FORMAL RELIABILITY ANALYSIS OF PROTECTIVE RELAYS IN POWER DISTRSIBUTION SYSTEMS

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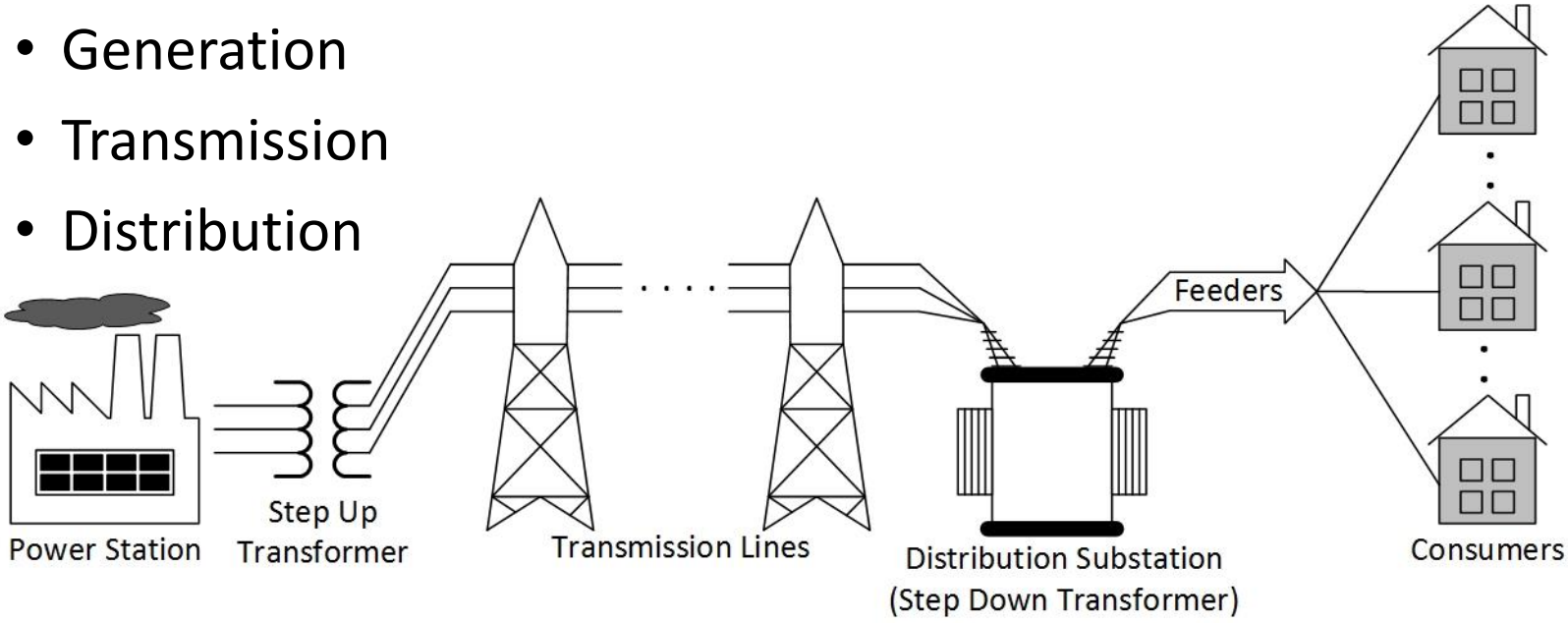
Introduction

- Power Distribution System (PDS)
  - Reliable transmission, distribution of electricity
  - From power station to end users
    - Generation
    - Transmission
    - Distribution



Introduction

- Main Components
  - Transmission Line
    - Route the power to substations
  - Transformer
    - Step up/down the voltage level
    - Appropriate according to end user
- Highly Sensitive and Safety-critical

Introduction

- Faults in PDS
  - Damage to expensive components
    - Switching surges, short circuits
  - Power blackout/failures
    - UCTE grid, Moscow blackout
- Ensure the safety and protection of PDS
  - Relays associated with each component
    - Sense the fault and remove the component

Reliability Analysis

- Basic Idea
  - Model the behavior (Markov Chains) and determine probabilities
- Traditional Approach
  - Analytical: models are analyzed using paper-and-pencil proofs or computer based numerical methods

