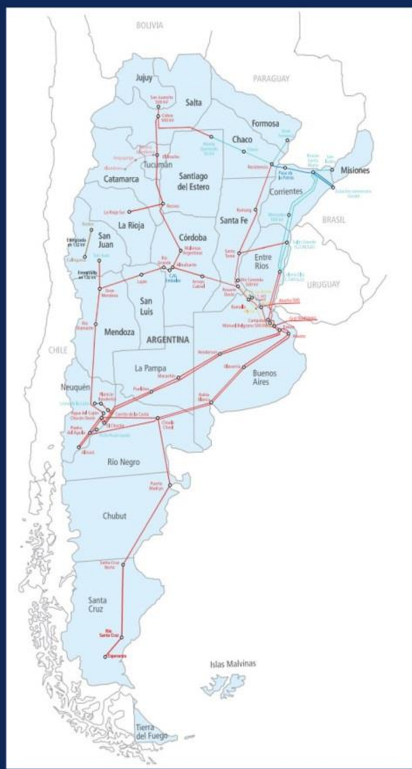
Master of Science Thesis

Steady-state technical assessment of an electric interconnection between Chile and Argentina, to export wind power by means of a 345 kV transmission line; including analysis of the policy framework required to manage the transaction.

Alberto Leal Ramirez



Faculty of Electrical Engineering, Mathematics and Computer Science
Department of Electrical Sustainable

NTNU – Trondheim
Norwegian University of Science and Technology

Faculty of Information Technology, Mathematics and Electrical Engineering
Department of Electric Power Engineering

SOWITEC

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Master of Science Thesis

For the double degree of Master of Science in Electrical Engineering from TU Delft & Master of Science in Technology-Wind Energy from NTNU

Alberto Leal Ramirez

TU Delft Student No.- 4261208
NTNU Student No.- 744402

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Faculty of Electrical Engineering, Mathematics and Computer Science
Department of Electrical Sustainable Energy
TU Delft

Faculty of Information Technology, Mathematics and Electrical Engineering
Department of Electric Power Engineering
NTNU

DELFT UNIVERSITY OF TECHNOLOGY
FACULTY OF ELECTRICAL ENGINEERING, MATHEMATICS AND COMPUTER SCIENCE

NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY
FACULTY OF INFORMATION TECHNOLOGY, MATHEMATICS AND ELECTRICAL ENGINEERING

The undersigned hereby certify that they have read and recommend for acceptance a thesis entitled:

STEADY-STATE TECHNICAL ASSESSMENT OF AN ELECTRIC INTERCONNECTION BETWEEN CHILE AND ARGENTINA, TO EXPORT WIND POWER BY MEANS OF A 345 KV TRANSMISSION LINE; INCLUDING ANALYSIS OF THE POLICY FRAMEWORK REQUIRED TO MANAGE THE TRANSACTION

by

ALBERTO LEAL RAMIREZ

in partial fulfillment of the requirements for the double degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING & MASTER OF SCIENCE IN TECHNOLOGY-WIND

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Dr. Ir. Laura Ramirez Elizondo

Associate Prof. Trond Toftevaag

ABSTRACT

Chile is an energy independent country; goal achieved due to the diversification of the energy matrix and promoting exploitation of renewable energies. On the other side, Argentina holds permanent electricity importations from its neighboring countries, relying on these transactions to supply its demand. The Northern Interconnected System (SING) is one of the two major electrical isolated power systems in Chile with current surplus capacity and ongoing renewable energy developments.

There is an existent not-operating, 345 kV transmission line between SING and the Interconnected Argentinian System (SADI), which in the past was completely dedicated to transmit power to Chile from a generation plant located in Argentina, without being fully interconnected to SADI.

Recently, there has been an increasing interest in restarting the operation of the 345 kV transmission line. Therefore, this work performs a steady-state assessment based on load flow calculations with the computational tool DigSilent Power Factory, in order to evaluate the impact and capabilities of transmitting power from Chile to Argentina. This is done by simulating under-development wind projects that the German company, SoWiTec, has in Chile. The created scenarios also take into account that the exported capacity to Argentina might come from other renewables such as solar power as well as conventional technologies based on gas and coal. Permissible voltage levels and thermal loading are monitored throughout the work, paying especial attention to selected electrical nodes where the 345 kV transmission line is connected and to the wind projects´ points of common coupling with the power system. In the case of exceeding acceptable limits, solutions and measures are proposed and documented.

This work also contains a commercial aspect in which the goal was to gain comprehension about the commercial structure that the interconnection SING-SADI will have. Ideas, being at the moment considered to be part of the policy framework to rule the transaction, have been gathered. Required regulation in Chile, possible commercialization modes, proposed scheme to manage the transaction and important features to be included at a regulatory level to empower renewable energies, were stated.

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List of Acronyms

B	Susceptance
C	Capacitance
CAMMESA	System Administrator Company of the Argentinian Electrical Market
CDEC	Economic Load Dispatch Center
CNE	National Energy Commission (Chile)
CONAMA	National Environmental Commission (Chile)
DSPF	DigSilent Power Factory version 15.1.2
ENRE	National Electricity Regulator (Argentina)
GUMA	Heavy Electrical Consumers (Argentina)
GUME	Light Electrical Consumers (Argentina)
GUPA	Particular Electrical Consumers (Argentina)
I	Electrical Current
kV	kilo Volts
L	Inductance
LNG	Liquefied Natural Gas
ME	Ministry of Energy (Chile)
MEM	Argentinian Electricity Market
MVA	Mega Volt Ampere
Mvar	Mega Volt Ampere reactive
MW	Mega Watts
MWh	Mega Watt hour
NCRE	Non-conventional Renewable Energy
NEA	Northeast Argentinian System
NOA	Northwest Argentinian System
P	Active Power
PCC	Point of Common Coupling
PF	Power Factor
PM	Market Price
PPA	Power Purchase Agreement
pu	Per Unit
Q	Reactive Power
R	Resistance
S	Complex Power
SADI	Interconnected Argentinian System
SEC	Superintendency of Electricity and Fuels (Chile)
SENER	Energy Secretariat (Argentina)
SIC	Chilean Central Interconnected System
SING	Chilean Northern Interconnected System
SIL	Surge Impedance Loading
TSO	Transmission System Operator
U	Electrical Voltage
X	Reactance
Y	Admittance

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I want to start by saying that last two years have been full of experiences, knowledge acquired, moving from place to place, new friends, responsibilities and hard work; perhaps some other things that have made me grown as a man, professionally and personally. However, it also involved being separated of loved ones, missing important and unrepeatable moments and giving last good byes.

