Transmission planning- From a market approach to a centralized one- The Chilean experience

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Abstract- **Electricity transmission planning does not have a common solution worldwide, with most countries trusting on alternatives adapted to the local energy markets' regulatory regime. The fast-growing conditions of the Chilean energy market, driven by private agents, meant the need to introduce changes to the original 1982 regulatory framework, being transmission pricing and investment among the main issues assessed in 2004. The original framework based on free market bilateral negotiations among the transmission owner and the interested parties had its main conflicts associated to the lack of transmission investment signals and lack of a common method to value and allocate the use of the existent transmission assets, that provoked a free rider actuation by some agents. For that reason transmission expansion and pricing was modified into a co-operative regulated scheme with participation of every agent participating in the energy market. As a result of the regulatory modifications, investments in the trunk transmission system have reactivated but some improvements to the process must be done.**

***Index Terms*—transmission planning, power system planning, transmission pricing.**

I. INTRODUCTION

Transmission expansion has become a central issue in the restructuring of the electricity market all over the world. Transmission systems costs represent close to 10% of the energy market price, however, because of its impact on relative competitiveness of participants in the energy market as well as short and long run economic efficiency of the whole electricity industry, it is vitally important to have efficient pricing schemes to tariff the use and expansion of transmission systems [1]. This matter is a relevant factor in developing countries like Chile, whose electricity demand has been growing up nearly 7% per year in the last decade. In that framework, open access to the existent transmission system and market rules to expand the transmission capacity, driven by local demand growth or new generating plants are the key issues to allow competition among agents in the energy market.

In South America the different regulatory frameworks include an open access transmission formulation and three initial planning models predominated in the 90's: central planning in Peru, Colombia, Bolivia and Brazil, regulated planning in Argentina and market planning in Chile. A central planning scheme is directed by government regulatory institutions that usually cannot address every market decision and therefore could differ from the system optimum. A regulated planning like the Argentinean case is an interesting approach because it allows the agents participation during the process to define and evaluate the transmission expansion project. A market based planning adopted in Chile would seem the best choice in terms of freedom to choose however it resulted in transmission underinvestment when the energy market and transmission pricing rules diverged.

The objective of this work is to describe the approach followed by Chile to define the transmission expansion in a fast developing country, with a fully deregulated competitive generation market, were the need for strong but efficient investment is required.

This paper is organized as follows: in Section II the Chilean market and the context of the planning and pricing challenges are presented. Then, the evolution of the pricing and planning schemes are reviewed in Section III prior to the major reforms that were implemented in 2004, and in Section IV the major reform in Chilean transmission regulation is analyzed, giving insight of the results obtained with the application of the new model. Finally, Section V addresses the challenges that still remain and Section VI concludes. This paper was prepared as a contribution to the panel session "Transmission Planning & Pricing" at the 2009 IEEE General Meeting.

II. EVOLUTION OF THE CHILEAN MARKET

Chile was a pioneer country deregulating and privatizing the electricity industry after the enactment of the Electricity Law in 1982. The electricity market was restructured in generation and distribution companies that were successively privatized at the end of the 80's. A system operator called Economic Load Dispatch Center (denominated CDEC by its Spanish name) was created in 1985 in charge of the secure and economic operation of the generation-transmission system and the management of the energy market transactions, which are valued using short run marginal costs (SRMC). One important characteristic of the Chilean main system, called the Central Interconnected System (SIC by its Spanish name), is its hydro-thermal capacity that requires the use of stochastic dynamic multi-reservoir models for operational dispatch planning. From the beginning of the 2000's SRMC are calculated based on multi-nodal and multi-reservoir models that provided better pricing signals to the energy market agents. The Electricity Law was amended in March 2004 with the introduction of significant changes to the transmission pricing and expansion procedures. Furthermore, in May 2005 the Electricity Law was amended to introduce

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improvements on the energy market long term prices applied to the contracts among generation and distribution companies, introducing energy contract auctions in a pay as bid scheme.

