

The Role of Frequency Regulation with High-Penetration of Renewable Energy Sources

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Motivation

- In recent years, electricity generation from intermittent renewable sources like wind and solar energy has increased substantially in Latin America.
- Renewable sources of energy are cleaner than conventional sources and can play a significant role in reducing greenhouse emissions.
- In the case of Chile, they can also have an important impact on reducing local pollution and its significant negative effects on human health.

Motivation

- One of the main challenges emerging from high penetration rates of renewable energy sources in the energy mix of power systems is the increasing need of faster-ramping the resources participating in the frequency regulation services.
- As part of a long-term energy strategy, the Chilean government has established the goal of increasing the share of renewable energy sources in the energy matrix to 70% by 2050.

Motivation

- The current trends in the growth of renewable energy projects and the government's ambitious goals for their integration in the energy matrix indicate that the entrance of massive variable generation capacity from renewable sources to the grid will probably occur in the near future.
- In a market like this, with a high penetration of renewables, the lack of regulation capabilities from variable technologies generates a significant stress on conventional generators that need to provide frequency regulation to the system without the help of their renewable counterparts.

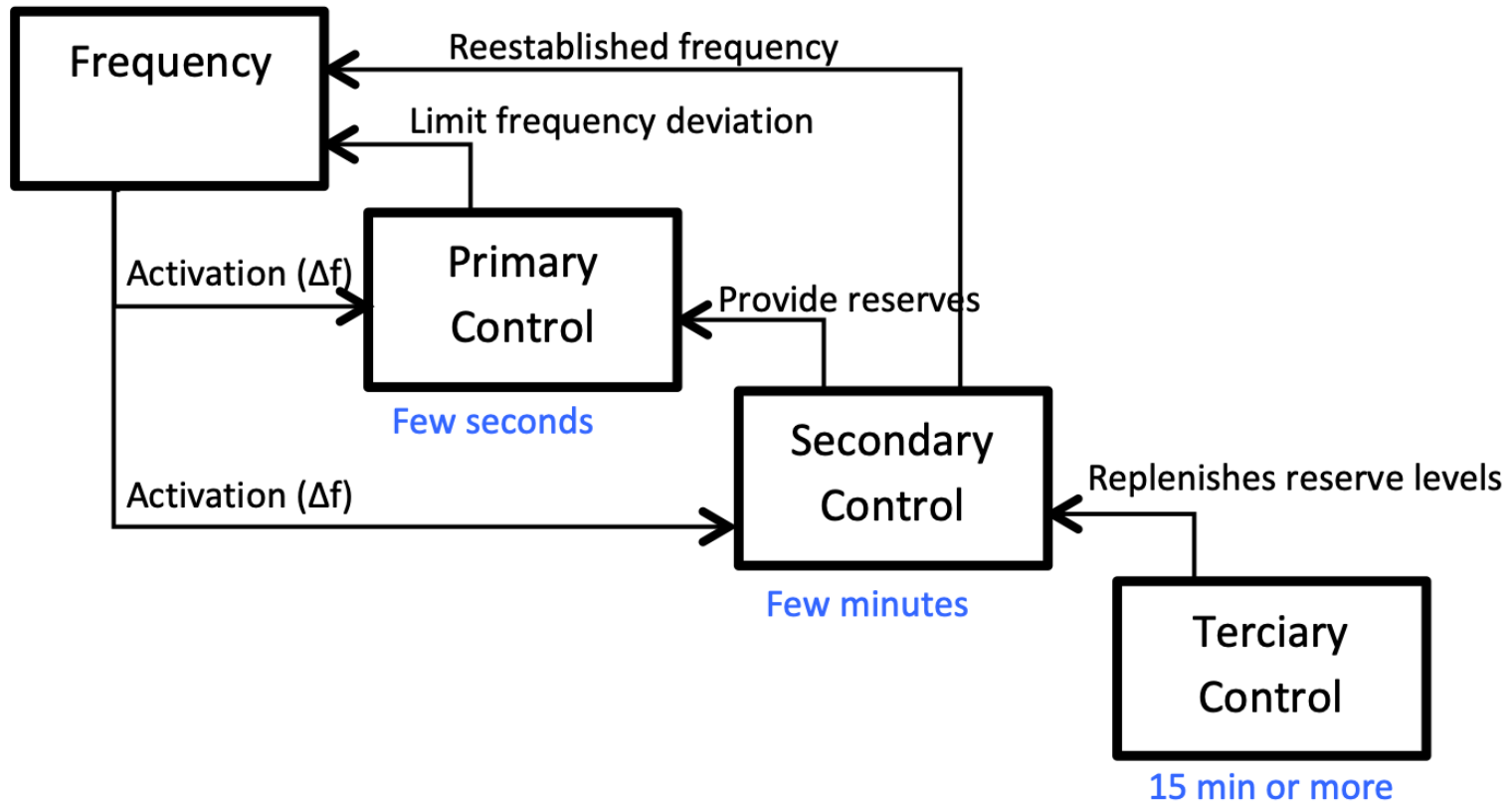
Motivation

- In 2012, for the first time the Chilean market operator introduced a new regulatory scheme for ancillary services that explicitly considers the cost of frequency regulation in the system.
- The new regulatory scheme set a fixed-compensation mechanism for the generators providing the frequency regulation service when they need additional maintenance, fuel consumption and investments to provide the service

Goal of the Paper

- We study the role of frequency regulation in an energy market with high penetration of renewables and examines the long-term economic incentives for the main generation technologies in the power system.
- The aim is to quantify the profitability of different generation technologies under a market-based regulatory mechanism and compare its effects with respect to the current cost-based regulatory scheme.

Frequency Control Scheme



Regulatory Schemes

- DS130 states that the regulator determines the remuneration each company should receive for investment cost, additional maintenance and additional fuel incurred by generation units by participating in the control of primary or secondary frequency
