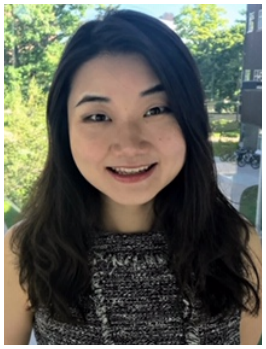
CPS: Medium: Collaborative Research: An Actuarial Framework of Cyber Risk Management for Power Grid






Chee-Wooi Ten[1], Lingfeng Wang[2], Yeonwoo Rho[1], and Wei Wei[2]
Michigan Technological University[1],
University of Wisconsin—Milwaukee[2]
ten@mtu.edu, wang289@uwm.edu , yrho@mtu.edu, weiw@uwm.edu
Award numbers: ECCS1739422, ECCS1739485

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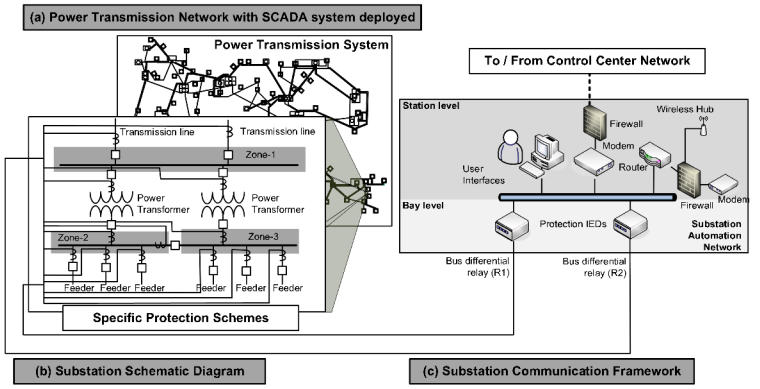
Cyber Insurance Premium for Bulk Interconnected Power Grids

IP-based substations, generating units, and other interconnected grids MUST be qualitatively and quantitatively established in the insurance incentive policies with security technologies against switching cyberattacks.



Cyber-Physical Relationship to Substation Switchgear and Control Center

Goals of This Project

Cyber-Risk Assessment Model

Hypothesized substation outages (*S-select-k*)

Islanding Implications

Steady-State Evaluations (Reverse Pyramid Model)

extends to

consistency verification

Probability-based Risk Modeling for Digital Relays

Dynamic Analysis

extends to

Hypothesized switching attack through compromised relays (*R-select-k*)

Cyber Insurance Premium Framework

Cyber-Risk Assessment Model

Power System Restoration

Steady-State Probability

Survey Studies on Economic Costs

Initial Data Inputs

create

Probability Mass Function (PMF) & Cumulative Density Function (CDF)

