Lessons from the 2010 Chilean earthquake and its impact on electricity supply

Juan Carlos Araneda, *IEEE Senior (jcaraneda@transelec.cl)*
Hugh Rudnick, IEEE Fellow (hrudnick@ing.puc.cl)
Sebastian Mocarquer, *IEEE Member (smocarquer@systep.cl)*
Pedro Miquel, *(pmiquel@systep.cl)*

Where is Chile?

Presentation Overview

- Chilean electricity market
- Earthquake in Chile
- Effects on generation and transmission
- Distribution damages and supply recovery
- Final remarks

Chilean electricity market (1/5)

Northern Interconnected System (SING)	
Max Demand (MW)	1,900
Sales (GWh)	13,656
Installed Capacity (MW)	3,573
Coverage	Region I - II
Population	5.7%

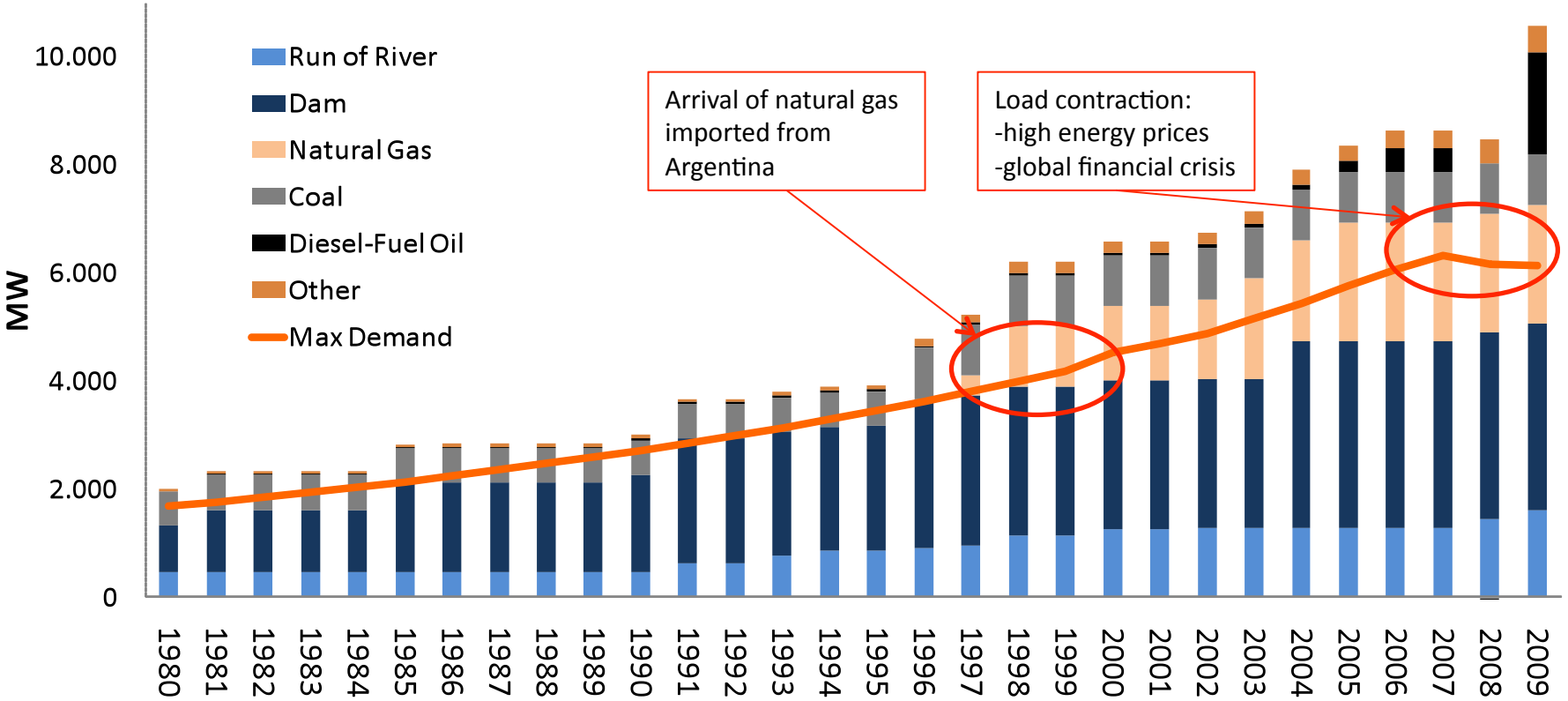
Aysen System	
Max Demand (MW)	21
Sales (GWh)	106
Installed Capacity (MW)	48
Coverage	XI Región
Population	0.6%

Central Interconnected System (SIC)	
Max Demand (MW)	6,139
Sales (GWh)	39,964
Installed Capacity (MW)	11,147
Coverage	Region III - X
Population	92.6%

Magallanes System	
Max Demand (MW)	45
Sales (GWh)	218
Installed Capacity (MW)	80
Coverage	XII Región
Population	1.1%

Chilean electricity market (2/5)