Reliability Analysis

- Analytical techniques
  - More accurate but less scalable
  - Prone to errors
- Simulation based techniques
  - More scalable but less accurate
- Formal Methods can be used to overcome the inaccuracy problems

Problem Statement

- To propose a methodological procedure for the reliability analysis of relay-based protection system in PDS

Methodology

- Propose a foundational model of relay-based protection of PDS
  - Applicable to relay protected transformers, transmission lines etc.
- Facilitate the construction of complex models by the addition of new states
- A formal probabilistic analysis approach

PRISM

- We use Probabilistic model checking
  - To cater for the stochastic behaviors of PDS

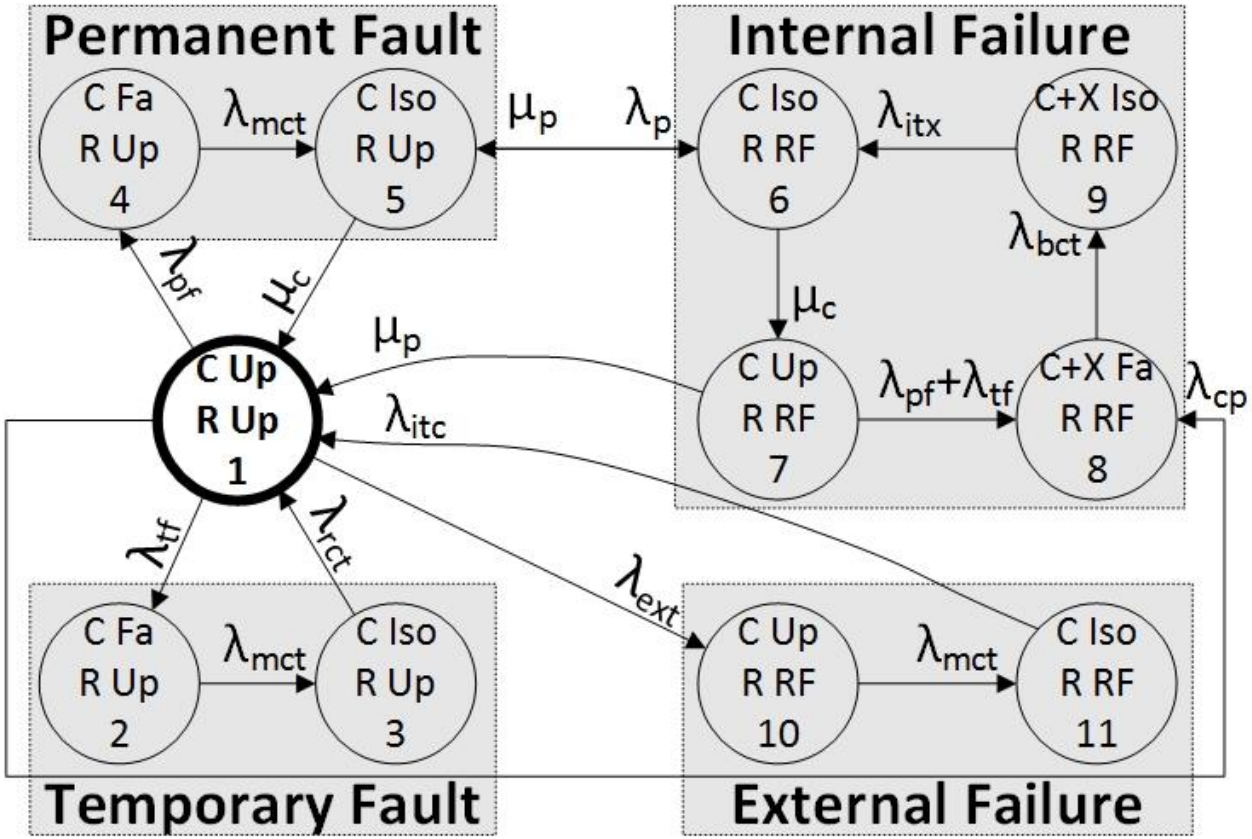
- We use PRISM
  - CSL
  - Efficient
  - GUI etc.