- Market based, which pays the highest opportunity cost in each hour to all the generating plants providing the regulatory service

Methodology

- The methodology used for the empirical analysis considers an Economic Dispatch Model - Optimization of Unit commitment (UC) problem using Mixed-integer linear programming (MILP).
- The market-based regulatory mechanism and the current cost-based scheme are both simulated for different levels of renewable penetration in the Chilean power system (ranging from 10% to 20%).

Methodology

- The main modeling elements in this segment of the Chilean system include thermal power plants (gas natural, diesel and coal), renewable energy plants (solar and wind energy), transmission flows and procurement of reserves.
- The generators in the system use both slow-responding units (i.e. coal-firing plants) and fast-responding units (from gas and diesel-burning plants).

Methodology

- In addition, the model uses forecast for wind and solar generation.
- We use PLEXOS to simulate the unit commitment (including, start up or shut down decisions) and dispatch (matching generation levels to load levels) of power generation units under a bunch of constraints.

Methodology

- The methodology used for empirical analysis has five stages.
- First, we used the profile of demand schedule for SING.
- Second, the SING 2017 generation matrix is used, which includes about 1,000 [MW] of installed photovoltaic capacity, to build generation profiles hourly according to the geographical location of each generation plant.
- Third, four photovoltaic energy penetration scenarios with different installed capacity were determined: E1 with 261.1 [MW]; E2 with 514 [MW]; E3 with 766.8 [MW] and E4 with 1019.7 [MW]. For each scenario, the primary and secondary reservation requirements are calculated.

Methodology

- Fourth, economic charge pre-dispatches are simulated in each scenario.
- Finally, with the results for every scenario, the profitability of the different generation technologies is calculated, under both remuneration criteria for complementary services: DS130 and market.
- The Internal Rate of Return (IRR) is used as a financial indicator to measure profitability

Data

- The data used for this purpose comes from the Northern Interconnection System (CDEC-SING) and it includes information on installed capacity of selected power plants, hourly power plant generation, hourly marginal cost on the transmission lines, and technical characteristics of each plant.
- SING is located in the far north of Chile, covering an area equivalent to 24.5% of the mainland (185 km²), where 6.3% of the country's population resides. Its demand is 90% industrial consumption, associated with mining, and only 10% is residential.