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Chapter 1

1. Introduction

1.1. Background

Energy is essential for running any human community. Therefore, not only the present society but also the future generations will rely on energy, in any of its forms, to perform industrial, scientific and everyday activities. Understanding the energy business, its generation, supply and utilization is a subject of great importance as it represents a large sector of the world's economy. In developed countries, the energy industry is worth around 5% of the Gross Domestic Product (GDP) and employs 4-5 % of the industrial workforce [1]. The nature of this sector is also multinational, since crude oil is transported all around the world, electricity is traded between countries and large quantities of natural gas are piped across international borders.

As economies and world population grow, the demand for energy increases. It is known that fossil fuels such as oil, coal and natural gas have a predominant position in the energy matrix. However, the evidence regarding climate change, global warming and pollution due to conventional generation sources, together to the limited fossil supplies, have trigged incentives to promote the use of non-conventional resources to generate electricity, and to create significant energy policies towards the employment of renewable energy such as wind and solar. These last two being the ones with more research support and maturity for massive electrical generation.

Nowadays, in some European countries as Denmark, Germany and Spain the penetration percentage of these technologies is already substantial, and it is expected that sustainable energy will also play an important role in the supply of electrical power in developing areas, such as Latin America, with a well-known huge potential for their implementation. This is the case of Chile and Argentina, being two of the leading and bigger economies in the region.

In past years there was a Chilean energy dependence on Argentinian resources, mainly based on natural gas supply, which started on 1997 and gained a significant importance in the Chilean electricity market. Afterwards, on 2004 restrictions on importing natural gas from Argentina created an unbalance between the generation and the system´s demand. This exchange is no longer available, as the flow was practically stopped by 2008.[2]

Even though the structure of the Chilean electric system will be explained in further chapters, at this point it is important to mention that Chile has two major electrical systems which roughly represent the 99% of the country´s installed capacity. These systems are known as the Central Interconnected System (SIC) and the Northern Interconnected System (SING); however, these two systems are not electrically connected, therefore each one operates as isolated network.

In order to solve the unbalance mentioned before, Chile had to restructure its energy matrix, doing this by mainly three measures:

1. Develop hydroelectric plants in the SIC, which by year 2013 were supplying almost 40% of this system´s demand, being of approximately 2900 MW.
2. Consider coal-fired and thermic plants, in both SIC and SING, as an economic alternative.
3. Invest on regasification terminals.

Nevertheless, the high expected prices of liquefied natural gas (LNG) and its volatility, anticipated LNG alternative to be considered as a backup function, more than a source for generation expansion. Therefore, coal stood up as the most economical alternative and it was considered in the country as a tool for development. The following figures are the exemplification of the undertaken measures to diversify the generation plan in Chile, specifically at the SING by 2013:

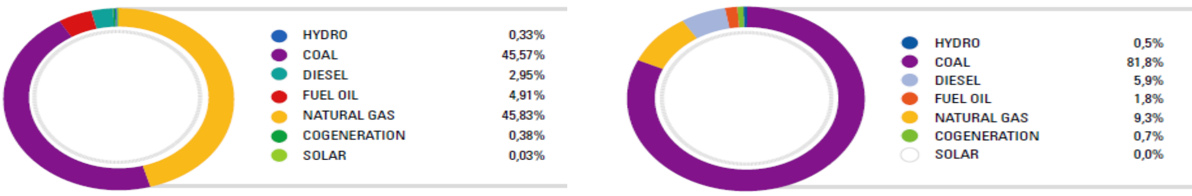


Figure 1 Left – SING Installed Capacity as per fuel type, Right – SING Gross Generation as per fuel [3]

Additionally, in 2008 a modification was introduced to the Chilean Electricity Law in order to encourage the entry of Non-conventional Renewable Energy (NCRE) into the electricity market. Two major undertakings have been launched for that purpose: improvement of the regulatory framework of the electricity market, and the implementation of direct support mechanisms for investment initiatives in NCRE.

Therefore in 2010, in despite of the shortage of natural gas from Argentina, SING was able to overcome the uncertainty of previous years and at the same time allowing significant displacement of Diesel and LNG fuel consumption. In 2010, SING will be remembered as the last year the system experienced supply crisis. Nowadays, Chile is an energy independent country; goal achieved due to the diversification of the energy matrix and promoting exploitation of the NCRE, such as Wind, Solar and Biomass.

In Argentina, the energy sector faced, and still faces today, an economic long-run mismatch between what the economy needs from the energy industry and what this industry can offer to the economy. In practice, this means a lack of investments in all energy subsectors since the end of 2001.

Consequently, domestic demand growth gradually absorbing installed capacity, including those investments originally committed to exportations. However, restrictions to exports were not enough to supply the domestic energy demand [5]. In 2004, Argentina restarted permanent importations from its neighboring countries of natural gas, fuel oil, and Diesel; as well as occasionally importing electricity from Brazil, Uruguay and Paraguay. During the last years, electricity transactions have been reduced more and more, but by 2013, Argentina still relies on these transactions to supply its demand, as it can be appreciated in Figure 2.