Modeling

- Continuous Time Markov Modeling (CTMC)
- Endrenyi's three state model
- Distinguishing features
  - Modularity
  - Incremental approach
  - Multiple faults

Modeling: Foundational Model

- Component Faults
  - Temporary
  - Permanent
- Relay Faults
  - Internal
  - External

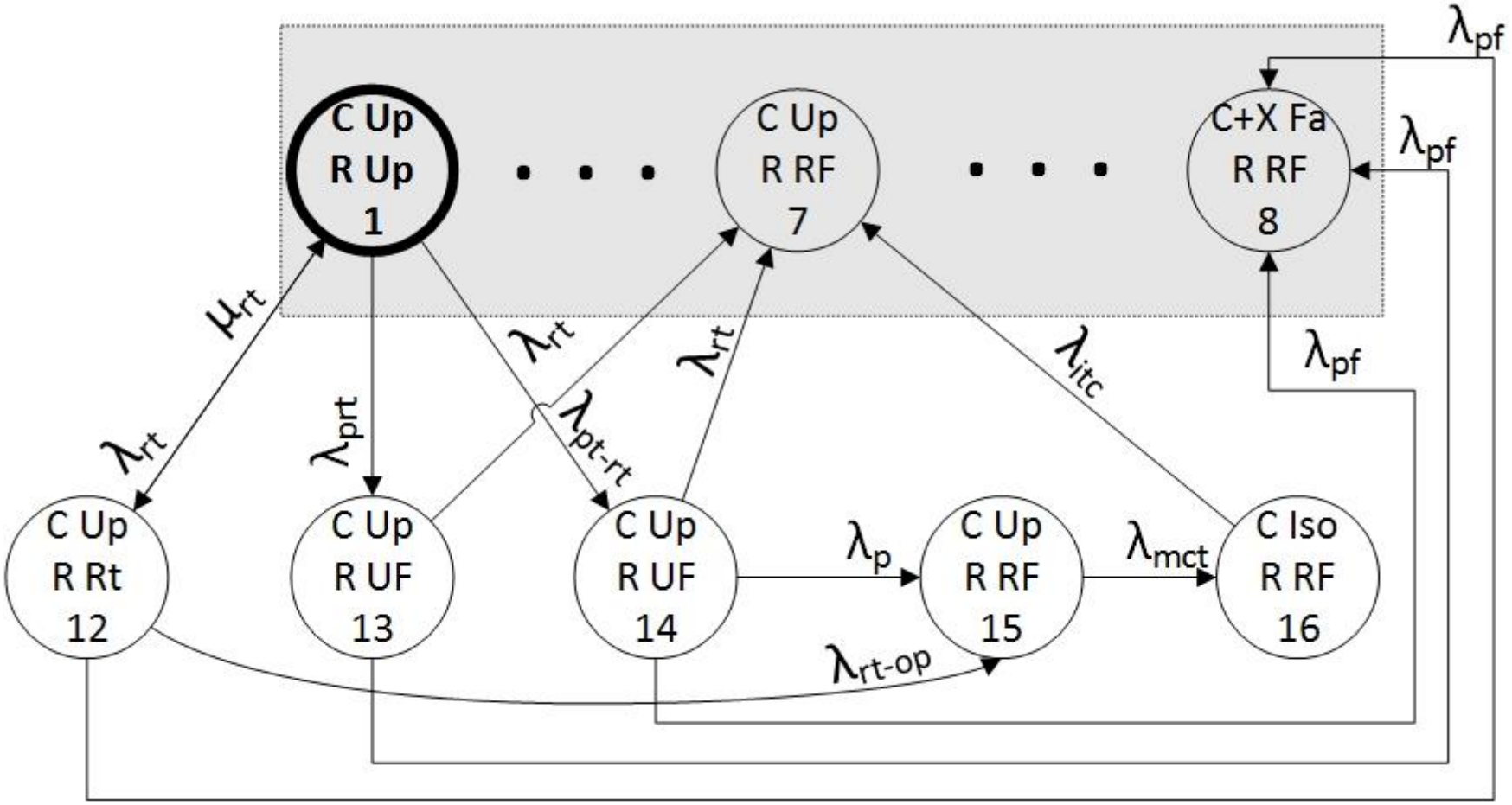


Modeling: Extensions

- Advanced testing procedures
  - Routine testing
  - Self checking
  - Continuous Monitoring