In Chile, generation is a competitive activity with full freedom to invest while transmission and distribution are recognized as monopolistic activities. Although it was recognized that open access to transmission capacity is essential for competition in generation, when privatization took place in the late 80s, the trunk transmission grid was left to Endesa, the Chilean largest generation company. In March 1993 Endesa created its affiliated transmission company Transelec in charge of the transmission assets planning, operation and commercial issues. Endesa was forced to divest itself of its transmission business following requests from the Antimonopoly Commission, which questioned interests of power producers in transmission issues [2]. The separation of Transelec from Endesa took place in October 2000 when Hydro-Quebec International (HQI) bought the company after an international bidding process. Afterwards, in June 2006, Transelec was sold to Brookfield Consortium of Canada after another bidding process conducted by HQI and the company has remained as the main electricity transmission owner in Chile. As of December 31st, 2008, Transelec owns 8,204 kilometer-circuits of transmission lines, 49 substations and 10,462 MVA of transformation capacity.

Electricity demand is expected to continue growing up linked to the Chilean economy growth. Figure 1 presents the SIC installed capacity and peak demand forecasting in the period 2008 – 2020, according to the projections of the National Energy Commission (CNE, by its Spanish name).

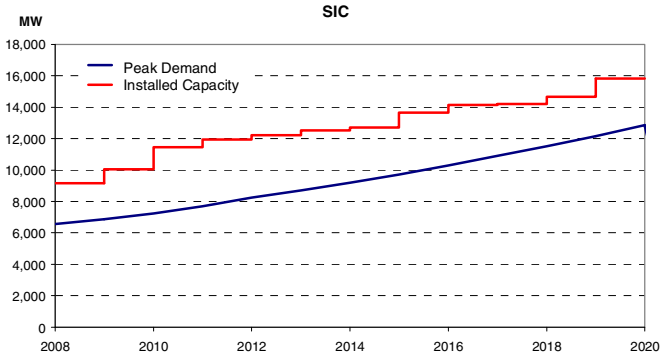


Figure 1. SIC installed capacity and peak demand forecasting (2008 – 2020).

III. TRANSMISSION PRICING AND PLANNING: 1982 TO 2003

Under the 1982 Electricity Law, complemented in 1990, the pricing and expansion of the transmission system was developed under bilateral negotiations between the interested user and the owner of the transmission facilities [3]. The main aspects are reviewed in the following section.

A. *Pricing of the existent grid*

Transmission owners had the right to receive revenues composed by the transmission SRMC (denominated IT, by its Spanish name), the Basic toll and, when applicable, the Additional toll. Under this scheme, tolls were paid 100% by generation companies. Furthermore, the transmission owner had to propose the corresponding payment to the users and a bilateral negotiation began. In case of disagreement an arbitration tribunal had to be agreed and designated by the parties in order to resolve the discrepancy. The basic regulatory framework to determine transmission tolls was a postage stamp with location signal. According to that framework, the annual payments were based on the Net Replacement Value (VNR) of the corresponding transmission assets, plus the Operation and Maintenance Costs (COyM). The annual revenue by transmission asset was equal to the AVNR+COyM, where the annuity of VNR (AVNR) was calculated over a 30 years period with a discount rate of 10%. Transmission owners received the transmission SRMC revenue for every transmission path (IT) from CDEC after the application of nodal SRMC to transactions in the energy market. Usually, in growing markets IT is insufficient to cover the total annual transmission costs, represented by the AVNR+COyM, for that reason the IT is complemented by a revenue called "toll", equal to AVNR + COyM - IT(ex-ante). On every path, tolls paid by the users were allocated on a pro rate according to the maximum transported power flow by the user over the maximum use of the rest of the users.

Power plant owners had to pay a Basic toll for the assets that belonged to the Area of Influence (AI) associated to their plants. The AI concept, shown in Figure 2, linked those transmission installations that permit the economic operation and market price taking by each plant. According to its business interests, the energy market agents had a different understanding of the concept of AI, making very difficult to reach bilateral agreements. A by-law enacted in 1998 made a precision on the definition of the Area of Influence as: "the minimum set of assets that connect the power plant with the nearest basic energy substation".

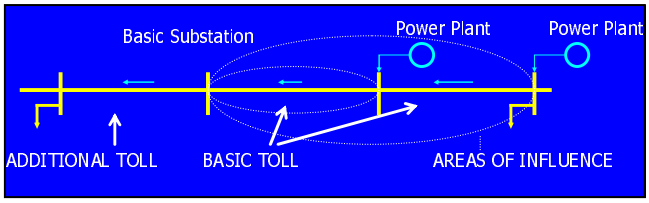


Figure 2. Area of influence, basic and additional tolls

Many publications described different methodologies to solve the AI problem [4, 7]. The location of the basic energy substation (which served as a reference for the whole interconnected power system) was determined every six months by the regulatory entity, the CNE together with the calculation of the regulated nodal prices, applicable to the transactions between generation and distribution companies. Owners of power plants that wanted to withdraw electricity for its customers from nodes outside the Area of Influence of their plants had to pay Additional tolls, calculated in the same way as the Basic tolls, except that the pro rate was calculated based on the withdrawn power to supply its customers. Once agreed by the parties, the Basic and Additional tolls lasted for five years. However, bilateral agreements were not easily achieved, and it often took long arbitration procedures.