- Installed capacity and peak demand in Central System



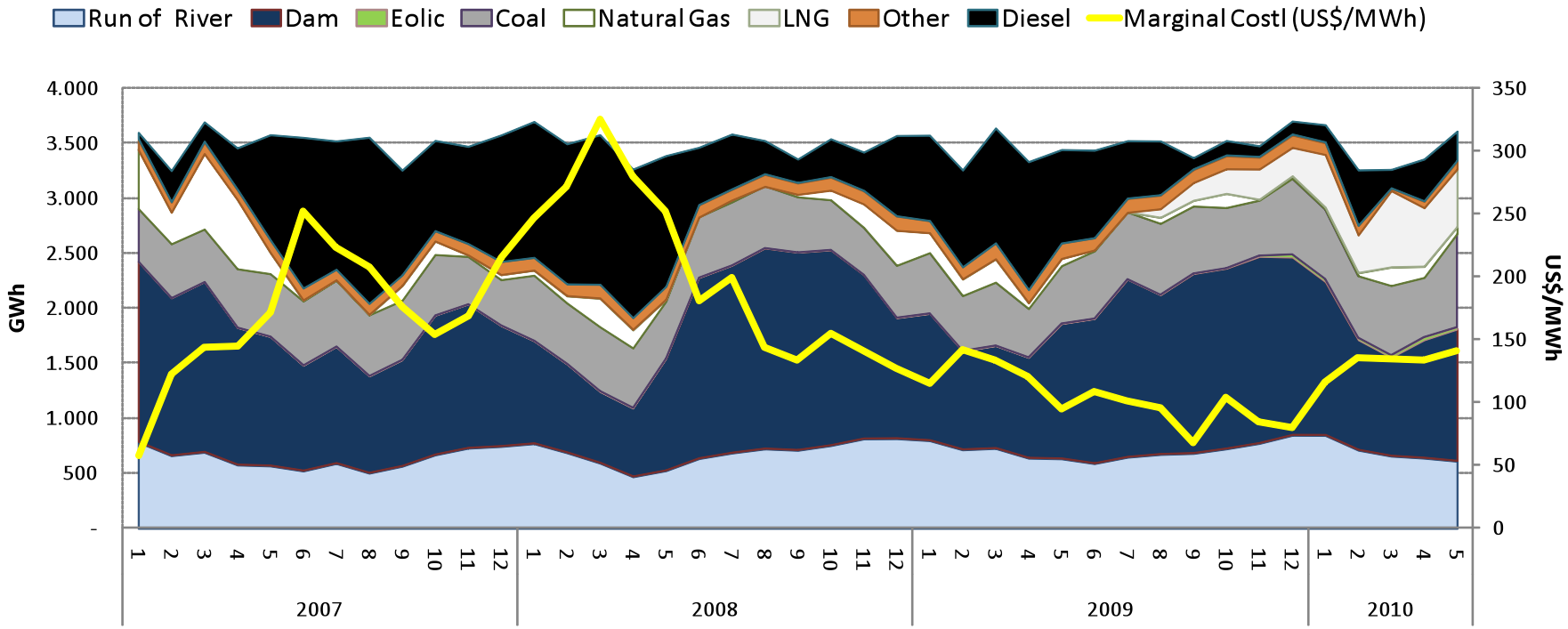
- Projected demand growth of 5 % per year 2010-2020

Chilean electricity market (3/5)

- Electricity sector based on a competitive market
  - Private competitive investment in generation
  - Regulated private investment in T&D
- Energy
  - Prices set in contract auctions (financial)
    - Large consumers (> 2MW) privately auctioned supply contracts
    - Distribution companies auction long term supply contracts in an observed process for regulated consumers(≤ 2 MW)
  - Spot market with marginal pricing
    - Wholesale market with exclusive access to generators
- Capacity payment
  - Price regulated: investment cost of supplying the marginal peak demand

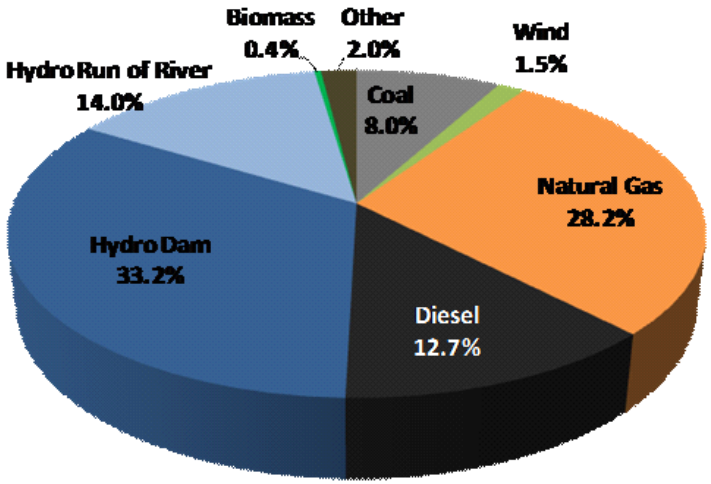
Chilean electricity market (4/5)

- Generation by technology and marginal costs (2007-2010)
  - Dependance on hydro and imported fuels
  - High volatility of marginal cost
  - Highest energy price in the region



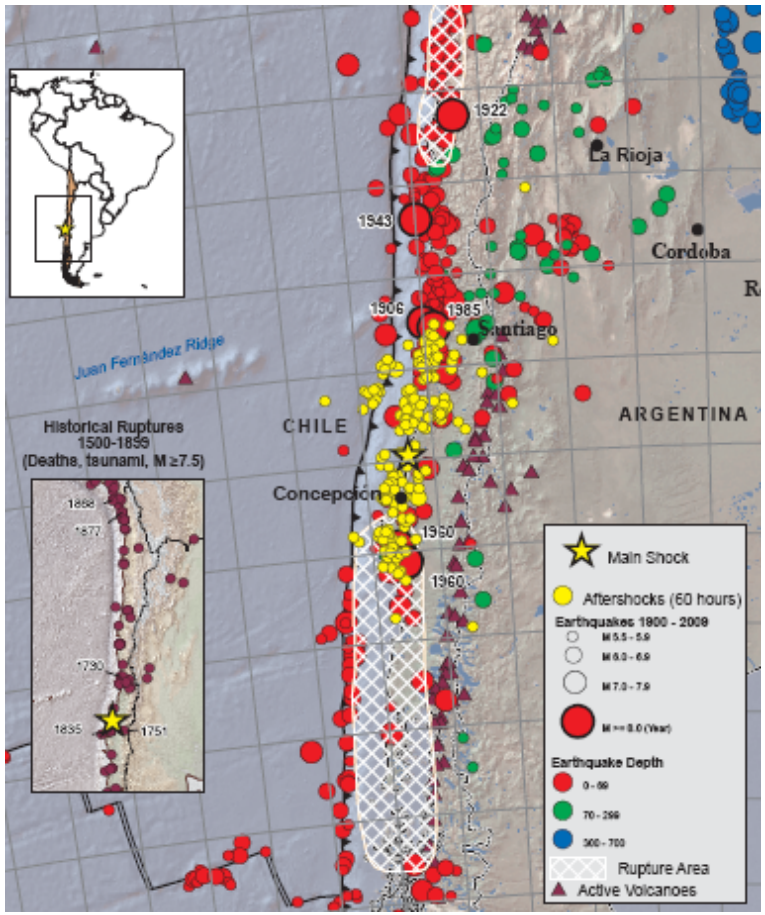
Chilean electricity market (5/5)

- Installed capacity in the central system
  - Low non conventional renewables participation
  - High participation of large hydro, both run of river and reservoirs/dam
  - Naural gas is being replaced by coal fired plants and hydro