- Additional states and transitions associated with each testing procedure

Example: Routine Testing



Reliability Properties

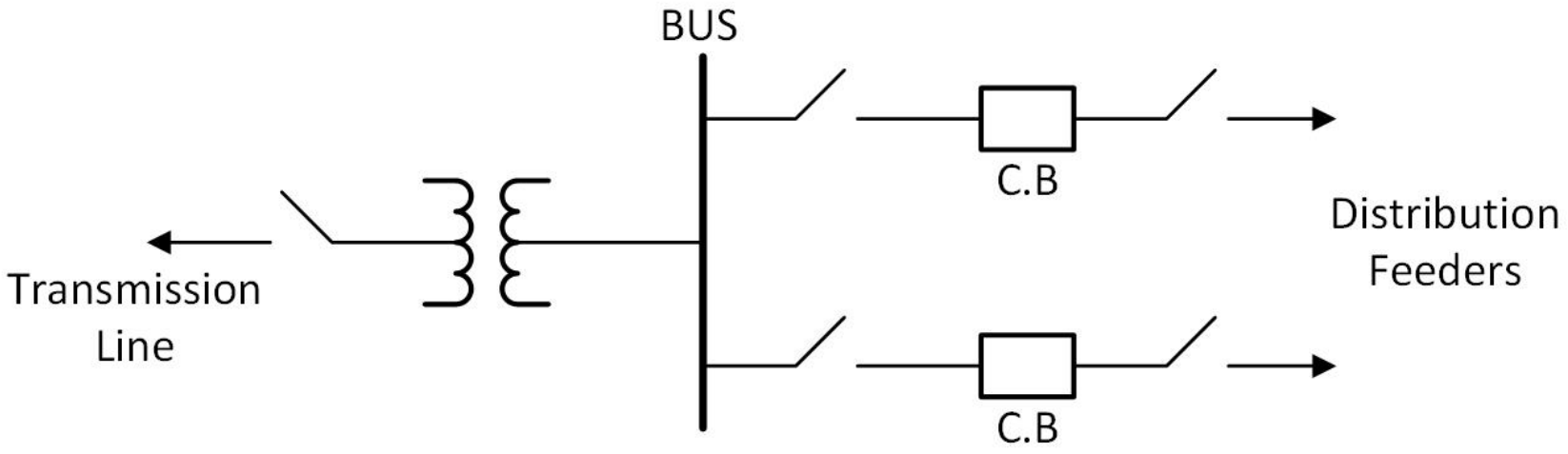
- Optimum testing intervals
- Steady state probabilities
- Reward based properties
- Fault clearing times