B. *Planning and expansion*

The 1982 Electricity Law established the right of interconnection and open access to transmission systems. For that reason, transmission owners did not have the obligation to

invest in the network development. Within this scheme, transmission planning and network expansions were identified in advance by Transelec and then proposed to be bilaterally negotiated with the users that will require the expansion of the transmission capacity. When successful negotiations occurred then investment agreements were established on a long term bilateral contract. Transelec, being the main transmission company, had natural advantages to identify future transmission capacity expansions required in the system because of its knowledge of the real power flows and its know-how to forecast the transmission system behavior using multi-nodal modeling, based on system economic operation under stochastic hydrological conditions.

The owners of the transmission system were not obliged to expand the capacity of the existent network and there were some few users that built their own transmission assets, for example, due to commercial competition among generation companies for new customers. Furthermore, some distribution companies invested in their own transformation capacity driven by lower price signals at high voltage levels. The experience demonstrated that transmission expansion was only possible when a dedicated user like a large generating plant or a large customer could afford the total cost of the expansion. However, in the trunk transmission system that is shared among many users, it was impossible to get them to co-operate and share the costs of the expansion. Free riders were always waiting for others to push on transmission expansion but they did nothing to develop the grid unless some commercial competitive advantages arose. If that situation had persisted beyond the enactment of the new Electricity Law in March 2004, a negative impact on the system reliability (as shown in Figure 3) and important congestion costs (as shown in Figure 4) would have occurred because of the lack of investment in the trunk transmission system.

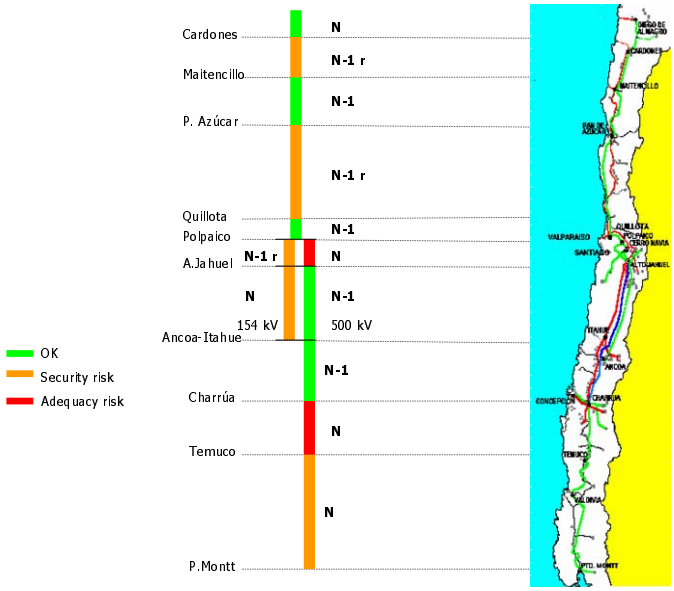


Figure 3. SIC Trunk system reliability status in 2004. All lines are 220 kV except Charrua-Ancoa-A.Jahuel 500 kV and Itahue-A.Jahuel 154 kV.

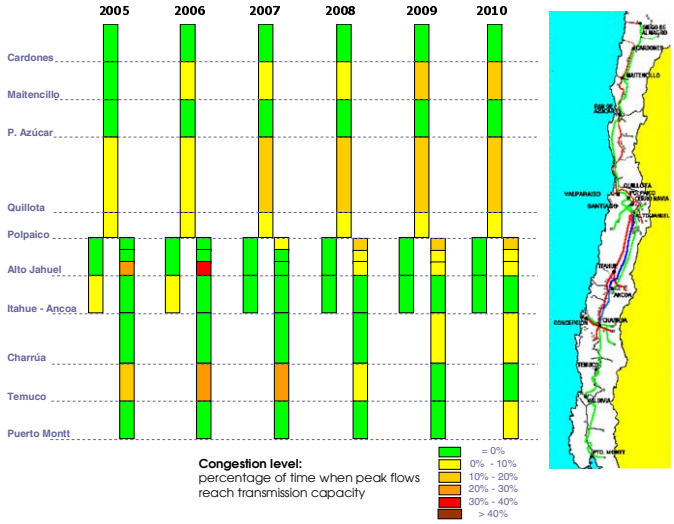


Figure 4. Congestions levels expected in the SIC Trunk system (2005 – 2010).