(GWh)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Import	Brazil	0	0	0	0	0	0	0	0	0	0	0	0	1
	Paraguay	12	11	12	9	12	11	7	12	10	12	13	14	135
	Uruguay	1	0	1	2	0	0	5	0	1	0	149	47	206
	TOTAL	**13**	**12**	**13**	**11**	**12**	**11**	**13**	**12**	**11**	**12**	**161**	**62**	**342**

Figure 2 – Energy imported by Argentina on 2013

1.2.Problem Description

The international agreements, established on 1997, for exporting LNG from Argentina to Chile, had also the infrastructure implication of installing and commissioning, in 1999, a combined cycle power plant in the Argentinian province of Salta, owned by the company AES GENER. The plant has two gas turbines and one steam turbine, counting all together for a total capacity of 642.8 MW. The electric gross generation of this plant was completely dedicated to Chile through a new 345 kV transmission line interconnecting Cobos substation in Argentina, and Andes substation in Chile. The connection was established first with the two gas turbines, one year later in 2000, the steam turbine joined SING´s generating system.

There was never the intention to establish energy flows between the Interconnected Argentinian System (SADI) and the SING, since the connection of the new plant to SADI was not foreseen at any time. However, in 2007, a project that made feasible to first connect the steam turbine to SADI, was carried out. Progressively, as consequence of the LNG restrictions and struggles to supply the electrical demand, the entire power plant was interconnected to SADI; which made also possible to electrically interconnect Northeast Argentinian System (NEA) with the Northwest Argentinian System (NOA). Since year 2012, the power flow between countries stopped completely and therefore the line was put out of service; operating condition that prevails nowadays.

Recently, there has been an increasing interest in restarting the operation of the transmission line, due to factors such as:

- Argentinian need of constantly import energy to supply its demand
- Utilization of expensive generation units, based on Diesel and Fuel oil, in the north of Argentina
- SING has a significant gap between its peak demand and installed capacity, which means the system has surplus opportunities to export energy to SADI.
- Expectations in having a more stable LNG future panorama in Chile, which would make possible to switch on LNG generation units; that at the moment are considered as idle capacity, hence not injecting any power into the system
- Multiple NCRE projects, particularly Wind and Solar, currently under development in SING
- Minimum infrastructure investment due to the already existent assets

Starting up the operation of the transmission line, in order to establish power transactions between both countries, requires the involvement of many energy market players like: system operators, transmission operators, energy policy makers, generation companies, consumers and governmental entities.

Corporations willing to enter or expand their presence in the market, have also an important role, as they need to assess the business opportunities for investment and development of new projects. That is the case of SoWiTec group which is a German wind power developer leader in Latin America, being active in countries like Brazil, Argentina, Chile, Mexico, Peru, Uruguay and Colombia. SoWiTec covers all areas of wind power development: Planning and design, including wind measurements and calculations of energy yields and wind farm profitability; project construction management; sales and financing; as well as technical and commercial management of operating wind farms.

SowiTec´s subsidiaries in Chile and Argentina are highly active in developing wind projects. For instance, the first large scale wind park connected to SING in 2013 was developed by SoWiTec Chile. This project is called Valle de los Vientos and has an installed capacity of 90 MW.

SoWiTec´s intensive activity in developing renewable energy projects, together with the possible upcoming interconnection of SING and SADI, pointed out the relevance to dedicate deeper analysis to this situation, by assessing the impact and capabilities of transmitting power from Chile to Argentina, while considering current under-development wind projects that SoWiTec has in Chile.

As it will be further stated in this work; Chilean situation in terms of incentives to NCRE, could be seen as more steady and mature than the one of its Argentinian counterpart. Therefore, considering also the factors mentioned before in this section, it does make acceptable to limit the scopes of this assessment to the scenario of transmitting power in the direction, Chile to Argentina.

The evaluation, to be presented in this work, requires paying attention to technical and commercial aspects in order to have a good insight.

The technical part will be focused in presenting the feasibility to export electrical power from Chile to Argentina, by assessing the capabilities of the existing 345 kV transmission line which interconnects both countries. Notable attention will be given to wind power generation at SING due to SoWiTec´s projects, but also considering that the exported capacity to Argentina might come from other renewables such as solar power or even from an improvement of the LNG availability condition.

Powerful simulation tools are nowadays available, permitting to integrate the electrical parameters of the power system´s infrastructure; such as transformers, lines, loads and generators; thus, load flows in steady-state can be used to:

- Quantify power flows in the line during different transmission volumes
- Determine possible needed reinforcements/adjustments for further integration of wind energy and,
- Analyze the reactive power linked to each operation condition of the line, which could lead to voltage complications

The commercial issue is related to the economic policy framework that would be possibly used to govern and rule this energy transaction. During the past years of the transmission line´s operation, the flow from Argentina to Chile was never considered as a crossed border transaction; therefore, Chile does not have the legal and commercial procedures for neither import nor export electrical energy. For this reason, it is important for SoWiTec to have clearer perspective of how the transaction would be commercially managed as well as the agents to be involved.

Finally, the technical and commercial aspects, included in this work, intent to help not only the private sector to understand this new condition, but also looks forward to support the growing interest from authorities of both countries to find mechanisms to use existing infrastructure and increase mutually beneficial cooperation between the two power systems.

1.3.Research Objectives and Questions

As it was mentioned in the previous section, the current work has both technical and commercial aspects. Therefore, the objectives are pointing on these two directions which at the same time are compatible and complement each other. Moreover, these objectives will aim to be of relevance in having an understanding of the technical viability to operate the transmission line with exporting purposes, which at the same time will help to further define SoWiTec´s commercial strategy towards its renewable project developments in Chile and Argentina.