Classification of States

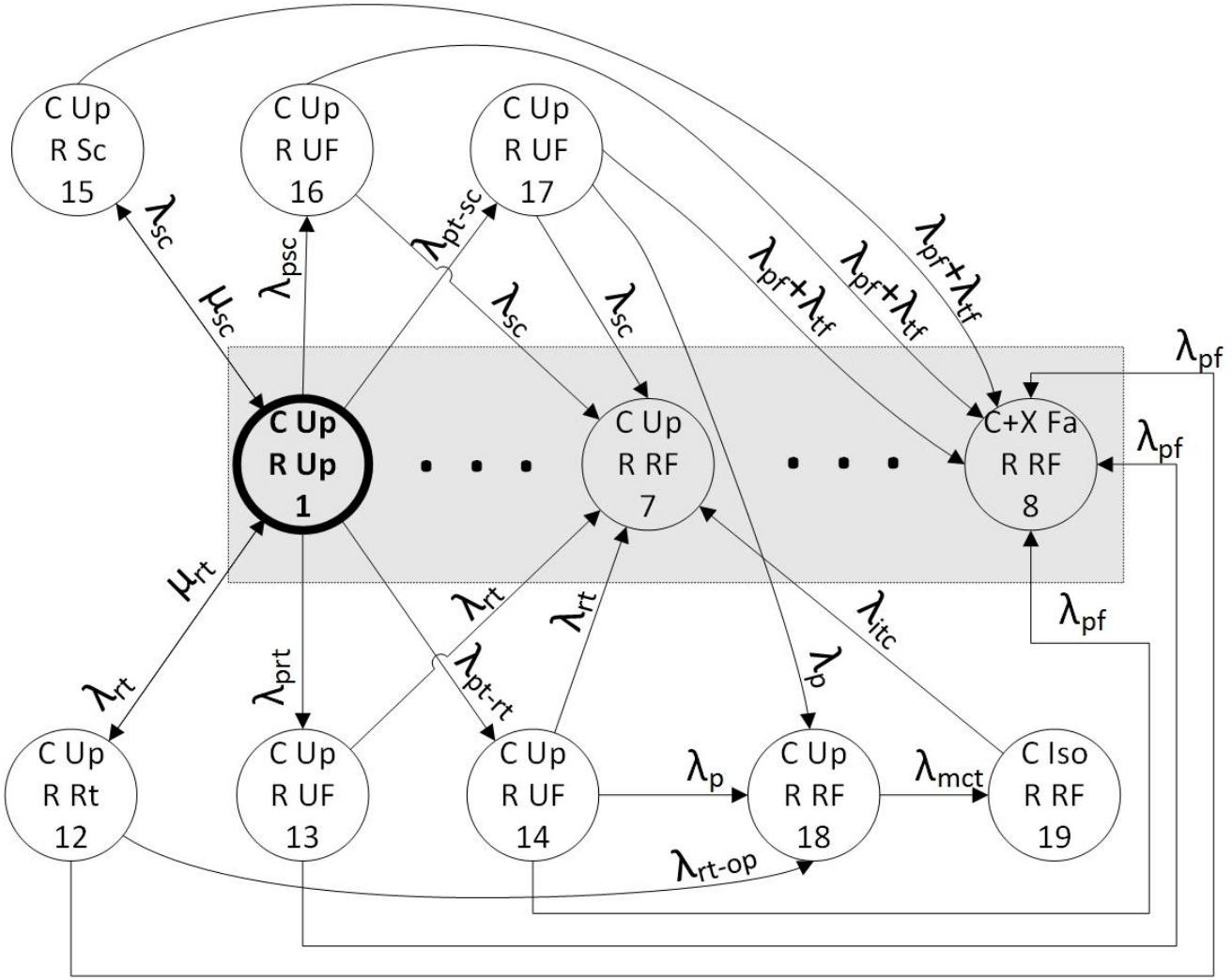
- Desirable states
  - Normal
  - Dependability
- Undesirable states
  - Unavailability
  - Security

Case Study

- A Typical Power Distribution System
  - 3 transmission lines
  - 1 transformer
  - Relay associated with each component

