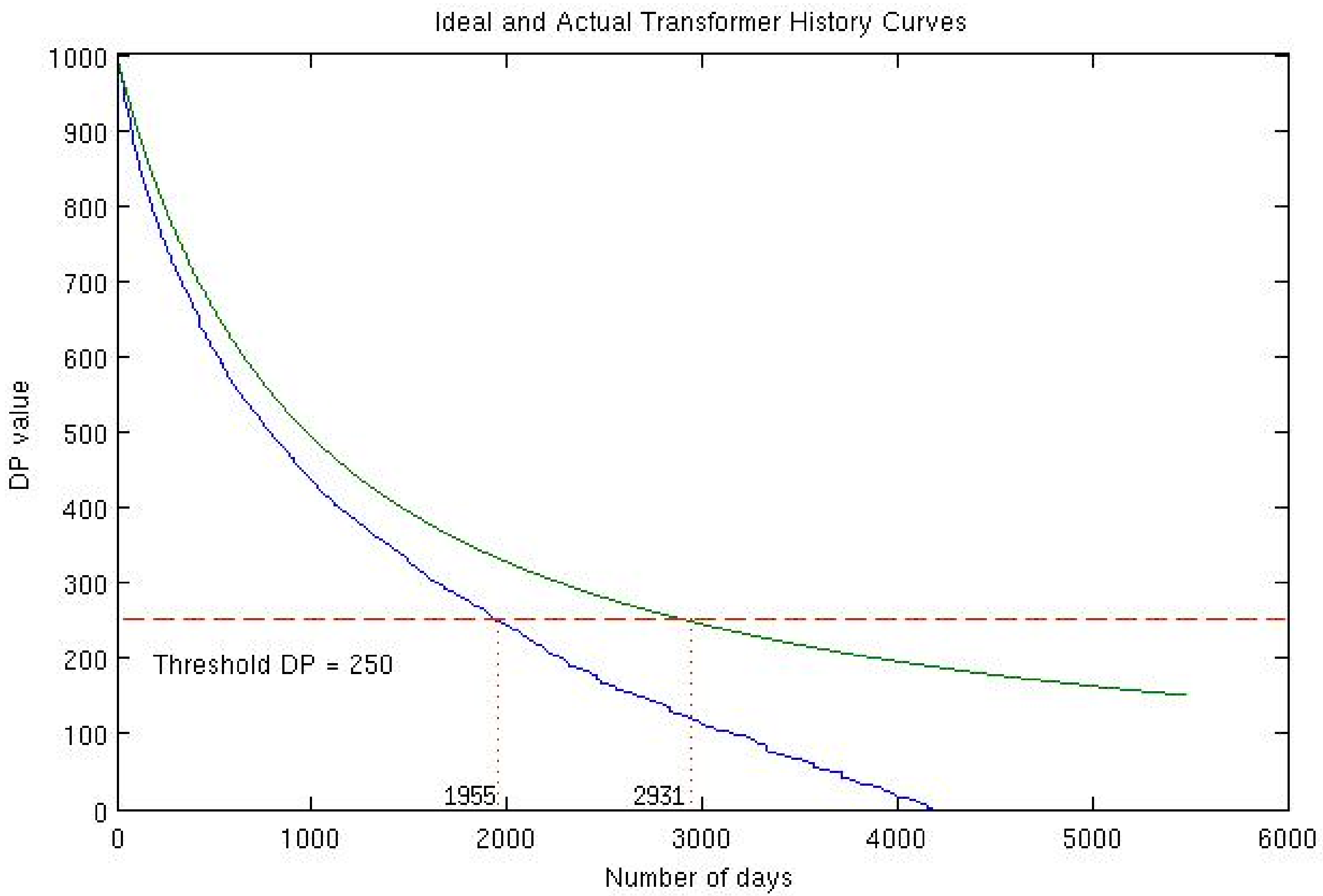
- Generate Input Data
  - Generate the ideal transformer curve based on the model
  - Generate transformer history curve by superimposing unpredictable events using a Generalized Extreme Value distribution
- Process Input Data
  - Estimate GEV distribution looking at the history curve and comparing it against model
  - Predict probability of failure in some set number of days using a monte-carlo simulation