Installed Capacity

Primary Energy	Net Power [MW]	Net Power %
Coal	1,932.7	48.4%
Natural Gas	1,441.2	36.1%
Oil	354.9	8.9%
Cogeneration	17.5	0.4%
Hydraulic	15.1	0.4%
Wind	88.9	2.2%
Solar (Photovoltaic)	140.1	3.5%
Total	3,990.4	100%

Results

- The empirical analysis simulates four different scenarios of high penetration rates of renewable energies in the Chilean power system. In each scenario both alternative regulatory schemes for financing the frequency regulation services are considered.
- Then the effects on conventional and renewable technologies by applying two different remuneration methods are considered.

Percentage generation by technology

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Coal	74.01%	71.87%	70.48%	66.96%
CC Natural Gas	16.28%	15.10%	13.16%	13.31%
Diesel engine	0.003%	0.003%	0.003%	0.027%
Turbine Natural Gas	0.02%	0.01%	0.01%	0.02%
Photovoltaic	3.46%	6.79%	10.12%	13.46%
Hydraulic	0.39%	0.39%	0.39%	0.39%
Wind	1.05%	1.05%	1.05%	1.05%
Thermosolar CSP	4.19%	4.19%	4.19%	4.19%
Cogeneration	0.59%	0.59%	0.59%	0.59%