IV. TRANSMISSION PRICING AND PLANNING (FROM 2004 ONWARDS)

The March 2004 Electricity Law amendment defined new procedures to calculate transmission tolls and created a co-operative planning process to expand the trunk transmission system with the participation of all involved agents under the co-ordination of the regulator [3]. The transmission system was separated in three segments: Trunk, Subtransmission and Additional Transmission, as shown in Figure 5.

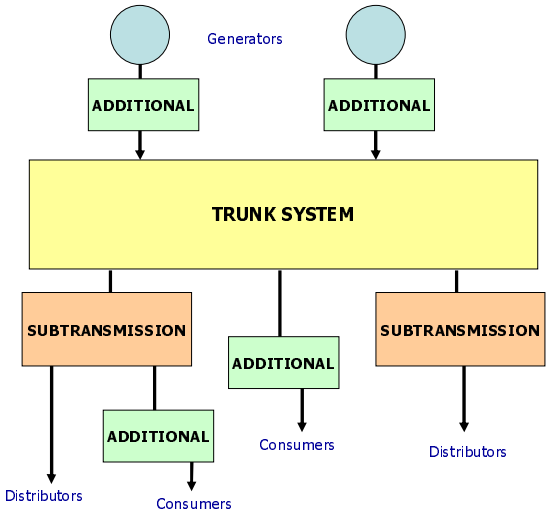


Figure 5 – Transmission segments under the new law.

Trunk system assets are those essential for competition in the energy market and are integrated by facilities over 220 kV that are economically efficient and necessary to supply the total demand. Subtransmission system assets facilitate access to consumers, with regulated and non regulated prices (higher than 2 MW). Additional Transmission systems assets are those dedicated either to non regulated price consumers or to connect power plants to the system.

Trunk and Subtransmission systems assets are determined by a decree of the Ministry of Economy (after a

recommendation by the CNE) and the tariffs are regulated every four years. The Additional Transmission revenues are bilaterally negotiated between the owner and the users.

A special tribunal called Experts Panel was created in order to resolve any dispute among agents or between agents and the regulator, in the operational and tariff processes.

Additionally, to complete the set of changes introduced by the new law, a Technical Norm of Security and Quality of Service was enacted in May 2005, but a market-based Ancillary Services managing system, including frequency control, voltage control and system recovery is still for implementation.

A. Pricing of the Trunk System

In the Trunk system a pricing framework based on postage stamp with location signal was established, but the allocation of tolls is different. A Common Area of Influence (CAI) is defined and inside it the allocation of the transmission tolls was established as 80% to generation companies and 20% to consumers. Outside the CAI tolls are paid by generation companies if power flows go toward the CAI and by consumers if flows go out of the CAI, for every expected operational state. The tolls are based on the Value of Investment (VI) of the corresponding assets, plus the Operation, Maintenance and Administration Costs (COMA). The annual toll per transmission asset is equal to the AVI+COMA-IT (ex-ante), where AVI is the annuity of VI calculated over an economic life span with a discount rate of 10%. Transmission owners also receive the transmission SRMC revenue for every transmission path (IT) from CDEC. On every path, tolls paid by the users are calculated by CDEC with an allocation pro rata according to the expected individual contribution to the power flows over every path at every operational state. Additionally, the IT are resettled every month in order to ensure that the surplus IT goes back to the energy market agents and not to the transmission owners, who are entitled to receive 100% of the AVI+COMA.