Major earthquakes in Chile

Year	City	Mag.
1575	Valdivia	8.5
1730	Valdivia	8.7
1751	Concepcion	8.5
1835	Concepcion	8.5
1868	Arica	9.0
1906	Valparaiso	8.2
1922	Vallenar	8.5
1943	Coquimbo	8.2
1960	Valdivia	9.5
1985	Santiago	8.0
1995	Antofagasta	8.0
2010	Concepcion	8.8



Building codes and technical standards

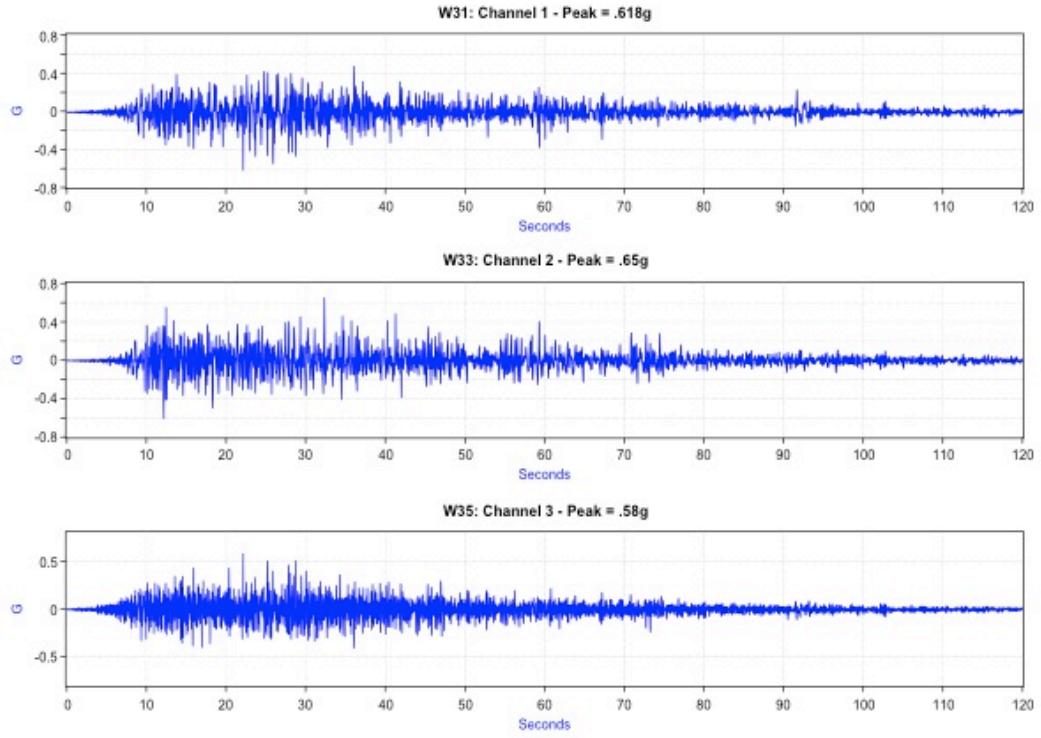
- High standards for seismic requirements regarding civil works.
  - Building codes in Chile are substantially the same as US codes (ACI 318, American Concrete Institute).
- High voltage electrical facilities must obligatorily fulfill the ETG 1.015 Chilean standard or the IEEE 693 standard in the condition of High Performance Level.
  - It specifies a maximum 0.50 g acceleration
  - Maximum horizontal displacement of 25 cm.
- Specific electrical requirements for construction and maintenance of high voltage facilities
  - Technical Norm for Security and Quality of Service
  - Defines technical and economic evaluations to determine the reliability level for the planning and operation of the power system.

2010 earthquake in Chile

- 03:34 hrs. February 27 2010:
  - 8.8 Richter shakes 6 regions of Chile (80 % of population)
  - Tsunami hits the cost minutes after
- Death toll: 521
- Missing: 56
- Injured: 12,000
- Displaced: 800,000
- Infrastructure affected:
  - 370,000 houses
  - 4,013 schools
  - 79 hospitals
  - 4,200 boats damaged
- Economic loss: 30 billion US dollars
- GDP per capita: 14,340 US$
- Population: 17,000,000

Strong acceleration for a long period of time

- Peak acceleration of 0.65 g for one of the horizontal records
- 70 seconds duration
- Continental plaque was displaced 10 m in average



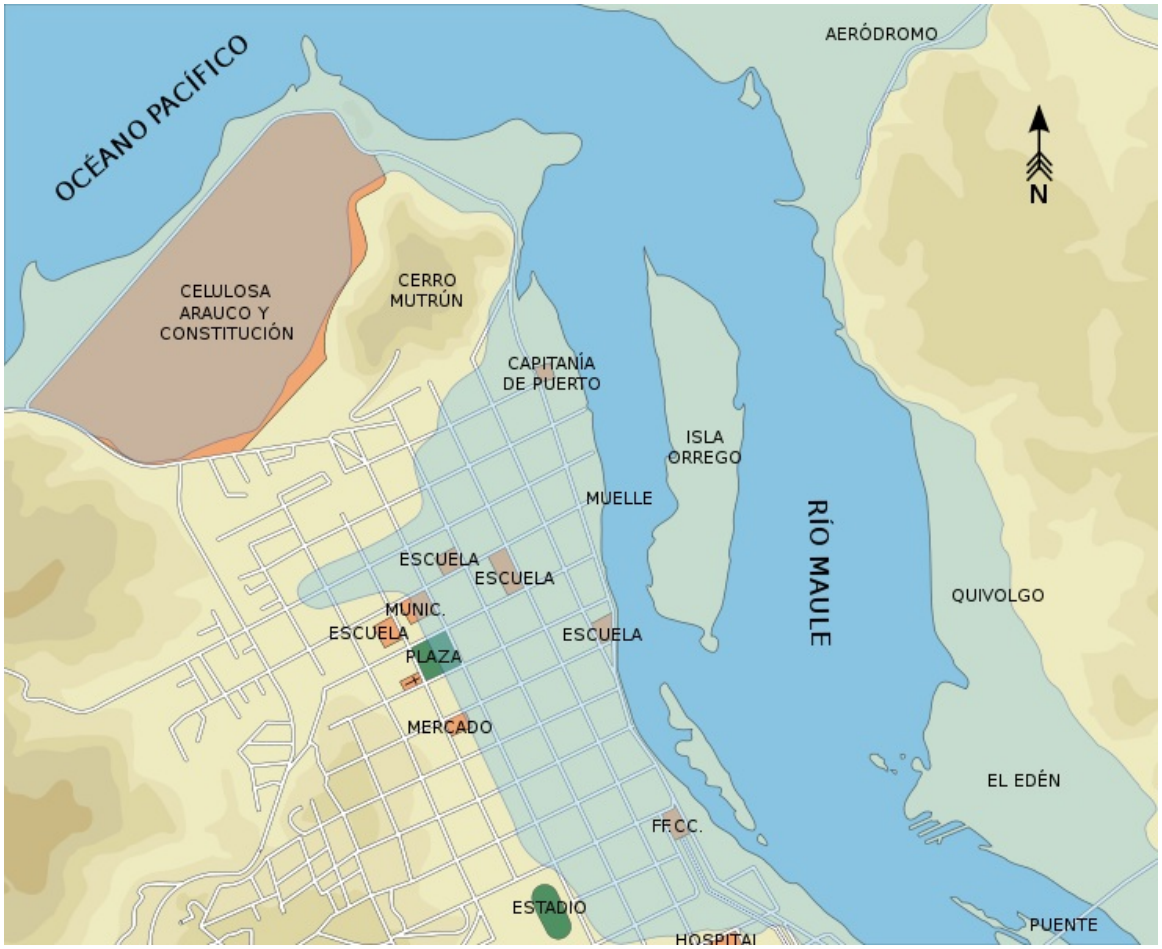
Earthquake effects: infrastructure collapse