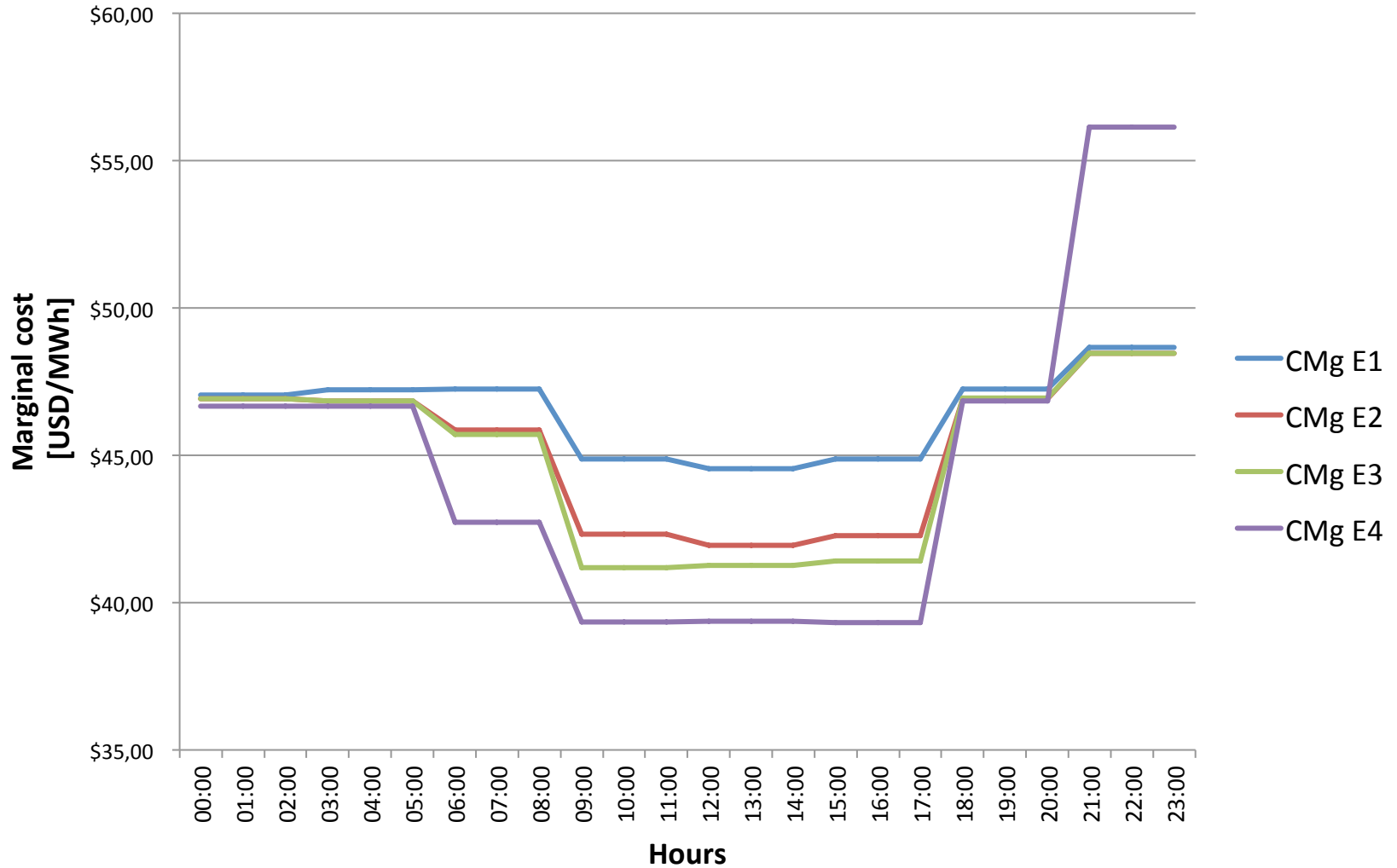
Results

- The results show that as intermittent renewable capacity increases in the power system, the average marginal cost of electricity decreases between 2.75% and 4%, and the total operational cost decreases between 3.6% and 10.5%. As a result, the profitability of all technologies also decreases in the long-run.

Annual average of the marginal cost of energy for each scenario

Installed Photovoltaic Capacity [MW]	Average Marginal Cost [USD/MWh]	Variation %
261.1	\$46.46	0%
514	\$45.18	-2.75%
766.8	\$44.84	-3.50%
1019.7	\$44.63	-3.94%

Average annual marginal costs



Results

- As expected, the technologies providing frequency regulation services are better off. In particular, the profitability of the natural gas power plants is the one increasing most, with a rate of return between 2.22 and 4.22 percent points higher under the market-based regulation compared to the cost-based one.
- On the contrary, under market-based regulation the rate of return of photovoltaic and Eolic power plants decreases 3.3% and 2.7% respectively.

Results

- The reason for this effect is that renewable sources do not provide frequency regulation services and need to buy energy in the spot market to provide the reserves corresponding to their energy generation. Finally, the results show that there are no significant differential effects between the regulatory schemes in terms of incentives to invest.

Internal Rate of Return (IRR) for different technologies

Remuneration	E1	E2	E3	E4
	Coal			
DS130	7.48%	7.47%	7.46%	7.45%
Market	7.42%	7.40%	7.41%	7.39%
	CC natural gas			
DS130	14.55%	14.59%	14.55%	14.85%
Market	14.87%	14.96%	14.88%	15.16%
	Photovoltaic			
DS130	4.60%	3.18%	2.66%	2.05%
Market	4.47%	3.08%	2.55%	1.98%

Internal Rate of Return (IRR) for different technologies

	CSP			
DS130	2.76%	2.73%	2.74%	2.72%
Market	2.71%	2.69%	2.68%	2.67%
	Wind			
DS130	3.80%	3.54%	3.47%	3.05%
Market	3.70%	3.45%	3.36%	2.95%

Conclusions

- In this study we evaluate the role of frequency regulation services in a power system with high penetration of renewables.
- In particular, one concern in the academic literature is that depending on the type of regulation considered, the incentives to invest in technologies that provide this service might diminish significantly.
- The simulation performed for the case of Chile show no significant differential effects in terms of incentives to invest between a regulatory scheme marked-based compare to one cost-based.