The first objective is to assess the technical feasibility for transmitting electrical power from Chile. This will be done, not only by stressing the transmission line until reaching its maximum thermal capacity in steady-state, but also by defining surplus generation scenarios, including different levels of NCRE penetration together with conventional resources.

The fulfillment of this objective will allow knowing the impact on the related infrastructure and in some other areas of the working networks. Additionally, it will permit to estimate if the employment of the nominal transmission capacity of the line is technically and operationally achievable from a steady-state approach. An analysis of these aspects is necessary in order to enhance and secure the reliability of both Chilean and Argentinian power systems working together.

The second main objective is to gain comprehension regarding the commercial structure that the transaction will probably have. Due to the magnitude of the project, as well as all the decision makers involved, it has to be clear that there are currently several alternatives being considered. Therefore, the target of this work is not to give an ultimate or final resolution, but to gather information of how the commercial panorama looks like; in addition to document the most important economic parameters being analyzed; hence describe the path, this issue, will most likely take until reaching an approved and valid scheme.

The expected outcome of this second objective is to aid companies, such as SoWiTec, in understanding the apparent future path to draw relevant conclusions for their investment decision, along with their interaction and position within this new scenario.

The research questions that aim to provide an answer to the main objectives are now outlined, along with the sub questions that will guide and set the boundaries of the current research.

1. When interconnecting SING and SADI, is the 345 kV transmission line technically capable to export surplus power being generated in Chile in order to supply Argentinian demand?
    a) From a steady-state point of view, is it feasible to use the entire transmission capacity of the line (thermal limit), without compromising the reliability of the power systems?
    b) Considering SoWitec´s wind projects under development at SING, what is the NCRE integration implication in the transferring flows within the line and the effect of them over the rest of the systems?
    c) What is the reactive power performance of the transmission line?
    d) Are the voltage levels kept under permissible limits according to the technical policies on each country, or what would be the necessary reinforcements/adjustments to secure this?
    e) One common practice when analyzing power systems with simulation tools is to balance the power flows through a reference machine. What would be the advantage of using a distributed slack approach instead?
    f) The power transfer between countries implies changes in the Argentinian dispatch, as consequence, expensive Diesel units would be switched off. Will the voltage and reactive power changes in the infrastructure be reflected at a local or system level?

2. What would be a reasonable scheme, by means of an economic policy-framework, to govern and rule the energy transaction between these two countries?
    a) What does Chile has to implement in its commercial power market policies to initiate this project?

b) Could the framework have similar structure as the on-going cases that Argentina currently holds with its neighboring countries?

c) What would be the considerations in order to make profitable this future scenario for the energy players involved?

1.4.Research Approach and Method

This research takes a technical-commercial approach for providing answers to the questions here stated. DigSilent Power Factory version 15.1.2 (DSPF), a computer aided engineering tool for the analysis of industrial, utility and commercial electrical power systems, will be used for the technical part. The next points describe concisely the methodology to be followed:

- Get from SoWiTec´s database the complete steady-state DSPF models of the Chilean and Argentinian networks
- Get familiarized with the structure, parameters, operation conditions and single line diagrams included in the models
- Merge the models into a single project, to afterwards proceed with the interconnection through the 345 kV transmission line
- Set as base cases when Chile and Argentina are operating separately, as well as when null transferring occurs while the interconnection is established but without modifying dispatches
- Select wind projects from the company´s pipeline and define operation scenarios, together with SoWiTec´s specialists
- Get familiarized with the wind projects and their technical characteristics in order to delimit wind scopes
- Define wind park models in DSPF and ways of representing the fluctuating behavior of the wind resource
- Load flows[1] in steady-state to quantify the available transmission capacity and impacts on the interconnected SING-SADI system
- Monitor selected nodes of the transmission line´s related infrastructure as well as nodes where wind power is being added.
- Obtain simulations´ load flow results such as voltage levels, overloading and losses
- Analyze and document active and reactive power flows in the transmission line between Chile and Argentina

[1] This is the terminology adopted according to literature review and also in DigSilent Power Factory User Manual; however Power Flow is also commonly used.

- Implement changes, adjustments and solutions to the models in order overcome possible problems in the electrical permissible levels
- Compare scenarios and state most representative results

The commercial method to attack the subject, analyze the current market measures, strategies to export and ideas surrounding this matter would be highly executed in a more person-to-person manner. Consequently, meetings, interviews, conference calls and email communications will be scheduled with some of the most relevant players taking part of this decision; such as the Ministry of Energy from each country, system and commercial operators and electrical infrastructure owners. Additionally, not only for the technical but also for the commercial part, relevant scientific literature is thoroughly studied.

1.5.Thesis Outline

This thesis consists of six parts:

Chapter 1 Introduction – this chapter – provides an overview of the developed work.
Chapter 2 Technical Theory and commercial framework serves as literature review for understanding the theory intended for load-flows analysis and influences in the infrastructure, it will set the background to improve the commercial framework.
Chapter 3 Network Descriptions and Modelling introduces the characteristics and components of the Chilean and Argentinian networks; it describes how the systems, once interconnected, are to be modeled in DSPF. It also indicates the relevant technical parameters to take into account.
Chapter 4 Technical Simulation Scenarios and Results will explain the milestones of each operation scenario simulated in DSPF. Solutions and main outcomes from the load flow simulations are also stated in this chapter.
Chapter 5 Analysis of Commercial feasibility intends to combine the most relevant arguments of the commercial framework given in Chapter 2 with the main ideas obtained through the person-to-person approach in order to describe the most probable and suitable framework to manage the transaction.
Chapter 6 Conclusions & Further Work presents a summary of the answers of the research questions as well as conclusions derived from the research. This chapter also includes recommendations for further work.

