resiliency assessment for investment policy on power systems

Moving from security to resiliency in Chilean network for the case of earthquakes

Tomás Lagos - Rodrigo Moreno - Fernando Ordóñez - Rafael Sacaan - Alejandro Navarro - Hugh Rudnick - Mathaios Panteli - Pierluigi Mancarella

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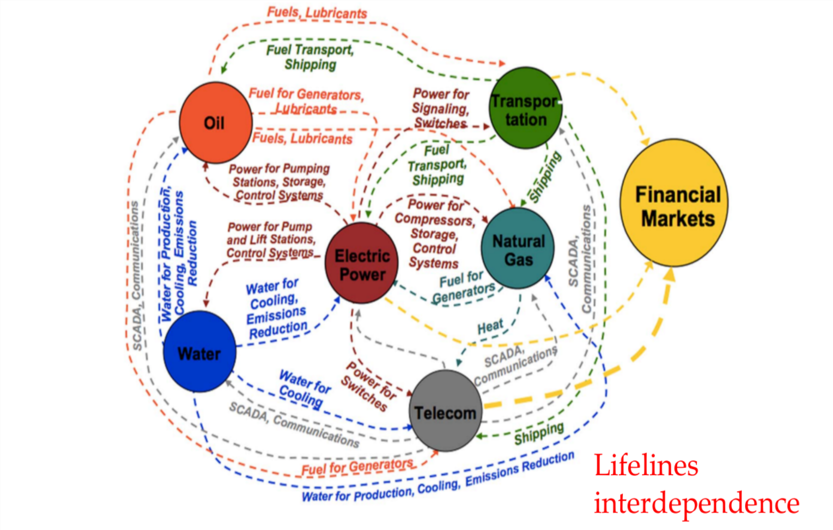
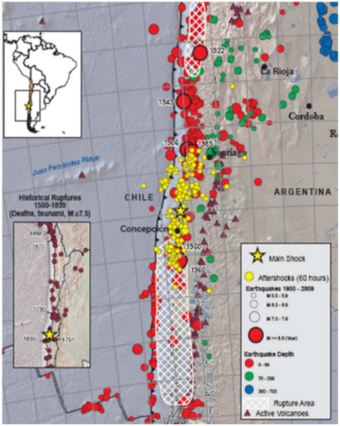
Introduction: Economies Life-Lines Interdependence



Introduction: Chile is a country of Earthquakes

- 1575 Valdivia 8.5
- 1730 Valparaiso 8.7
- 1751 Concepción 8.5
- 1835 Concepción 8.5
- 1868 Arica 9.0
- 1906 Valparaíso 8.2
- 1922 Vallenar 8.5
- 1943 Coquimbo 8.2
- 1960 Valdivia 9.5
- 1985 Santiago 8.0
- 1995 Antofagasta 8.0



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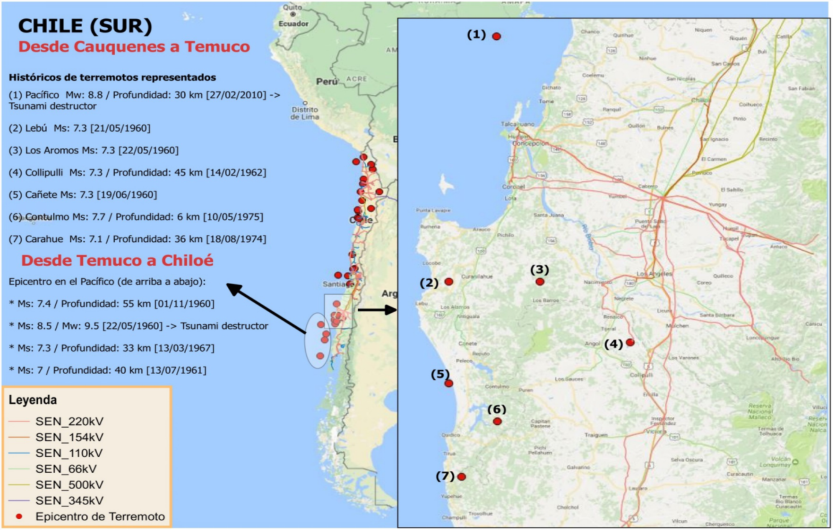
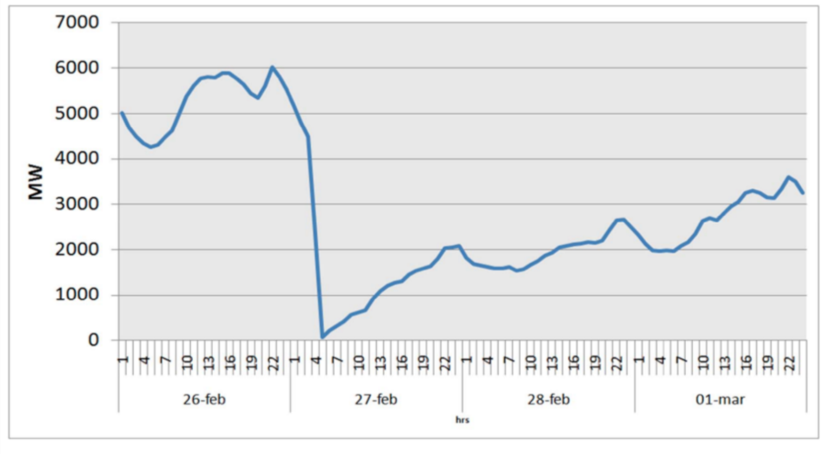


