Investigating the Statistical Laws of Power System Blackouts

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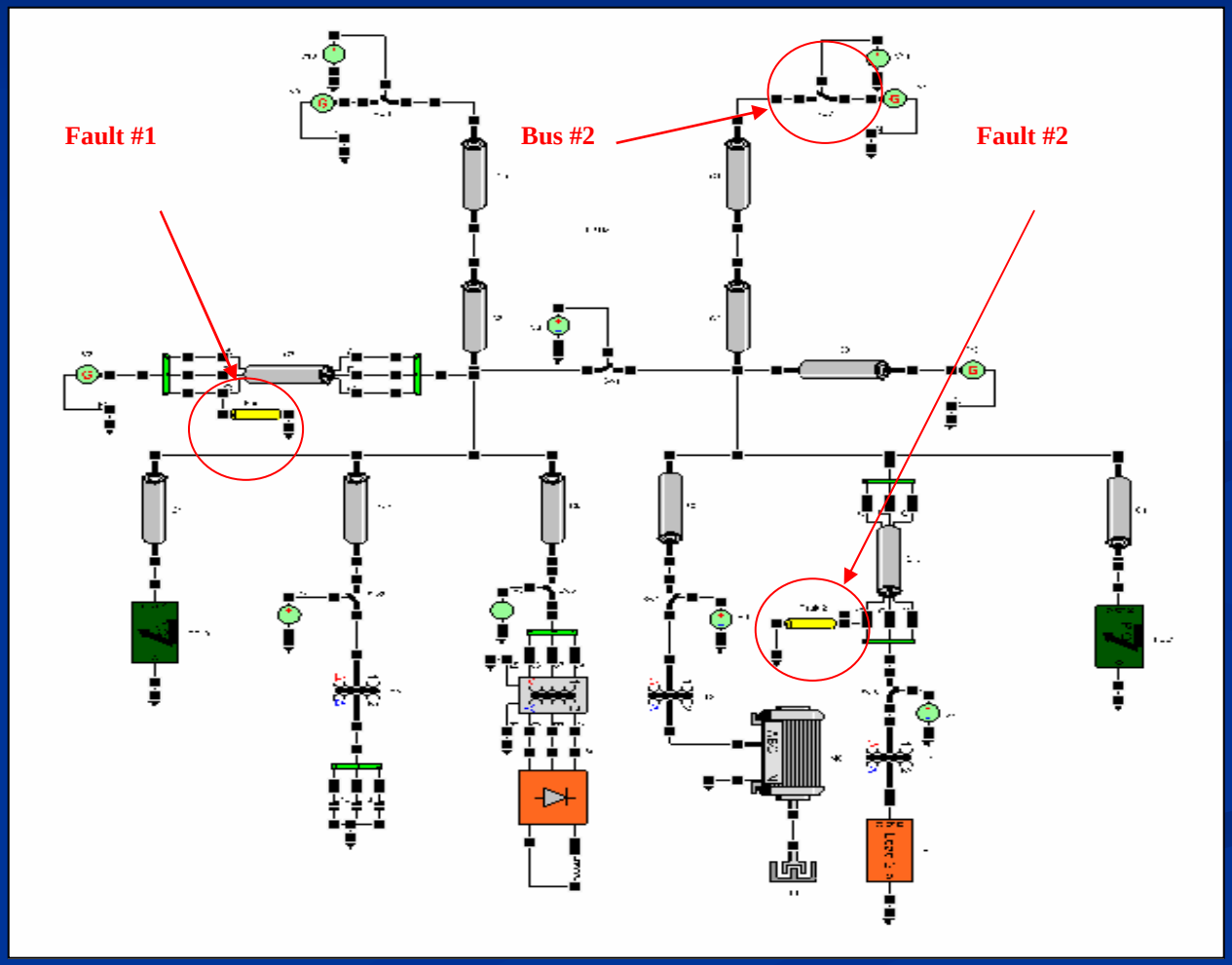
California Earthquake ?