Chapter 2

2. Technical Theory and Commercial Framework

2.1. Technical background

2.1.1. Load flow Calculation

An important tool for the planning of electrical power systems is the load flow calculation. The main goal is to determine significant parameters of the power system for normal operation and under emergency conditions, for example:

- Voltage magnitudes and phase angles at substations and busbars
- Currents and/or active and reactive power flow on overhead lines, cables and through transformers, as well as the resultant loading
- Active and reactive power losses of power equipment
- Exchange of active and reactive power between power systems
- Balance of generation and load
- Required voltage control of transformers and generators
- Reactive power compensation needs at busbars, made available by generators or other compensation equipment

Assuming symmetrical three-phase operation is generally adequate; the following equations can be stated as the basic expression in which the load flow calculation is based:

$$\overline{\boldsymbol{Y}} = \frac{\overline{\boldsymbol{I}}}{\overline{\boldsymbol{U}}} \quad (2\text{-}1)$$

$$\overline{\boldsymbol{S}} = \sqrt{\boldsymbol{3}} \cdot \overline{\boldsymbol{U}} \cdot \overline{\boldsymbol{I}}^{*} \quad (2\text{-}2)$$

On the basis of admittance Y and power S, the voltages are calculated at given in-feed power and/or load at the busbars. If the current I is substituted in equation (2-2) by equation (2-1), then nonlinear-quadratic equations are obtained; mathematical procedures such as the Newton-Raphson method are available to give solution. It is not within the scopes of this work to explain in detail such a method, although is important to mention that DSPF makes use of this method to solve the load-flow.

Nodes are defined as PQ when the voltages at the busbar are calculated for given active power P and reactive power Q. If the node is defined as PV, then the voltage U at the node is kept constant with given active power and the reactive power Q, needed to maintain the voltage, is calculated.

Loads in the power system can be defined as constant impedance, where its active and reactive parts must be defined; or as constant current which requires as input data the current and the power factor. Normally, for load-flow calculation in high-voltage transmission systems, the load is assumed as constant power with active and reactive parts.

For the balance of active and reactive power, normally a common practice is to define a balance node called slack bus. The differences of the summarized losses, loads and in-feeds, are balanced at the slack and it has to be ensured that it can actually feed or absorb the calculated balance as generation or load. A load flow study for a system under actual or normal operating conditions is called a base case. The results from the base case constitute a benchmark for comparison of changes in network flows and voltages under different operation scenarios or contingency conditions.

A load flow calculation is stated to be steady-state analysis because it reflects the system conditions for a certain point in time, such as for instance at maximum demand; therefore defined as a condition in which all the variables and parameters are assumed to be constant during the period of observation.

2.1.2. Transmission capabilities in long lines

For the purposes of this work, a simple model will be used to facilitate the understanding of active and reactive power transmission, as they highly depend on the voltage magnitude and angles at the sending and receiving ends. In Figure 3, synchronous machines are indicated at both ends; the voltages are assumed to be fixed and can be interpreted as points in large systems where voltages are stiff or secure. The sending and receiving ends are connected by an equivalent reactance including series resistance and reactance as well as shunt conductance and susceptance.

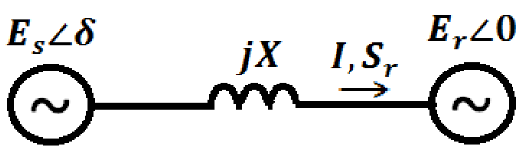


Figure 3 – Basic Model for calculation of active and reactive power transmission

The following relations can be calculated for the receiving end:

$$P_r = \frac{E_s E_r}{X} \sin\delta = P_{max} \sin\delta \quad (2\text{-}3)$$

$$Q_r = \frac{E_s E_r \cos\delta - E_r^2}{X} \quad (2\text{-}4)$$

Similarly for the sending end:

$$P_s = \frac{E_s E_r}{X} \sin\delta = P_{max} \sin\delta \quad (2\text{-}5)$$

$$Q_s = \frac{E_s^2 - E_s E_r \cos\delta}{X} \quad (2\text{-}6)$$

The relation for active power are the same as the line is being treated as a lossless system where the maximum power transfer is at a power angle δ equal to 90°, however this angle can be considered as nominal as the real maximum power occurs at a different angle when including losses or resistive shunt loads. From equations 2-3 and 2-5, it can be clearly seen that active power transfer depends mainly on the power angle.

In the case of the reactive power, it is possible to approximate equations 2-4 and 2-6 for small angles by using $\cos\theta \cong 1$:

$$Q_r = \frac{E_r(E_s - E_r)}{X} \quad (2\text{-}7)$$

$$Q_s = \frac{E_s(E_s - E_r)}{X} \quad (2\text{-}8)$$

Therefore, from expressions 2-7 and 2-8, it can be stated that reactive power transmission depends mainly on voltage magnitudes and it flows from the highest voltage to the lowest voltage. Minimize transfer of reactive power is crucial as it cannot be transmitted across large power angles (due to long lines and high real power transfers) even with substantial voltage magnitude gradients.

Losses are also fundamental when talking about transmission capabilities in long lines; the losses across the series impedance of a transmission line are resistive (I^2R) and reactive (I^2X), in which for I^2, the following can be stated:

$$I^2 = \bar{I} \cdot \bar{I}^* = \left[\frac{P - jQ}{\bar{V}^*}\right]\left[\frac{P + jQ}{\bar{V}}\right] = \frac{P^2 + Q^2}{V^2} \quad (2\text{-}9)$$

Therefore,

$$P_{loss} = I^2R = \frac{P^2+Q^2}{V^2}R \quad \text{(2-10)}$$

$$Q_{loss} = I^2X = \frac{P^2+Q^2}{V^2}X \quad \text{(2-11)}$$

As it can be appreciated from equations 2-10 and 2-11, to minimize losses, reactive power transfer must be also minimized and voltages need to be kept high, hence voltage stability in the line will be maintained.