Earthquake effects: large industrial fires

Earthquake effects: structural damage and collapse

Tsunami effects: larger cities

Tsunami effects: floodings smaller towns (Constitucion)

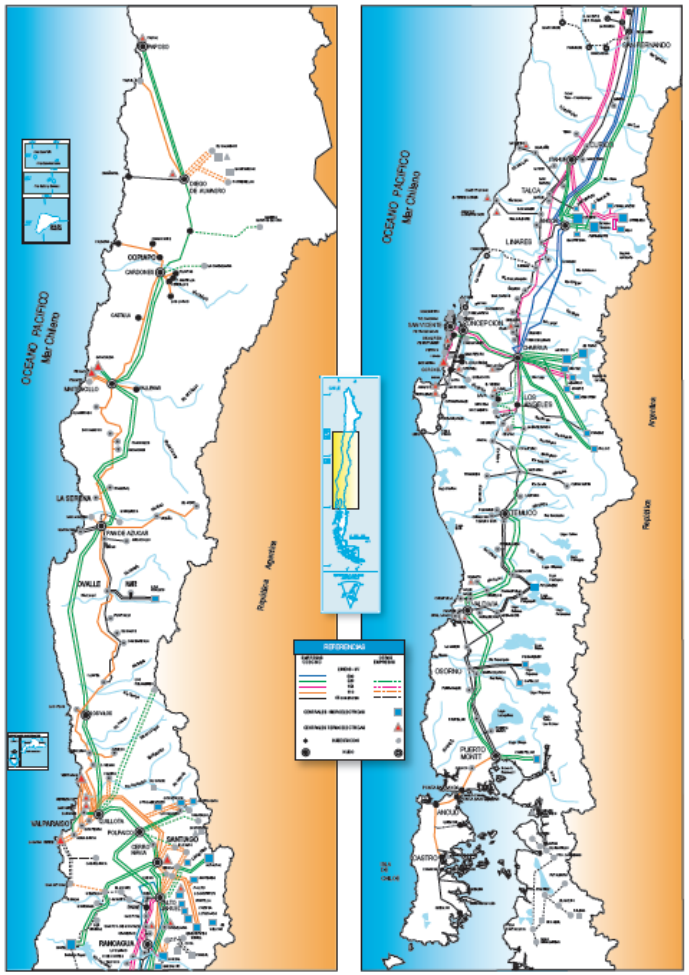


Tsunami effects: large costal areas

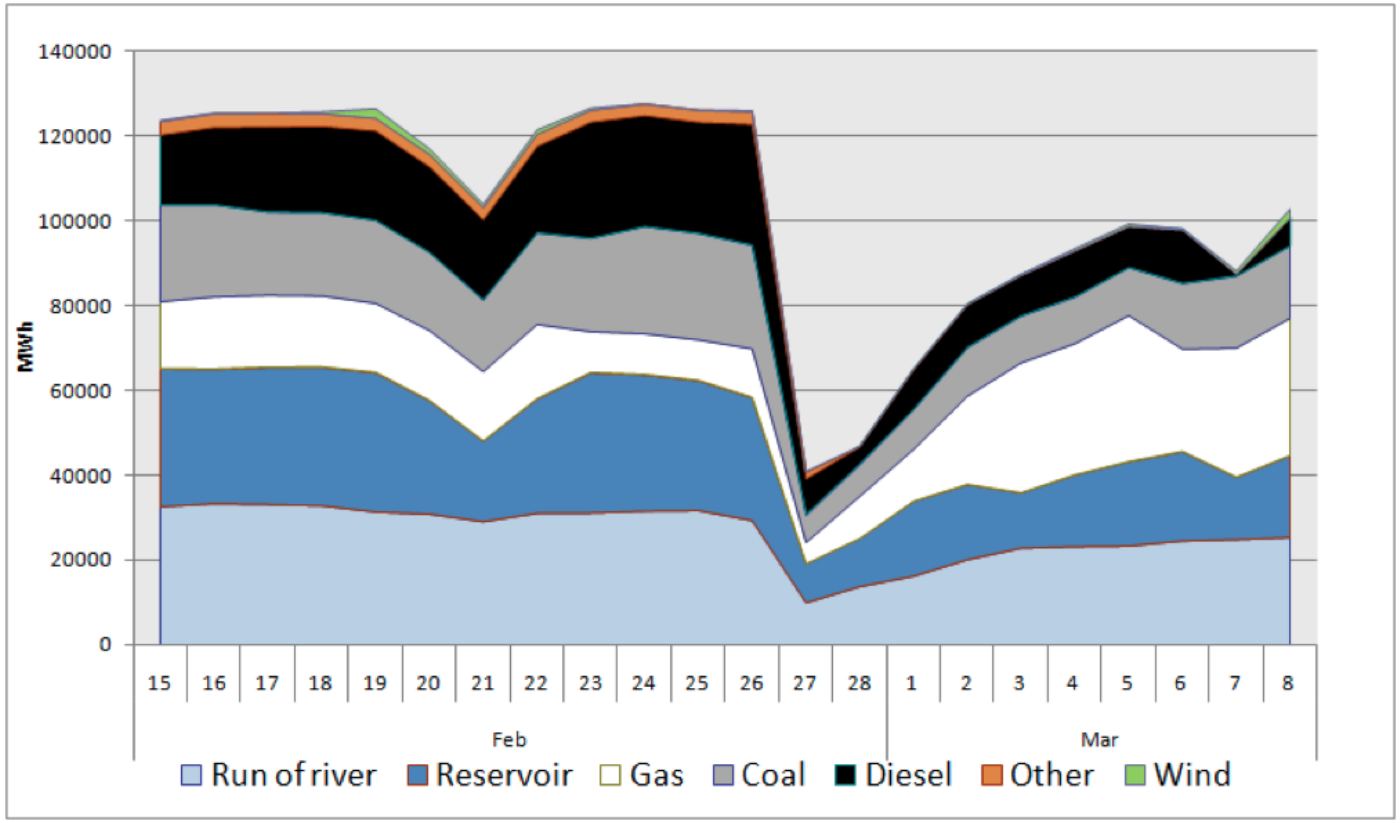
Tsunami effects: floodings smaller towns (Constitucion)