62% within next 30 years

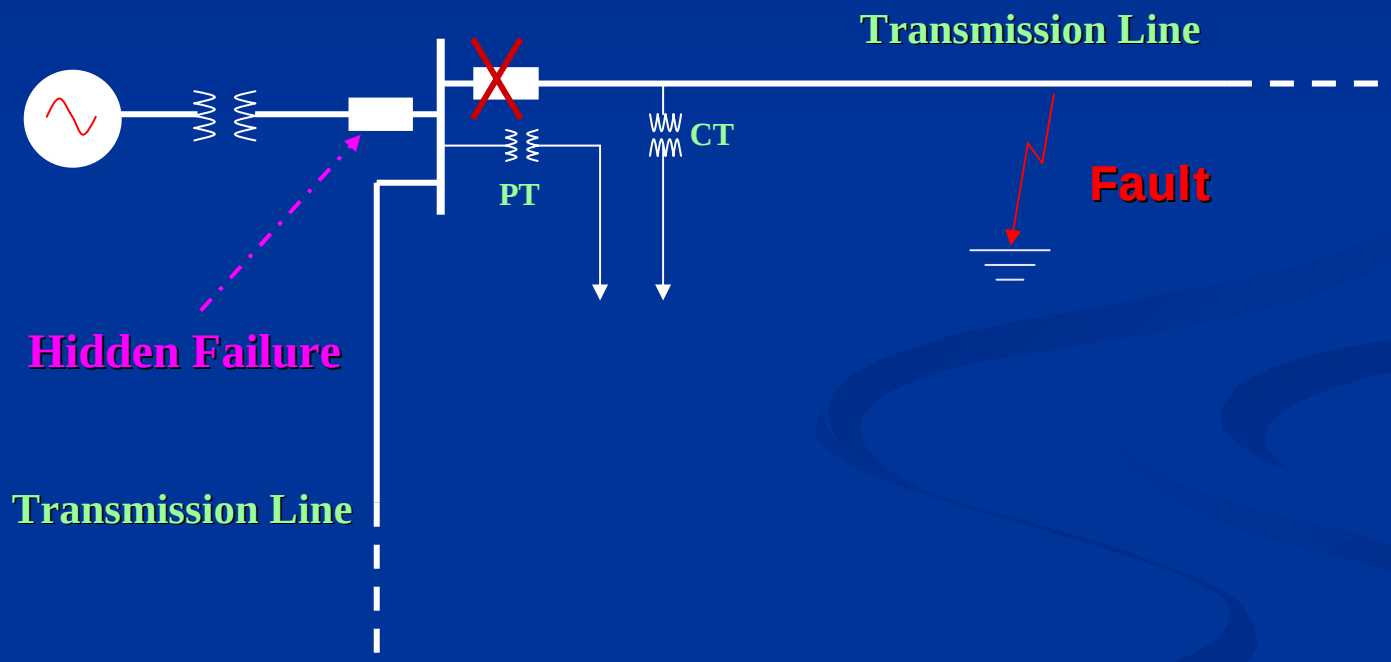
Causes of Power System Blackouts

	Primary Causes	Causes of Cascading	
		Deterministic Factors	Probabilistic Factors
Blackouts	1. Primary protective relay failure 2. Line fault 3. High winds causing line out 4. Line sagged into trees 5. Hidden failure 6. Lighting 7. Phase-to-ground fault 8. Tower causing multiple lines out 9. A sequence of line trappings 10. Etc.	1. Under-frequency 2. Overload 3. Over-current 4. Low voltage 5. Etc.	1. Failure of the tap-changing mechanism 2. Additional lighting 3. Failure of Communication channel 4. Failure of Backup device 5. Operators' unawareness of failures 6. Failure of EMS system 7. Etc.