Transmission lines both produce and consume reactive power, the net values must be either absorbed or generated by the system at each line terminal; this can be summarized as follows:

- Line shunt capacitance → Produces reactive power = $\mathbf{V^2B}$ (B=ωC, line shunt susceptance) → Relatively constant as voltage must be kept within +/-5% of the nominal value
- Line series inductance → Consumes reactive power = $\mathbf{I^2X}$ (X=ωL, line series reactance) → Varies as the currents changes from heavy to light load periods

The loading where reactive power production equals consumption is known as surge impedance loading (SIL), so by setting $\mathbf{V^2B = I^2X}$, and solve for the surge or characteristic impedance:

$$Z_0 = \frac{V}{I} = \sqrt{\frac{X}{B}} = \sqrt{\frac{L}{C}} \quad \text{(2-12)}$$

and consequently the SIL is defined as the power delivered at rated voltage to a load impedance equal to Z_0, which besides representing the ideal loading where reactive power production and consumption are equal; additionally the voltage and current profiles are uniform along the line:

$$P_{SIL} = \frac{V^2}{Z_0} \quad \text{2-13}$$

The approach to obtain expression 2-12 is considering a typical high-voltage lossless line transmission line, as the one depicted in Figure 3, where conductance and resistance are neglected.

2.1.3. Voltage stability and reactive power compensation

Voltage stability results in progressive voltage decrease or increase and it has often been viewed as a steady state viability problem suitable for load flow analysis. The ability to transfer reactive power from production sources to consumption sinks during steady operating conditions is a major aspect of voltage stability **[6]**. However, the network maximum power transfer limit is not necessarily the voltage stability limit, as this last term indeed involves dynamic processes which are out of the scope of this work, thus this section will be limited to talk about reactive power compensation.

Reactive power compensation is often the most effective way to improve both power transfer capability and voltage stability; the most common forms are series capacitors banks, shunt reactors and capacitors, static var compensators and tap changing of transformers. The 345 kV line between Chile and Argentina is equipped with series capacitor bank in the Chilean side and shunt reactors at both ends, thus the background here presented will be focused on these two technologies.

In general, increased reactive power generation due to high capacitance causes problems at light loads and usually long transmission lines need shunt reactor compensation; however, the reactors are sometimes switched off during heavy load.

Series capacitor compensation has traditionally been associated with long transmission lines; however, nowadays it is also applied on shorter lines to improve voltage stability. Series compensation reduces net transmission line inductive reactance, meaning that the reactive generation (I^2X_C) compensates for the reactive consumption (I^2X) of the transmission line. The reactive generation increases with the current squared, thus compensating when most needed; this can be seen as a self-regulation property. On the other hand, at light load, series capacitors have little effect.

Series capacitors are almost always in transmission lines, rather than within a substation bus arrangement. They may be at line terminals or at intermediate points along the line. For very long lines, they are located at line terminals unless developed substations are available along the path. Moreover, since the reactive power rating and the cost of series compensation is proportional to the current squared, advantage is taken of short-time overload capability. Standards allow overload current of 135% for thirty minutes and 150% for five minutes. Therefore, the time-overload capability allows time for operators to reschedule generation, bring gas turbines online, or shed load **[6]**.

Shunt compensation involves the use of shunt capacitors during peak load conditions to generate lagging VARs at the receiving end and shunt reactors during off peak conditions to absorb line generated VARs to avoid voltage instability. Capacitor banks supply part of or full reactive power of load, thus reducing magnitude of the source current necessary to supply load. Consequently, the voltage drop between the sending end and the load gets reduced, power factor will be improved and increased active power output will be available from the source [7]. Reactors are discrete devices designed to absorb a specific amount of reactive power at a specific voltage, today shunt reactors are fundamental compensation used on high voltage lines; mainly used to keep the voltage rises down during light or no-load conditions, thus compensate for the unwanted voltage effects due to the line capacitance.

By applying both series and shunt compensation to long lines, transmission of large amounts of power efficiently and within the desired voltage constraints can be achieved. Ideally, the series and shunt elements should be placed at intervals along the line; series capacitors can be bypassed and shunt reactors can be switched off when desirable [8].

2.1.4. Distributed Slack

As mentioned in section 2.1.1, the conventional approach in load flow calculations consists assigning a slack generator, which will establish the power balance within the system. Besides this traditional approach, DSPF offers the option of balancing considering the participation of all synchronous generators according to their scheduled active power, which by purposes of this work will be referred as Distributed Slack.

During the load flow calculation in DSPF, balancing by reference machine means that all generators operate with its active power set-point. If the generators are set as PQ, P and Q are fixed; likewise, if the generator is set as PV, Q will be calculated according to the voltage set-point. Furthermore, the slack or reference machine (external grid or synchronous machine) will be adapted, it will feed or absorb the power; only P and Q of the reference machine are changed (or Q of the synchronous machines if set as PV). The active power set-points of other generation units stay as given in the dispatch load flow settings of the element.

On the other hand, as all machines take part in the control in the distributed slack method, P is not fixed for the generation units; hence, P for every single unit will be adapted according to the system´s operation requirements. In DSPF, the option distributed slack only refers to P; therefore, the Q balancing will still be covered in a big share by the reference machine.

In the actual operation of electric power systems there is no single slack bus, instead there are many generators distributed geographically throughout the system which take on the function of a slack bus. To account for this, a distributed slack bus power flow analysis is needed.

In case of having several synchronous machines in a large system, just as in the case of interconnecting SING and SADI, the distributed slack by generation will be more realistic as the synchronous machines will change their operating points instead of keeping them in a fixed position.

2.1.5. Wind power integration and general technical challenges

Integration of large scale wind power may have severe impacts on the power system operation; therefore, attention has been increased on wind farm performance in power systems. Consequently, steady and dynamic requirements that wind turbines must meet in order to be connected to the grid, have been developed. Examples on such requirements are capabilities of contributing to frequency and voltage control by continuous modulation of active power and reactive power supplied to the transmission system, as well as the power regulation rate that a wind farm must provide.