Tariffs in the Trunk system and the expansion plan are determined every four years based on a Trunk System Study. The steps followed to develop the study are as follows:

- CNE publishes the terms of reference of the study and coordinates the elaboration process. The participants can challenge those terms and raise a discrepancy to be resolved by the Expert Panel.
- The study is bided, awarded and supervised by a committee integrated by eight representatives: two from the regulatory bodies – Ministry of Economy and CNE –, two from generation companies, two from trunk transmission companies, one from distribution companies and one from non regulated price consumers.
- The study is developed by the international consultant who won the bid and he has eight months to complete it.
- The results of the study are:
  - The assets belonging to the existent trunk system.
  - The AVI and COMA of the existent assets and the indexing formulas.
  - The expansion plan of the trunk system, indicating the corresponding commissioning date.
- After the conclusion of the study and the public audience where the consultant presents the result of the study, the CNE has 45 days to elaborate a Technical Report based on the results and considering the participants comments. The valuation of the existent assets included in the Technical Report can be challenged by participants and then raise a discrepancy to be resolved by the Expert Panel.

The first such study was developed by the consultant consortium Synex-Electronet-CESI between January and October 2006. During this time all the involved agents, with conflictive interests, had the right to send comments to each one of the four interim reports presented by consultant and to the final report. Afterwards the CNE released a technical report based on the study results and considering the comments presented by the agents, in March 2007. There were several discrepancies resolved by the Expert Panel in May 2007 and finally in July 2007 the Trunk system decree was enacted with the valuation of the existent trunk system. The process for the second study will start in 2009.

B. Planning and expansion of the Trunk System

Transmission investments in the trunk system are the result of the expansion plan proposed in the Trunk System Study. The expansion plan is determined through a planning process that has got the following inputs:

- Nodal demand forecasting prepared by CDEC.
- Generation expansion scenarios prepared by CNE according to information provided by the participants.
- Fuel prices projection.
- Transmission projects proposed by the participants.
- Reliability criteria according to the Security and Quality of Service Norm.

The expansion plan is the set of trunk transmission projects that minimizes the updated cost of transmission investments, system operation and outages over a 10 years period.

Once a year, the system operator CDEC must revise the Trunk expansion plan according to the current market conditions, particularly demand and effective generation development, with a consultation process including all the involved agents. Then CDEC recommends the corresponding trunk transmission projects to the CNE. Afterwards the CNE has 30 days to release the expansion plan of the Trunk System with the projects that must begin construction in the next 12 months. The participants can, once again, challenge the expansion plan and raise discrepancies to be resolved by the Expert Panel.

There are two types of projects determined in the expansion plan:

- New trunk projects that are independent of the existent grid are awarded via an international bidding process conducted by CDEC. The transmission company that offers the minimum AVI+COMA will be the winner. This value will be kept by four tariff periods (20 years) after which the asset will be valued in the corresponding Trunk System Study.
- Upgrades of the existent trunk grid that are allocated on the corresponding owner, who has to bid the project under an open and competitive process. Bids are allocated to the constructor that offers the minimum value of investment with a cap equal to the referential VI plus 15%. If the bidding is unsuccessful the owner must require a study by an independent consultant that explains the causes and, if it

is justified, the Ministry of Economy is entitled to release a decree with a higher VI, and the owner can perform a new bidding process.

In this context, there have been three processes to determine the expansion of the trunk transmission grid:

1) Immediate construction works in 2004

A 'fast track' expansion plan was included in the 2004 new law in order to improve the systems security of supply via urgent trunk projects for immediate construction. These projects had to cover the trunk system expansion between 2005 and 2008, just in time to coordinate with the first set of projects to be determined by the Trunk System Study. According to this mandate CDEC proposed to CNE a set of projects in May 2004 and finally CNE enacted the corresponding decrees in September 2004.

Three new projects with a VI of around US$ 90 Million were bided by CDEC in the beginning of 2005 and 2006, with three new entrants that competed with Transelec to win the bids. Transelec won two of the three bids. Additionally, six upgrade projects with a VI of US$ 85 Million in the trunk system were defined by the regulator and allocated to Transelec, as the owner of the existent assets to be upgraded.

2) First trunk expansion plan in 2007

The trunk expansion decree was enacted in November 2007, after CDEC revised the first expansion plan determined in the Trunk System Study. One new project with a VI of around US$ 47 Million was bided by CDEC in the beginning of 2008, with four new entrants competing with Transelec, who finally won the bid. Additionally, 23 upgrade projects were defined by the regulator, 22 allocated to Transelec and 1 to another company.. Only 5 projects were awarded at the first auction and the rest have been awarded after a new VI was settled or they are still waiting for a new VI. Upgrades under construction have a VI of US$ 76 Million. Figure 6 presents the Transelec annual investment, according to the commissioning date, that have been awarded as new projects or upgrades as a result of the Immediate Construction process (2005-2008) and the First Trunk System Study (2009-2011).