Operations of Power Systems



Operations of Power Systems



Motivations

- Investigate the general features of blackouts

  (essentially statistical factors are involved)
- Predict the occurrences of blackouts for a given system
- Identify the vulnerable components for a given system
- Improve the prevention ability against blackouts

Mechanism of Cascading Failures

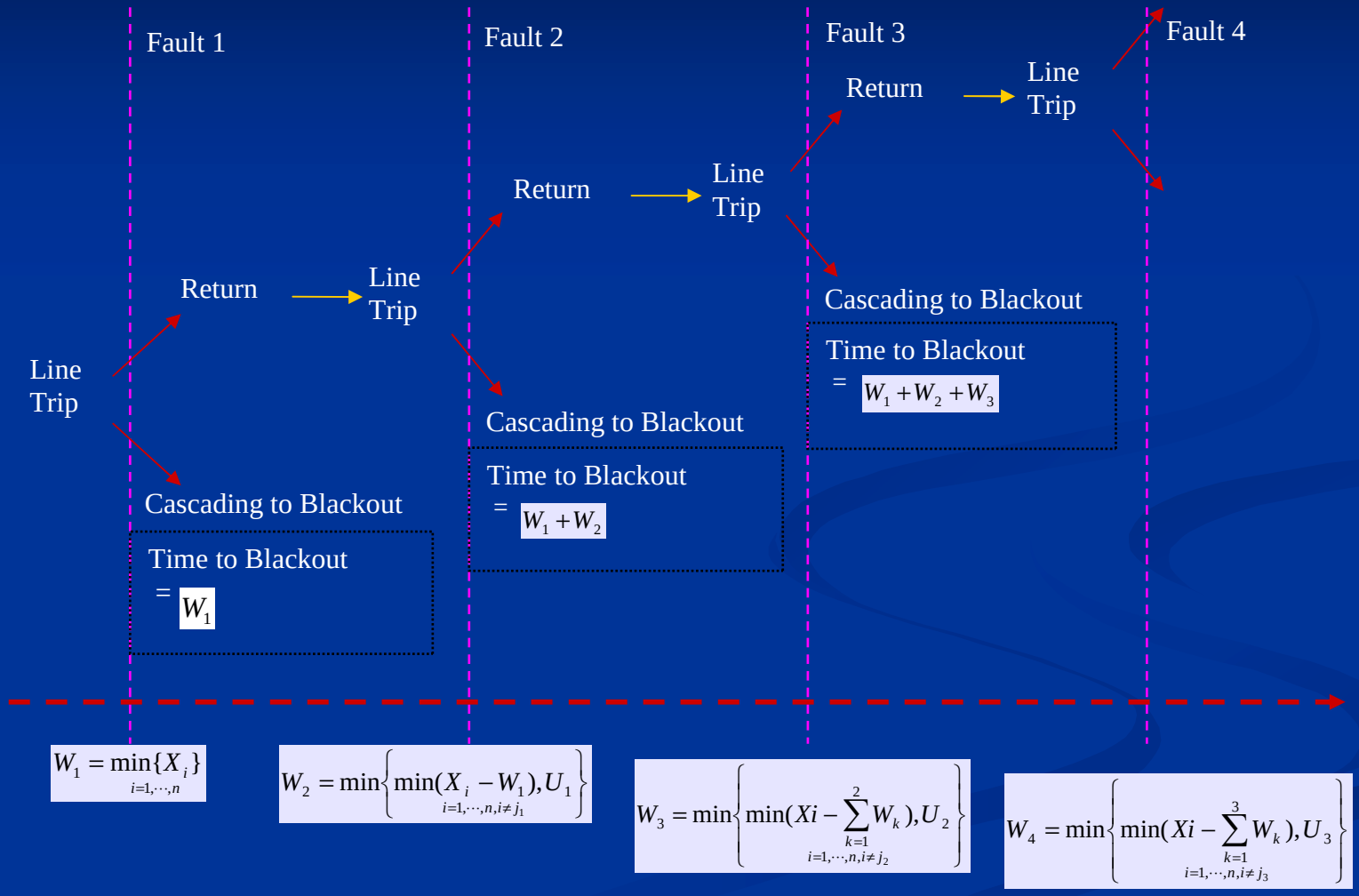
Two causes of cascading failures:

- Deterministic (Operation violations)

  Ex: overload on a line causes further line trips

- Probabilistic (Hidden failures, etc)

Mechanism of Cascading Failures



Mechanism of Cascading Failures

Statistics Theorem:

Minimum of a number of random variables follows the Exponential Distribution

Therefore,

W_i follows the Exponential Distribution with same parameter

i=1, 3, 5, …

Distribution of Blackouts

Gamma Distribution:

Sum of exponential distributions with the same parameter

Since the probability of falling in different levels is different, so the distribution of Blackouts is a Mixture of Gamma Distributions

Distribution of Blackouts

Gamma Distribution:

The density function

$$f_{\gamma_k,\beta}(x) = \frac{x^{\gamma_k - 1}\exp(-x/\beta)}{\beta\gamma_k\Gamma(\gamma_k)}$$

Where shape parameter γ_k and scale parameter β has the density function

Distribution of Blackouts

Let X_k be a Gamma random variable with shape parameter k and scale parameter β;

Let X be the life of the system which takes the value X_k with probabilities p_k, $1 \le k \le K_0$, where K_0 is the maximal level.

The distribution function of X

$$P(X \le x) = \sum_{k=1}^{K_0} p_k P(X_k \le x)$$

Its density function

$$f(x) = \sum_{k=1}^{K_0} p_k \, f_{\gamma_k, \beta}(x),$$

Numerical Tests

Using Monte Carlo Simulation

Flexible to include all factors associated with Blackouts

However,

MCS is very time-consuming.

It is difficult to study big systems.

Numerical Tests

Approach to save the simulation time

Two kinds of factors causing cascading failures:

- Probabilistic ←→ Hidden failure, etc
- Deterministic ←→ Operation violations

Observation:

Deterministic processes are repeated, Ex, power flow analysis

Numerical Tests

Approach to save the simulation time

Critical Lines: a set of line or line combinations which cause cascading failures because of operation violations

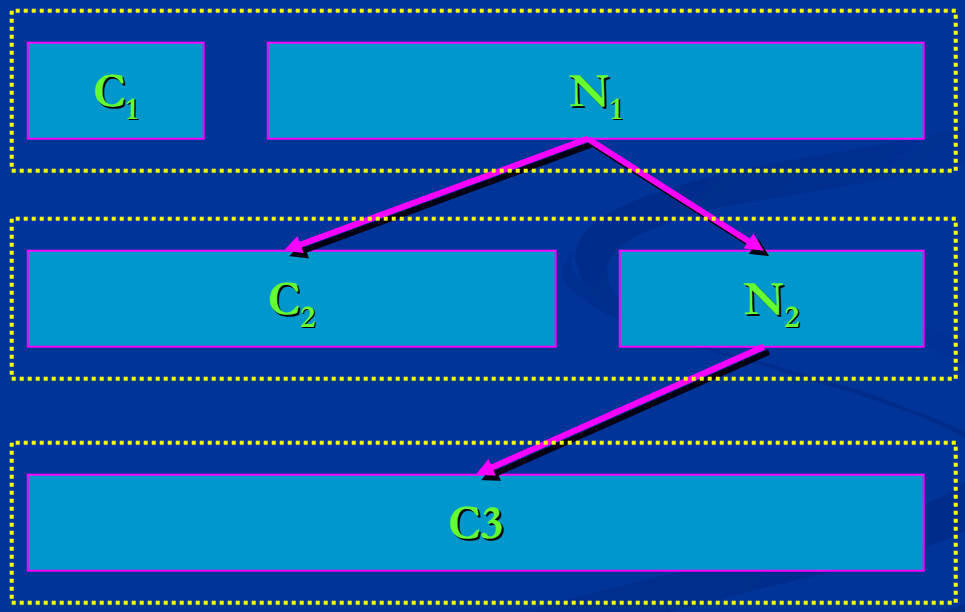
Approach:

During MCS, whenever a tripped line falls in the set of critical lines, a cascading failure occurs without further calculations

Numerical Tests

C: set of Critical Lines

N: set of None Critical Lines



Numerical Tests

24 bus power system is used

Regular MCS	MCS using Critical Lines
4608 seconds / 125 days	408 seconds / 122 days

Thanks for you attention!

Questions?

Further questions:
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