Immediate effects of the earthquake

- Immediate complete blackout for a 4,522 MW load
- Island scheme for grid supply recovery
  - Five Islands at first
  - Subsequently two islands
- Severe damage to distribution networks

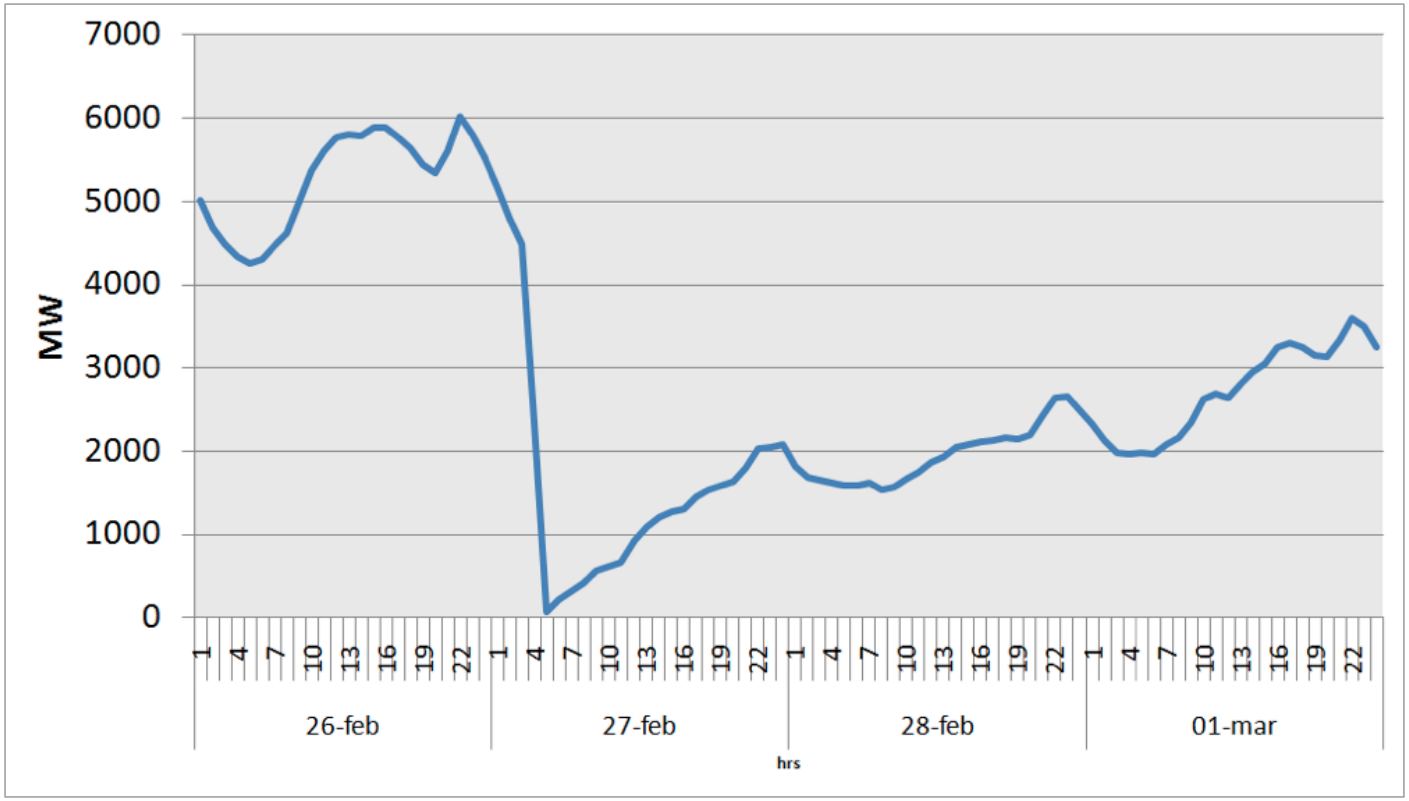


Supply evolution before and after earthquake



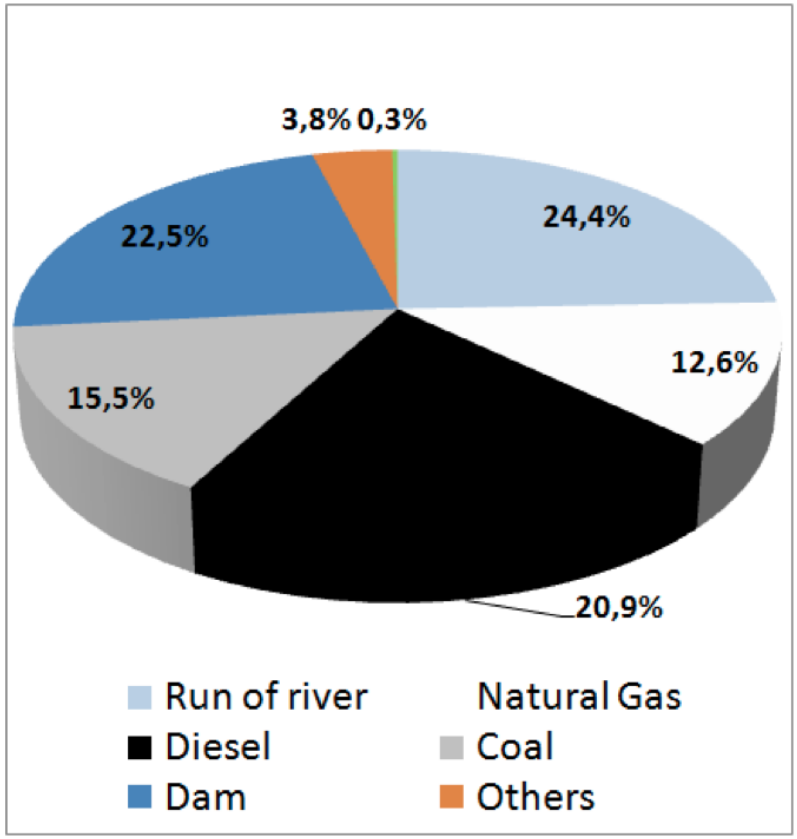
Hourly load evolution after the earthquake