Not just Chile..

China, Haiti, Indonesia, Italy, Japan, Mexico, Philippines, Turkey, and the US have experienced severe earthquakes that resulted in serious damages to their energy supply infrastructure, see Zhang (2018) [1], Barrientos (2018) [2].

Resiliency Curve: 2010 Chilean earthquake



Outline

1. Problem
2. Assessment
3. Solving approach
4. Results

Problem

"Maximize the resilience of the Electricity Network, where the measure is the energy not supplied (ENS), using as decision variable alternative investments for network enhacement"

Two ways to model the system's fragility:

- Resilience: Consider high impact low probability (HILP) scenarios (earthquakes-blizzards-storms-hurricanes)
- Probabilistic security (reliability): Risk neutral, minimize ENS subject to operational failure rates

Resilience	**Reliability**
HILP	Risk neutral
All failures after the shock	Failures occur throughout the operation
Concerned with customer interruption and infrastructure recovery	Concerned with interruption time

Formulation

Main issue: "Endogenous two stage stochastic mixed integer program"
The Discrete Optimization problem is formulated as:

$$\begin{aligned} \min_x \quad & \{\mathbb{E}_\xi[ENS(x,\xi)]\} \\ s.t. \quad & \textstyle\sum_{i=1}^m a_i x_i \leq b, \\ & x_i \in \{0, u_i\}, \qquad \forall i \in M, \end{aligned} \tag{1}$$

- Here x_i represent all network enhancement decisions (adding new lines, anchoring/hardening substations, etc).
- a_i represent costs associated with implementation of x_i and b is the budget allowed to be spent in system's resilience.
- ξ is the realization of uncertainty: Pair of hazard and damage state of network components.
- We assume that the function $ENS(x,\xi)$ is unknown, but we can estimate $ENS(x,\xi_i)$ via a simulation experiment.

Resilience Assessment: $ENS(x, \xi)$

- Simulation of the system is accounted using the Unit Commitment model: "Mixed Integer Linear model that solves the dispatch of the generating units for each period on the time horizon."
- With a slight modification of [3] on the power balance restriction and the cost function we get the post earthquake operation simulation model:

$$\sum_{e \in i^+} f_e^t - \sum_{e \in i^-} f_e^t + \sum_{g \in G(i)} P_g^t = d_i^t + ENS_i^t, \ \forall i \in V, \ \forall t \in T, \tag{2}$$

$$\sum_{t \in T} \sum_{g \in G} (P_g^t cp_g + vu_g^t cu_g + vd_g^t cd_g) + \sum_{i \in V} ENS_i^t c_{ens}. \tag{3}$$

- This new formulation is what we call PCED (post-contingency economic dispatch).

Earthquake propagation model

- In the case of earthquakes, we need to model, firstly, their magnitudes and locations and, secondly, their attenuation profile.
- For the attenuation we use the model proposed by Boroschek, which offers a more accurate representation for Chile [4].
- Boroschek proposes that peak ground acceleration (PGA) attenuation at any position r from the earthquake's epicenter follows (4).