Ideal Transformer Curve

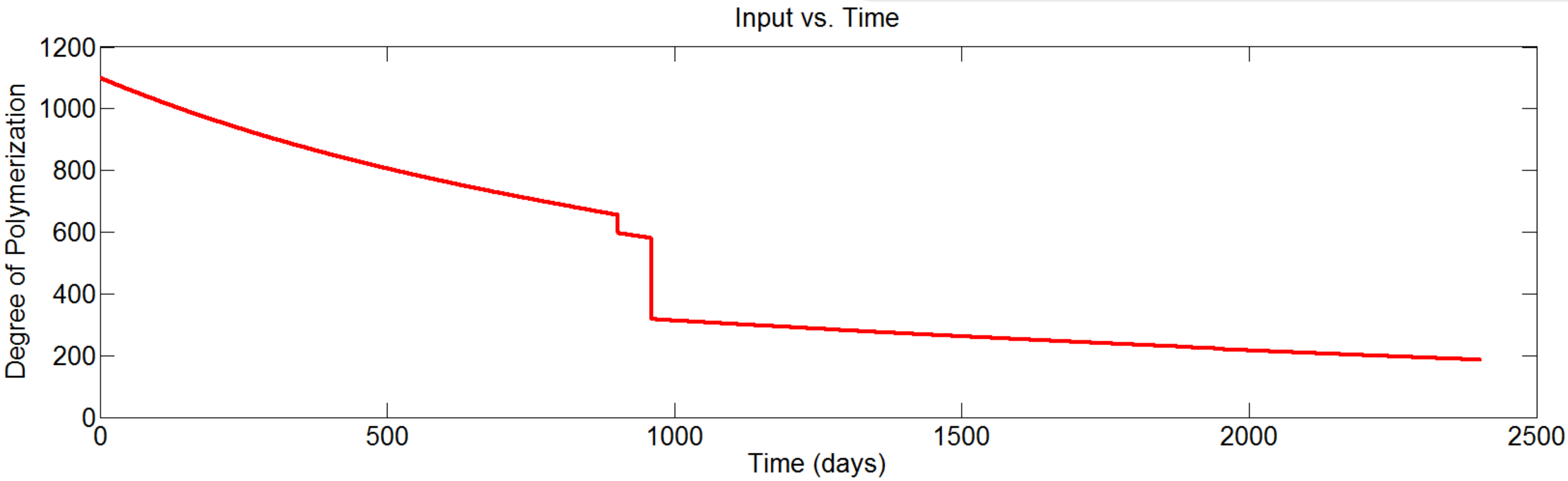


DP(t0) = 1200
Threshold DP = 250
Ideal transformer lifetime ~ 6000 days ~ 16 years