- Blackout with a load loss of 3.000 MW
- Slow recuperation of load over subsequent hours and days



Generation on the day of the earthquake

- 4,522 MW where dispatched at the moment the earthquake struck



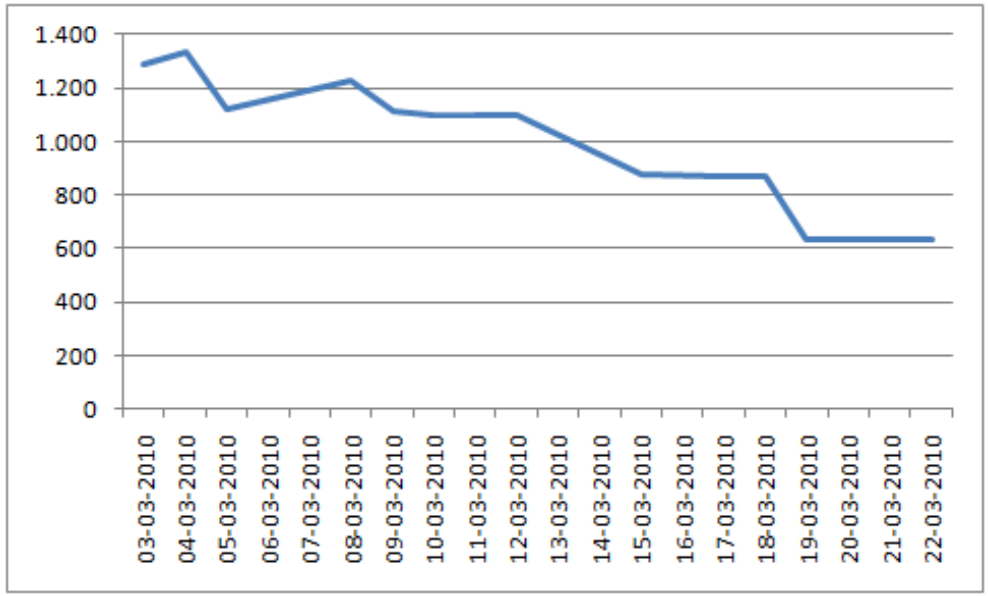
Impact on operation

- Severe impacts on country's communication systems.
  - Basic systems (mobile networks, emergency alert schemes, public order control) did not operate at all or as desired and caused additional harm.
- Difficulties also arose in the communications and telecontrol schemes of most transmission substations and power plants, complicating system recovery and operation.
  - No alternative backup radio systems.
- System operator (CDEC-SIC) had additional difficulties throughout the emergency
  - SCADA system in use (for over ten years), was not able to provide information required for system recovery (alarms could not be trusted as they were often incorrect).
- Land line phone calls had to be used to learn on local conditions and supervise actions for equipment and system restoration.

Availability of generation facilities

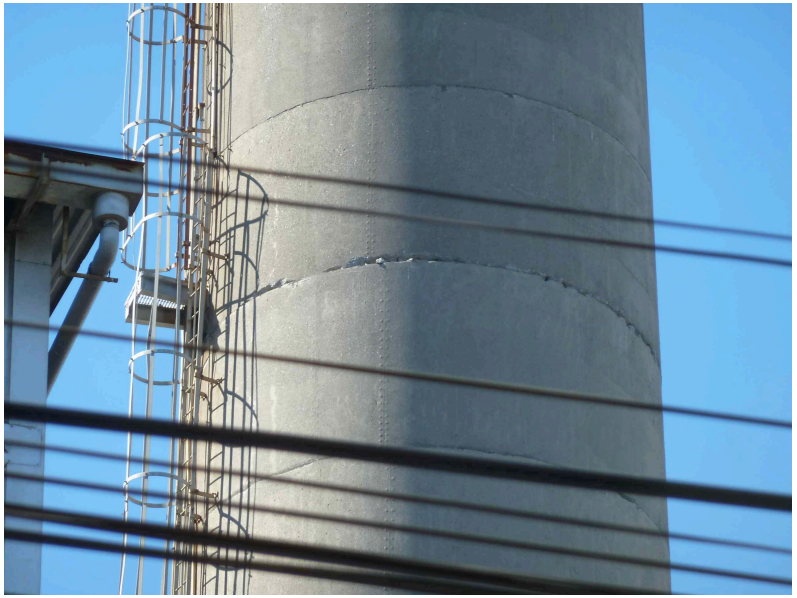
MW	Availability of generation facilities
3,000	Unavailable immediately after the earthquake
2,257	Available within the next 30 days
693	Required major repairs
950	Under construction were also damaged

Unavailability of generation units (MW)



Damage to generation plants

- Mainly thermal generation plants sustained damages
- Also important plants under construction suffered damages, delaying their commissioning
- Most common problems:
  - Cooling systems, transformers, communications, lines, etc



Coal plant chimney fractured

Transmission damages

- Damages concentrated in one transmission line
  - 3 towers from 154 KV line
- At substation level the damages were mainly focused at:
  - 500 kV bushings (high failure rate)
  - 500 kV pantograph disconnector switches
  - 220 kV circuit breakers (live tank type)
  - 154 kV circuit breakers (air compressed type)

	Total	Damaged	%
Substations	46	12	26%
Transmission lines (km)	7,280	1.6	0.02 %

Transmission damages

- Damage to transmission lines

Hualpen-Bocamina line (3 towers)