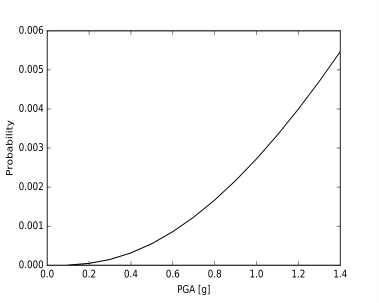
$$\log_{10}(PGA(r,h,M)) =$$

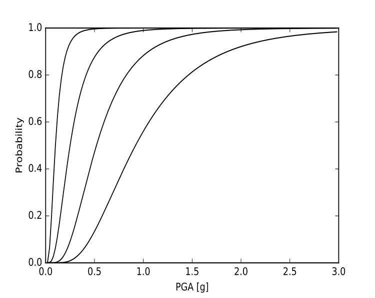
$$-1.86+0.26M+0.01h-0.01R+0.31-(1.52-0.10+M)+\log_{10}(R) \quad (4)$$

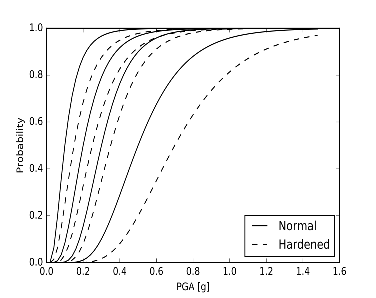
Where M is the earthquake's magnitude in the Gutenberg-Richter scale. Given the hypocenter (ex, ey, h), then $r = \sqrt{(ex-x)^2+(ey-y)^2}$ and $R = \sqrt{r^2+(0.07\cdot 10^{0.36\cdot M})^2}$.

- The results is on units of [g], the gravity acceleration constant.

Damage scenario modeling for earthquake case







Reliability assessment: $ENS(x, \xi)$

All the same, but without earthquakes the security assessment model only takes into account the hourly failure rates on its components, using historical data.

Component	Failure rate [occ/yr]	Restoration time (normal) [h]	Restoration time (hazard) [h]
100-km line	0.8	28	56
Substation	0.2	21	42
Generator	5	58	116

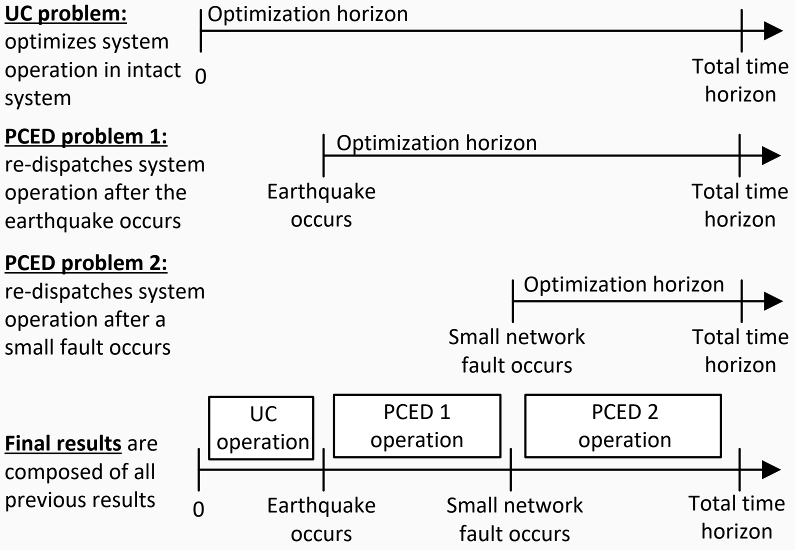


Figure: Interactions between UC and PCED models.

Industrial Strength COMPASS (ISC)

- At an upper layer, we consider a heuristic procedure to solve these discrete decision problems. The Industrial Strength COMPASS was first proposed in Nelson (2009) [5].
- Use a three stage procedure:
  - Global phase: Niching Genetic Algorithm (NGA).
  - Local phase: COMPASS algorithm converges to a locally optimal solution according to confidence parameters.
  - Clean-up phase: Ranking and Selection (R&S) procedure.

Chilean case study: SEN year 2024

Gen Cap. (per technology)	35.6 [*GW*]
hydro	30%
Solar	8%
Wind	6%
Coal	21%
Gas	20%
Oil	13%
Peak Demand	11.3 [*GW*]
Number of lines	71
Number of nodes (simplified)	42