Generate History Curve

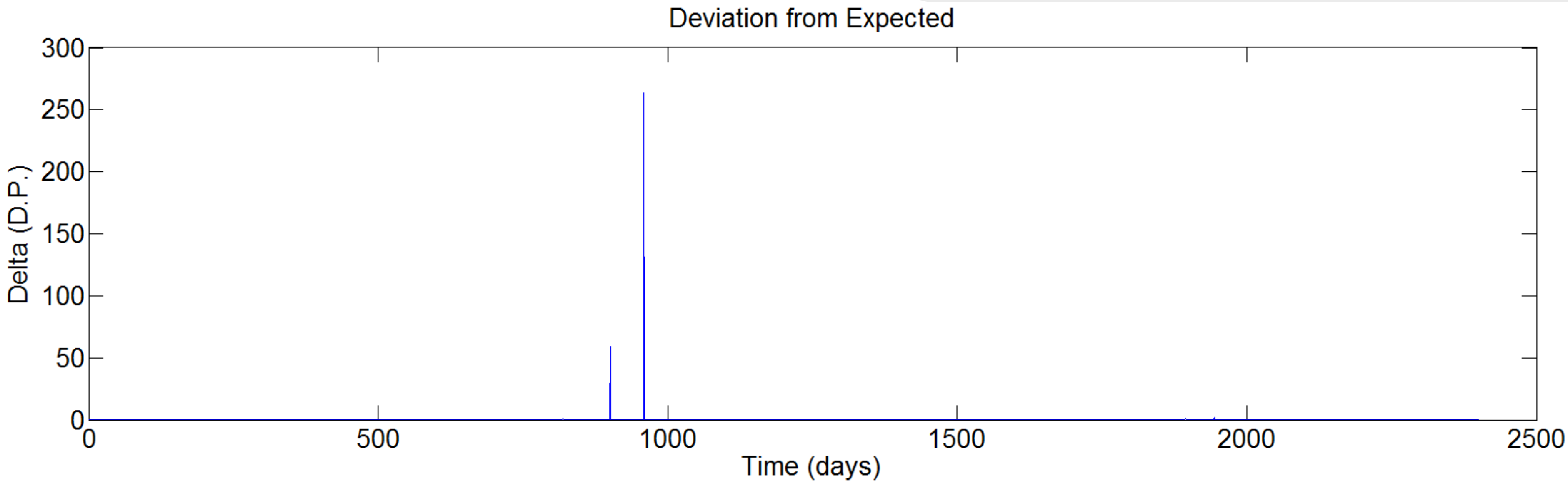


Generate History Curve



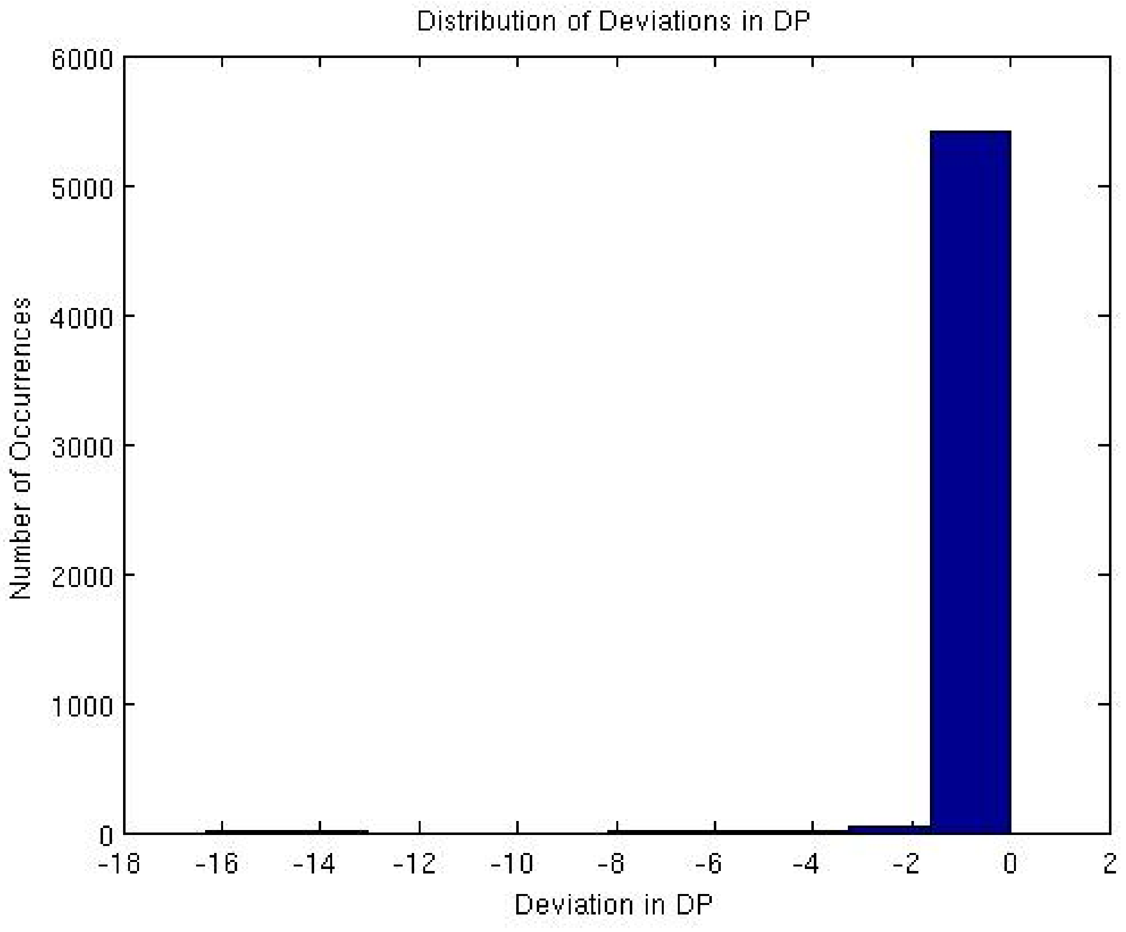
Example of a highly unlikely catastrophic event expediting transformer failure