Transmission damages

- Substation damages

Transmission damages

- Substation damages

Transmission damages

- But most remained available

Capacitor bank without damage

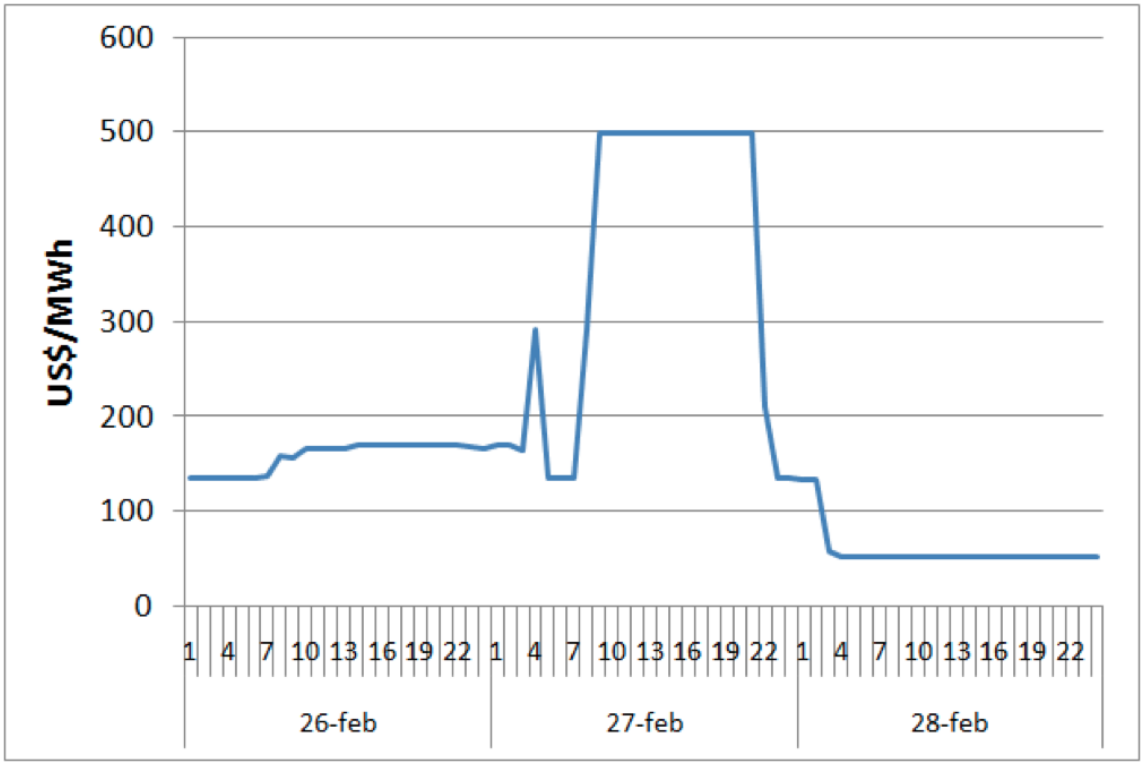
Circuit breakers with sufficient damping

System recovery process

- Recovery process of the interconnected system

City	Event	Date	Time
	Earthquake	February 27	03:34
Santiago	Supply recovered	February 27	03:58
Temuco	Supply recovered	February 27	04:05
Copiapo	Supply recovered	February 27	05:05
La Serena	Supply recovered	February 27	06:35
Puerto Montt	Supply recovered	February 27	10:31
Rancagua	Supply recovered	February 27	14:46
	Two islands interconnected	February 27	18:46
Concepción	Supply recovered	February 28	10:24
Talca	Supply recovered	February 28	11:38

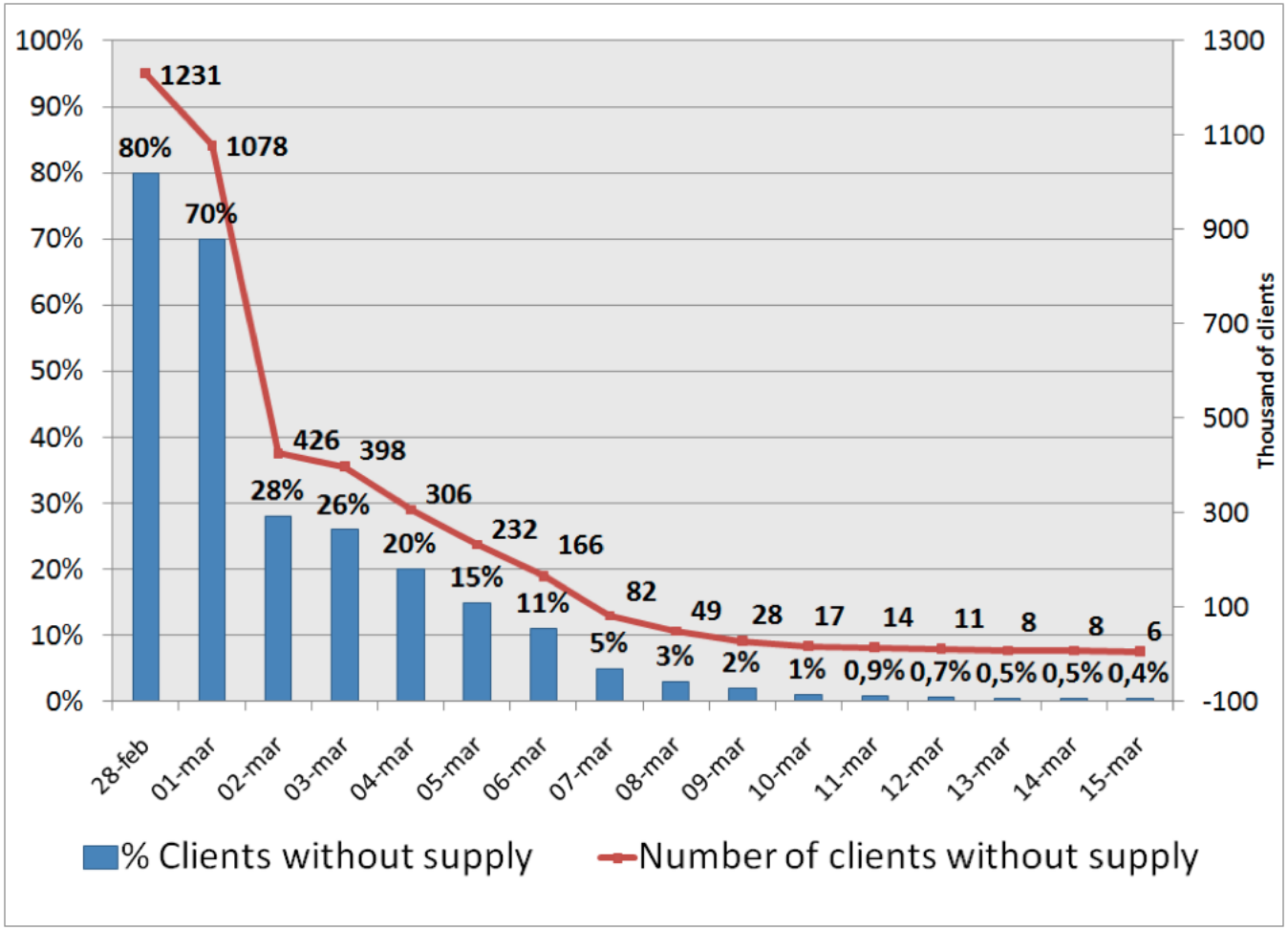
Hourly spot price at bus bar close to epicenter (Charrua 220 kV)