combine

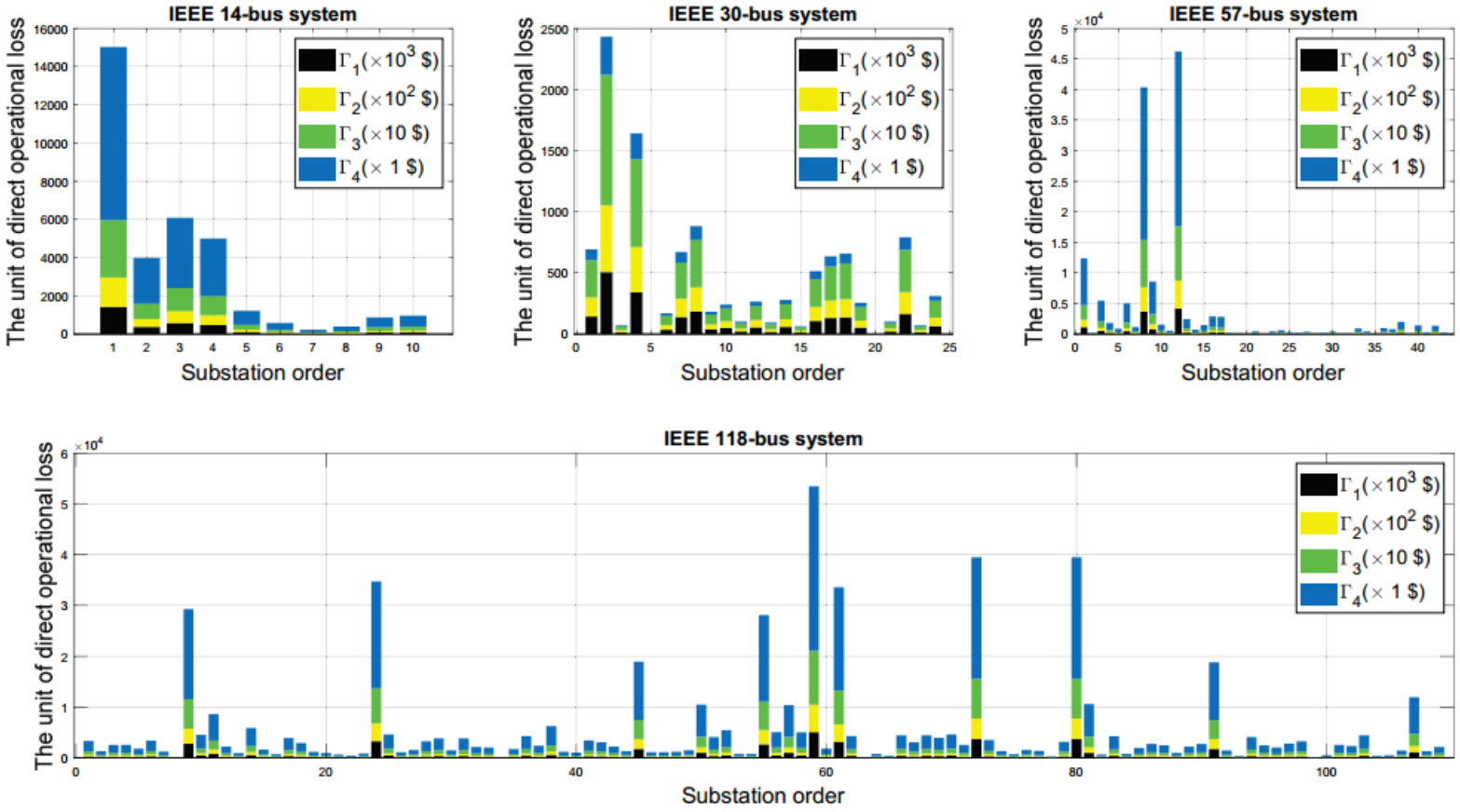
Ruin Probability Calculation

calculate

Cyber Insurance Premium

Direct Operational Losses in Financial Term

- Intrusion anomalies and security event extraction from cyber systems
- Relationship between pre-disturbance (prior execution of switching attacks)
- During power outage on locational marginal pricing
- Restoration efforts and time



Preliminary results Based on Claim Size and Premium Policy

The ruin probability $\varphi(u)$ for the initial risk reserve u is fundamentally defined as:

$$\varphi(u) = Pr\{M > u\} = 1 - F_M(u)$$

$M = L_1 + L_2 + \cdots + L_n + \cdots + L_N$, is defined as maximal aggregate loss

$F_M(u)$ represents the cumulative density function (CDF)

Each random variable L_n represents claimed loss for insurance company. It is assumed that the number of claims N follows a geometric distribution, satisfying: $Pr\{N = n\} = (1-q)q^n$, where $q = 1/(1+\theta)$

Results of Ruin Probabilities and Premium Policy											
IEEE 14-bus system (10 substations)			IEEE 30-bus system (24 substations)			IEEE 57-bus system (43 substations)			IEEE 118-bus system (109 substations)		
initial reserve	theta	Ruin Prob.	initial reserve	theta	Ruin Prob.	initial reserve	theta	Ruin Prob.	initial reserve	theta	Ruin Prob.
0		1.586E-03	0		6.376E-04	0		3.971E-04	0		1.016E-03
5	100	5.276E-05	5	100	3.254E-06	5	100	3.971E-04	5	100	6.977E-06
10		7.250E-05	10		3.628E-06	10		3.404E-08	10		5.987E-06
System Constants	lambda	0.0067	System Constants	lambda	0.0157	System Constants	lambda	0.0289	System Constants	lambda	0.0724
	h	0.5		h	0.5		h	0.5		h	0.5
Mean Claim Size	VOLL	$ 4,467,000	Mean Claim Size	VOLL	$ 3,166,400	Mean Claim Size	VOLL	$ 19,895,000	Mean Claim Size	VOLL	$ 139,010,000
	DC	$ 480,170		DC	$ 340,360		DC	$ 2,138,600		DC	$ 14,943,000
	AREP	$ 93,851		AREP	$ 66,525		AREP	$ 418,000		AREP	$ 2,920,600
	LMP	$ 28,373		LMP	$ 1,954		LMP	$ 134,920		LMP	$ 891,590
Feasible Premium Policy	VOLL	$ 3,022,819	Feasible premium policy	VOLL	$ 5,020,960	Feasible premium policy	VOLL	$ 58,071,516	Feasible premium policy	VOLL	$ 1,016,496,724
	DC	$ 324,931		DC	$ 539,709		DC	$ 6,242,360		DC	$ 109,269,193
	AREP	$ 63,509		AREP	$ 105,489		AREP	$ 1,220,100		AREP	$ 21,356,595
	LMP	$ 19,200		LMP	$ 3,098		LMP	$ 393,818		LMP	$ 6,519,663