Technical constraints of power generation integration in a power system may in general be associated with the thermal limit, frequency and voltage control, and stability. Wind turbines may be connected to AC system at various voltage levels, including the low, medium or high voltage systems; the suitable voltage level depends on the amount of power generated.

Some of the most relevant technical challenges to overcome when interconnecting wind power to the grid are voltage variations and harmonics, which are concisely explained in this section.

- Voltage variations

On the local level, voltage variations are the main problem associated with wind power. This can be the limiting factor on the amount of wind power which can be installed. In normal operational condition, the voltage quality of a wind turbine or a group of wind turbines may be assessed in terms of the following parameters:

    - Steady-state voltage under continuous production of power

        - The voltage at the point of common coupling (PCC) should be maintained within utility regulatory limits as operation of wind turbines may affect the voltage in the connected network. It is recommended that load flow analyses be conducted to assess this effect to ensure that the wind turbine installation does not bring the magnitude of the voltage outside the required limits.
    - Voltage fluctuations
        - Fluctuations in the system voltage may cause perceptible disturbances depending on the magnitude and frequency of the fluctuation. This type of disturbance is called voltage flicker. There are two types of flicker emissions associated with wind turbines, the flicker emission during continuous operation and the flicker emission due to generator and capacitor switching. The allowable flicker limits are generally established by individual utilities.

As it was explained before, reactive power is one of the major causes of voltage instability in the network, due to the associated voltage drops in the transmission lines and losses contribution. In the case of wind farms, locally installed capacitor banks may compensate the reactive power demand in case of using wind turbines equipped with induction generators. For wind turbines with self-commutated power electronic systems, the reactive power can be controlled to minimize losses and to increase voltage stability; thus, these wind turbines can have a power factor of 1.00, as well as have the possibility to control voltage by controlling the reactive power.

- Harmonics

Harmonic disturbances are a phenomenon associated with the distortion of the fundamental sine wave, and are produced by non-linearity of electrical equipment. Harmonics causes increased currents, power losses and possible destructive overheating in equipment; they may also be the problem source in communication circuits [9].

2.2.Commercial Background

2.2.1. Overview of Chilean Electrical System (SING)

The Chilean system consists of three segments: generation, transmission and distribution. It is formed by four isolated systems; however, two of these represent the major grids:

- SIC supplies the central zone of Chile with length extension of approximately 2.100 km. It represents 71% of Chile's total installed capacity, and supplies electricity to almost 90% of the population.
- SING supplies the northern zone of Chile. It roughly represents 28% of Chile's total installed capacity, but only supplies electricity to 5.8% of the population.

The 345 kV transmission line between Chile and Argentina, connects SADI to Chile, but only to SING. Therefore, as long as SING and SIC remain separated, then this future interconnection won't have operational nor direct commercial effects at SIC. Subsequently, SING will be the core focus of this study.

SING is a power system with special characteristics and behaviors; almost dominated by a thermal generation matrix, generation units concentrated and remote from consumption centers, high percentage of industrial demand (mining) and a secondary manual frequency control, are some of the features that makes the system peculiar. Moreover, it is important to mention that the nominal frequency in Chile is 50 Hz.

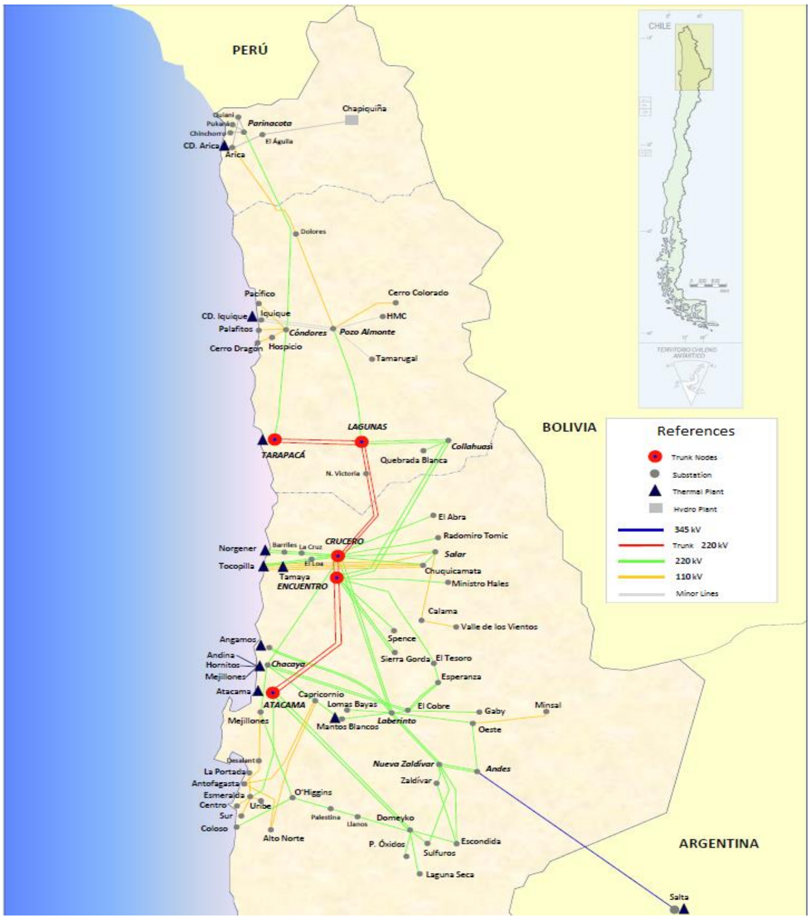


Figure 4 – SING Simplified Diagram

Generation Installed Capacity	4,607.4 MW
Maximum Demand	2232 MW
66 kV Transmission Lines	398 km
69 kV Transmission Lines	278 km
100 kV Transmission Lines	80 km
110 kV Transmission Lines	1,357 km
220 kV Transmission Lines	5,238 km
345 kV Transmission Lines	408 km