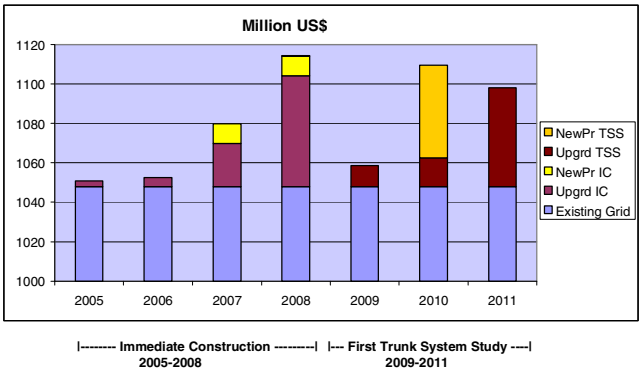
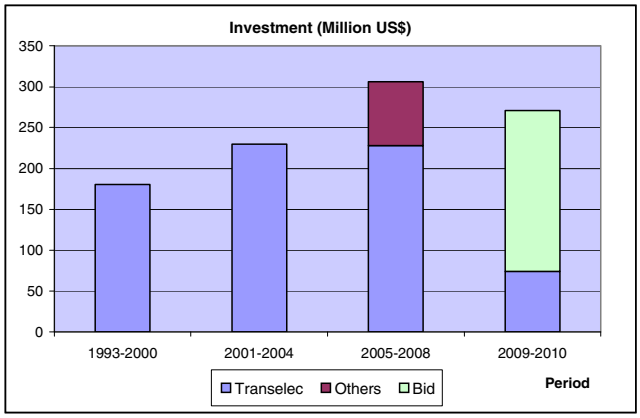


Figure 6. Transelec existing grid VI and investment 2005-2011 (new projects and upgrades).

3) Expansion plan revision in 2008

The last trunk expansion plan was proposed by the CNE in January 2009 after CDEC sent its revised proposal of projects in November 2008. It contains two new projects with a VI of US$ 197 Million and five upgrade projects with a referential VI of US$ 74 Million. Some discrepancies were raised to the Expert Panel and finally in March 2009 the trunk expansion plan for the period 2009-2010 will be settled.

In summary, from 1993 until 2010 a growth in the annual trunk transmission investment is shown in Figure 7, correlated with the growth in demand and the construction of new power plants in the SIC and with one new entrant owning trunk transmission assets.



Average Inv per year	22,6	57,5	76,5	135,5

Figure 7. Trunk transmission investment (1993-2010).

C. *Pricing and planning in Subtransmission and Additional Systems*

Tariffs in the Subtransmission system are determined every four years based on the concept of Economically Adapted Network [5] and they must allow the recovery of the average costs of investment, operation, maintenance and administration, and transmission losses. Planning in subtransmission is performed by the same owners and the expansion plans are under their responsibility to meet demand growth under the reliability standards. The first set of subtransmission studies was performed during 2006 and the CNE released its technical report in November 2006. Afterwards, discrepancies were presented by some subtransmission owners to the Experts Panel which released its resolution in January 2007. After a long delay in the preparation and review by the CNE, the subtransmission decree was finally enacted in January 2009.

In the Additional systems, pricing and investments have continued been developed under bilateral negotiations.

V. MAIN CHALLENGES

The Trunk System Study put on the arena new sets of trunk projects to meet the constant growth of electricity demand in tuning with the country's economic development. The new transmission scheme introduced competition for the development of new projects in the trunk system and the obligation to accept transmission upgrades by the owners of the existent grid. New projects have been successfully awarded after the bidding processes organized by CDEC. However

upgrades have been partially successful because some of them have failed to meet the VI + 15% cap. The same situation has repeated two times: Transelec proposed a set of VI for the upgrades to CDEC, who defined investments with a lower VI, the upgrade projects were bided by Transelec and the construction companies could not meet the VI limit. On those cases new decrees were required to the CNE in order to increase the VI, producing a delay in the projects commissioning date of around six months. Improvements could be introduced to allow a faster response, such as an automatic increase in the VI cap, assuming that there is a competitive construction market for transmission assets. This type of solution was implemented in the energy auctions for distribution companies in Chile.