Extract Deviations



Compute the deviations at each step using interpolation techniques

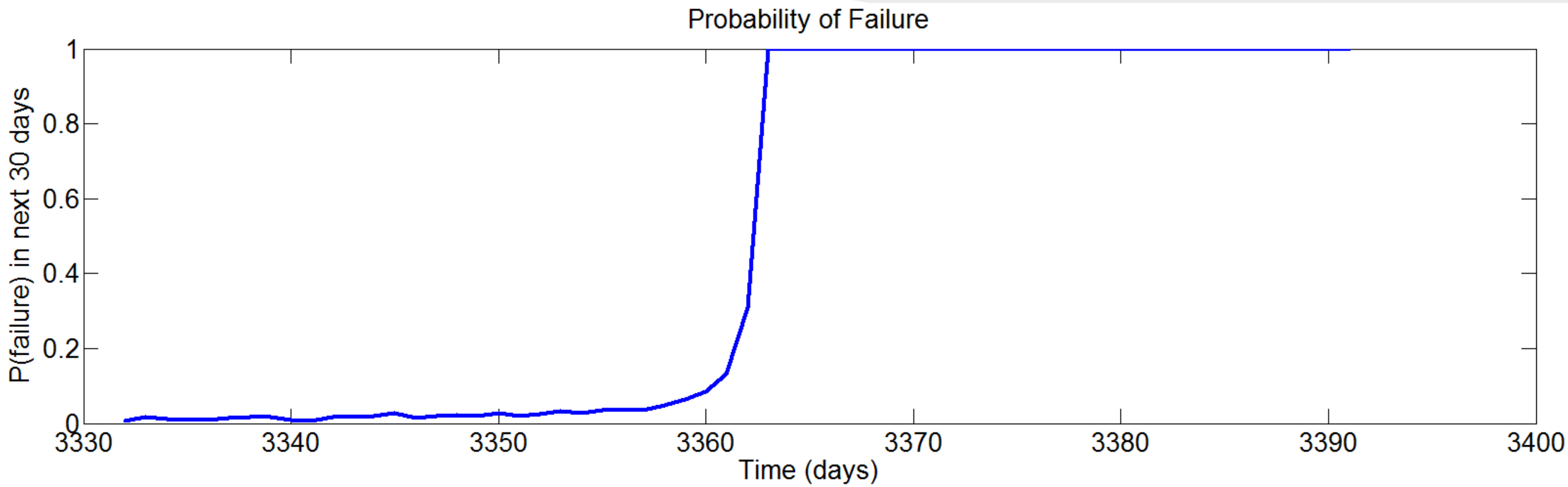
Estimate The Distribution



Fitting data to the GEV distribution,

mu ~ 0
sigma ~ 0.05
shape ~ -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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