Chilean case study: SEN year 2024

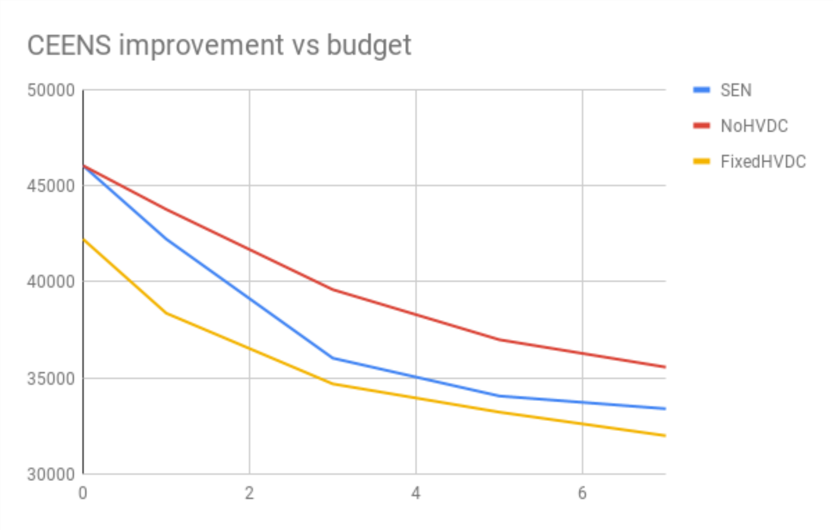
Investment options considered:

Lines	(6,8) = Cautin-Charrua (9,6) = Ciruelos-Cautin (9,32) = Ciruelos-Pichirropulli (11,7) = Cruc.+Enc.-CerrN+LAguirr (18,13) = Laberinto+Domeyko-Cumbre
Seismic buses or DG	1 = Alto Jahuel 7 = Cerro Navia+Lo Aguirre 8 = Charrua 11 = Crucero+Encuentro

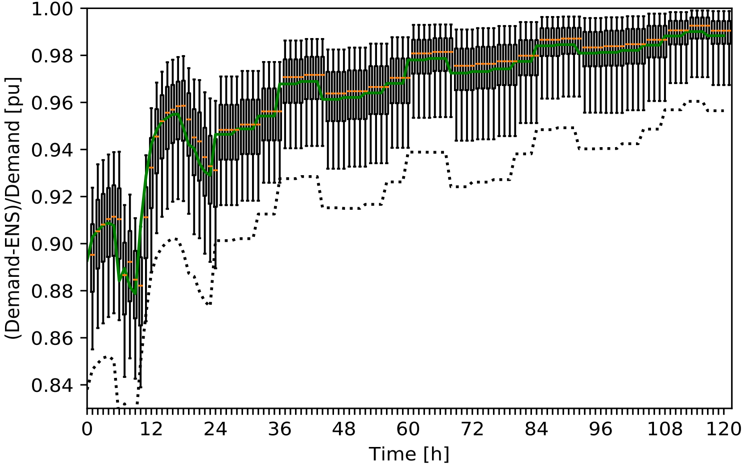
Resiliency vs Reliability investments

Reliability		Resilience	
Solution	Value [MWh]	Solution	Value [GWh]
11 - 7	348	11 - 7	42.2
18 - 13	392	7	43.2
9 - 32	523	1	43.5
6 - 8	580	8	44.5
9 - 6	617	11	44.6
⋮	⋮	⋮	⋮
Base	696	Base	46.0

Loss versus Budget



Resiliency Curve Distribution: Base vs HVDC



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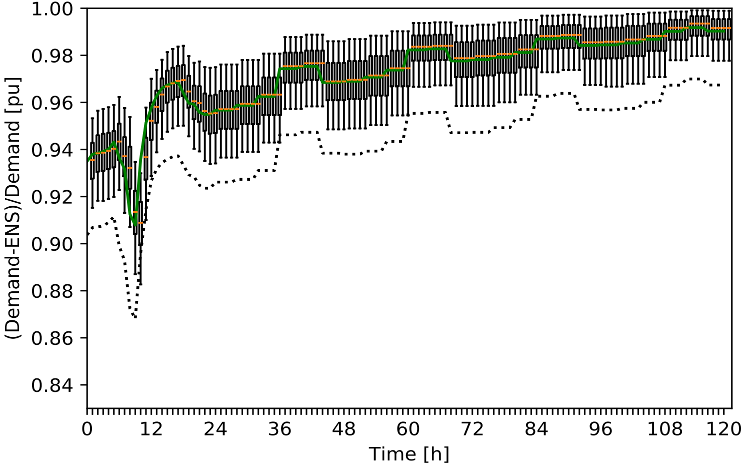

Conclusions and Remarks

- For earthquake case studies, resiliency prescription policy is better approach than security policy.
- New methodologies and models show that probabilistic security standards should be updated, breaking the risk neutral paradigm.
- Models developed show great flexibility to model different investments, the complex system's dynamics and different kinds of natural hazards, in a straight forward manner.
- However the heuristic does not provide convergence guaranties, it has shown for reasonable size investment budgets, and smaller size instances that it is very robust to deliver optimal and near optimal solutions in practice.

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Questions?

Thank you!