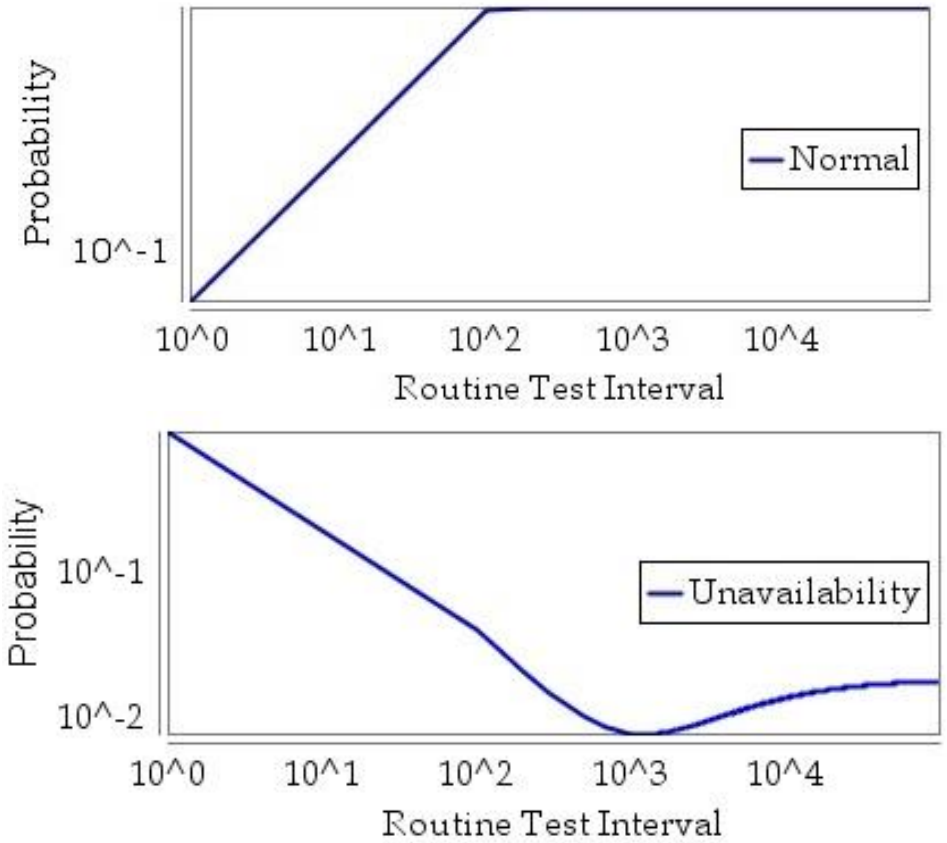


Case Study-Transmission Line Model



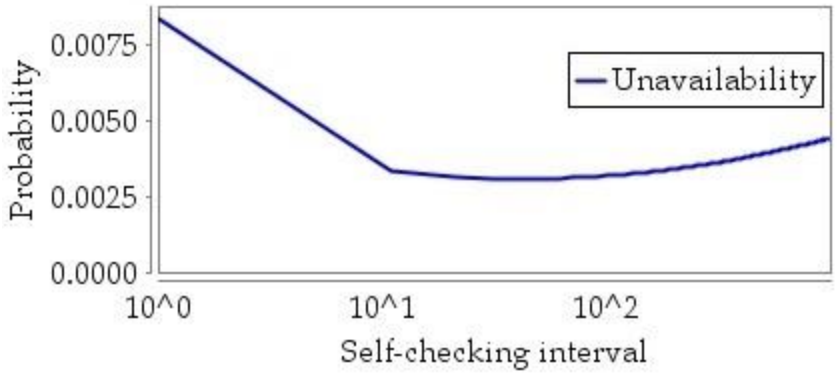
Case Study-Results

- Optimum Routine Test Interval

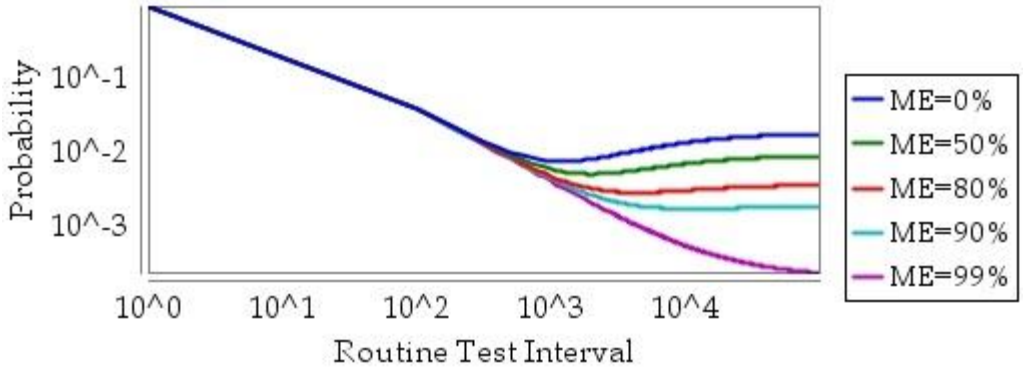


Case Study-Results

- Optimum Self Checking Interval



- Sensitivity Analysis



Conclusion

- Foundational model
  - Component and relay faults
  - Advanced testing procedures
  - Considers multiple faults
  - Can be extended to any topology

- More accurate and scalable approach

Future Work

- Extend the model to include failures due to
  - Backup relays
  - Current Transformer
  - Voltage Transformer
  - Circuit Breaker etc

Thank you