Effects in distribution networks

- 4.5 million people were initially affected by the extended blackout.
- 80% of clients were without supply the day after the earthquake and this reduced to 0.4% two weeks after
  - Mainly in Concepcion and Talcahuano, next to the earthquake epicenter an tsunami.
- Some distribution networks were destroyed by the effects of the earthquake
  - Houses fell over street lines
  - Lines were washed away by the tsunamis
  - For example 40,000 houses were destroyed out of 1.5 million supplied by CGE).
- Besides those distribution installations directly damaged, there was little damage elsewhere.

Distribution: Evolution of clients without supply



Distribution: effects of earthquake

- Extended damage in distribution networks

Distribution: effects of earthquake

- Extended damage in distribution networks

Distribution: effects of earthquake

- Extended damage in distribution networks

Distribution: effects of earthquake

- Extended damage in distribution networks

Distribution infrastructure

- Distribution poles in Chile are mainly compressed pre-stressed concrete poles, which are well founded, and support important mechanical stresses.
  - Exceptions in overloaded poles in cities (telephone, cable TV, etc)
- Distribution aerial transformers are often placed between two poles and a steel support, thus they also withstand well an earthquake.

Distribution infrastructure

- Distribution infrastructure still standing after earthquake and tsunami

Distribution infrastructure

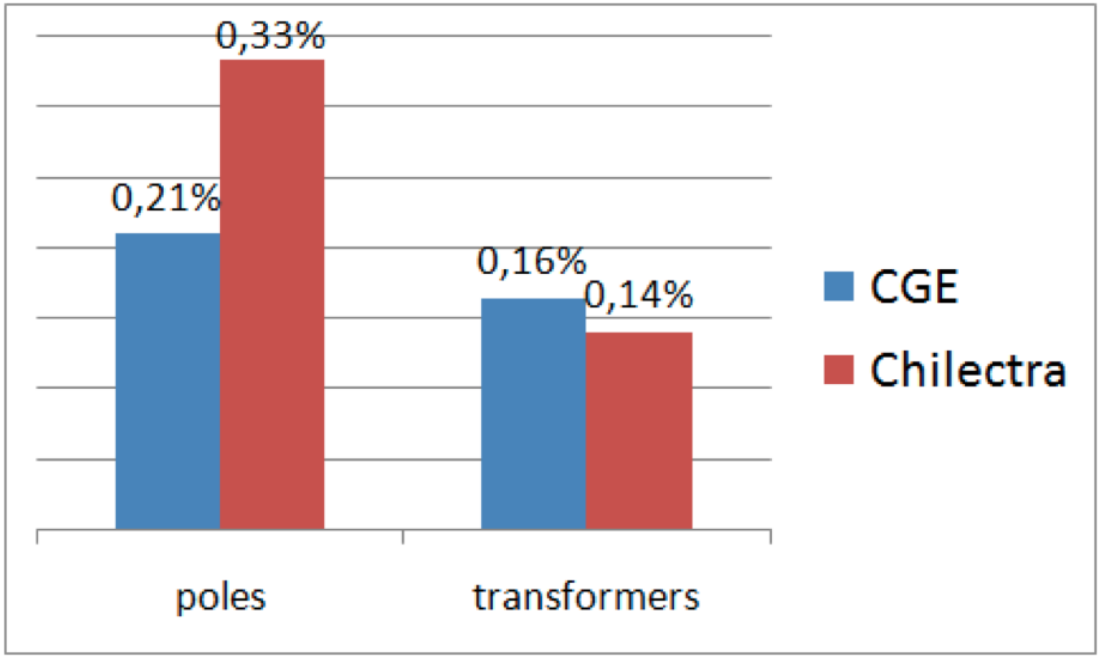
- Heavily loaded poles in main cities

Main challenges restoring supply

- Main difficulties in restoring supply to houses took place at the connection point between the low voltage lines and the buildings.
- Companies have equipment and human resources to repair normal failures
  - But in an earthquake, the problem is quite different. Communication problems, difficult physical access to locations, no resources to manage the huge number of needed repairs. Companies involved human resources brought from other regions, even other countries.
- Mobile generating units brought to support recovery of supply, particularly in more isolated areas.
- Challenges for distribution companies lasted months after the earthquake
  - Many latent faults, caused by the quake, that could not be detected when repairs were been made days after the event, or if detected, were secondary to the objective of supplying consumers as fast as possible.
  - Arrival of winter, with rain and wind, started igniting these faults in a a massive way, demanding the companies to comply.

Equipment damage at distribution level

- Small proportion of distribution equipment was damaged



760,000 poles in CGE
300,000 poles in Chilectra

50,000 transformers in CGE
20,000 transformers in Chilectra.

Final remarks

- International experience confirms greater damage expected at transmission and distribution levels
- Generation and transmission infrastructure had an excellent response, confirming effectiveness of high technical standards
- Serious issues in communication made response phase very difficult
- Operational procedures must reviewed not to prevent blackout in case of a major earthquake, but to speed up system recovery.
- Must be careful to not overreact to low occurrence frequency events
- Economical analysis must be performed to assess preventive versus corrective investments
  - Failure cost

Further reading

- More information of the Chilean electricity market:
  - Publications
    - http://www.systep.cl/publicaciones.php
  - Monthly reports
    - http://www.systep.cl/reportes.php

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