Another important challenge is the long period between each trunk transmission planning study, every four years, and the once a year revision. In particular the one-year review of the trunk expansion plan by CDEC has been an issue to debate because the agents cannot wait for a year to find the transmission solution when they decide a new power plant or a new consumer like a mining company is approved. Defining the generation or demand projects under effective development cannot wait until those projects are under construction because the time required to construct a substation is around of 24 months and the time required to construct a new transmission line is around 36 months. Additionally the negotiation of rights of way for new lines with land owners could be facilitated by getting a concession, granted by the law, but the problem relates to the large time required to get that concession by the government institutions, affecting the commissioning date of new projects. Usually the commissioning date of new lines has been delayed by excessive environmental discussion and the lack of concessions at the right time.

A key aspect that still remains as a barrier for the implementation of efficient transmission solutions is the dissociation between a competitive free generation market and the centralized planning in the transmission system. The access to information of new generation investments is a sensitive issue for private companies, who will delay the provision of such information as much as it is possible in order to secure competitiveness. Also, due to the nature of the generation market, projects may change; postponed or new ones appear in a short period of time, generating the necessity for flexible planning methods. The downside is that the solutions achieved could often be considered incremental solutions that limit themselves to follow the generation market but don't represent the most efficient alternatives in the long term.

A discussion about grid reliability and the application of the brand new Technical Norm in the transmission planning study developed by the consultant of the Trunk System Study also occurred, consideration the opinion of the interested agents. It is quite clear that under market conditions it is not possible to improve reliability because it is another "shared asset" demanded by consumers but not by individual generators that must pay transmission tolls. On this sense generators have pushed on a discussion about the use of load shedding schemes to replace transmission expansions, proposing the socialization of the system costs.

Chilean experience is unique in the world because it was a pioneering step in a small system, in tuning with the opening of the country's economy. Although, there are still a lot of things to do, from planning point of view it can be stated that transmission investments for the next years must start as soon as possible and require a modeling effort of the grid under uncertainties like demand growth and the location and technology of future power plants. Another important source of uncertainty in the Chilean energy market has been the unreliable supply of natural gas from Argentina that finally meant the search for alternative energy sources that led the country back to coal power plants, as one of the most economic solutions, plus the revival of some large hydro power plants in the south of Chile [6]. Renewable energy sources like wind seem another interesting contribution but not as the solution in a constant growing economy.

Transmission planning is always a need because of the shared characteristic of the transmission assets and transmission owners and system operators must head the process to forecast the future use of the grid under different scenarios and uncertainties. Letting the market decide the expansions failed to be the answer for the Chilean transmission system. Shared transmission assets need some co-operative work and regulatory support to avoid free rider attitude by some market agents and blockage to transmission projects that are not commercially convenient for some agents. The costs associated to the security of service provided by the transmission grid is another "asset" that should be allocated on the demand side instead of the producer side. Planning under different scenarios enlightens everybody but lets the market the option to decide.

Finally, another challenge that has arisen is concerning large interconnection lines between areas with important generation potential and the existing interconnected systems. Such is the case of the Aysen Region, in the Chilean Patagonia, where important hydro resources are available for exploitation, and a 2,750 MW project has been presented for environmental licensing that could be connected directly to Santiago through a 2,000 Km HVDC line. Under current legislation such transmission line should be classified as an additional line, and the main concern is that the construction of such line does not become a barrier for the construction of future projects in the region, especially due to the high environmental and social costs of a transmission line of that magnitude.

VI. CONCLUSION

The Chilean electricity market has evolved towards a self-sustained generation sector, where the private agents have invested according to price signals. This successful generation market has been achieved thanks to the open access to transmission capacity. Transmission pricing and expansion methods played an important role in this process. Practical experience probed that letting the market decide freely for the expansion of the main transmission grid was not successful, resulting in underinvestment, congestions and areas with problems of security and quality of service. Introducing regulated rules for pricing the use of the trunk transmission grid has improved the revenue recovery of 100% of the regulated AVI+COMA of the trunk system assets. Transmission investments have reactivated due to the co-operative process defined in the new law, identifying and approving new expansions and upgrades on the trunk grid. There are still improvements to be made to the process, particularly related to the dynamic growth and uncertainties associated to the electricity growth, where demand growth has been met by

multiple options of generation projects, requiring transmission expansion decisions that fit in the optimum way to the future development of the system.

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VIII. BIOGRAPHIES

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