Table - 1: SING Main Infrastructure Overview, Data 2014

Regarding the transmission system, three segments are defined at SING: trunk, sub-transmission and additional systems. Trunk system assets are those essential for competition in the energy market and are integrated by facilities over 220 kV, economically efficient and necessary to supply the total demand. Sub-transmission system assets facilitate access to consumers, with regulated and non-regulated prices (clients of capacity equal or higher than 2 MW). **Additional transmission systems assets are those exclusively dedicated either to non-regulated price consumers or to connect power plants to the system [10]**; transport in these systems is ruled by private contracts between parties and their expansions are negotiated also between owner-user. Currently, **the line between Chile and Argentina corresponds to this last segment**.

Distribution systems are comprised of lines, substations and equipment that enable the distribution of electricity to end-users. Distribution companies operate under a concession system for public distribution services, with a service obligation and regulated tariffs for the supply of regulated customers. High voltage distribution operates in different ranges, between 400 V and 23 kV. On the other hand, low voltage distribution networks operate at 220/380 V.

2.2.2. Overview of Argentinian Electrical System (SADI)

SADI is also formed by generation, transmission and distribution. Generation occurs in a competitive and mostly liberalized market in which 75% of the generation capacity is owned by private utilities. The generators are divided into eight regions: Cuyo, Comahue, NOA, Center, Buenos Aires/Gran Buenos Aires, Litoral, NEA and Patagonia.

Thermal plants fueled by natural gas are the leading source of electricity generation. Argentina generates electricity using thermal power plants based on fossil fuels (54%), hydroelectric plants (41%), and nuclear plants (4%). Residential consumption accounted for 29% of the total, while industrial represents the 43% and commercial-public represents 26%.

Due to the complexity and size of SADI, Figure 5 on the left illustrates only the high voltage main transmission system (500 kV), on the right it depicts the sections in which the whole system is divided.

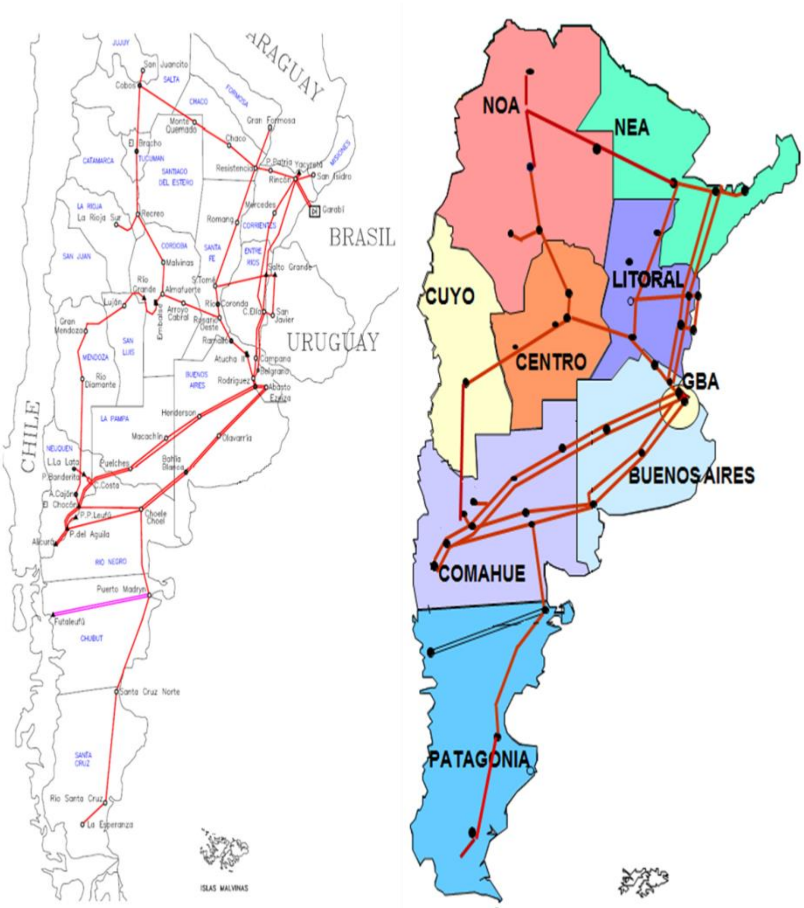


Figure 5 – SADI High Voltage System and subdivisions

Generation Installed Capacity	31,000 MW
Maximum Demand	25,450 MW
132 kV Transmission Lines	27,730 km
220 kV Transmission Lines	2,835 km
330 kV Transmission Lines	1,120 km
500 kV Transmission Lines	14,000 km

Table - 2: SADI Main Infrastructure Overview, Data 2014

The transmission and distribution sectors are highly regulated and less competitive than generation. There are ten transmission companies, nine regionals uncharged of electric transmission within a particular zone and one operating the national electricity transmission grid (Transener) under a long-term agreement with the Argentine government, which included all the 500 kV lines as well as some of 220 kV. In the distribution sector, three private companies dominate the market with 75%.

2.2.3. International exchanges in South America

Electrical interconnections with neighboring countries, under certain conditions, can be a relevant contribution to the security of energy supply and for the price equilibrium. However, it should be seriously considered as preventing energy dependence, because it might compromise the security of supply in the long term. Nevertheless, from an economic and energy security point of view international exchanges can be attractive.

The first approach to achieve energy exchanges between countries in South America was the joint exploitation of hydropower resources in neighboring rivers. It is the case of the Uruguay River between Argentina and Uruguay, the Parana River between Paraguay and Argentina and between Brazil and Paraguay. These projects, which finally culminated in what are now binational dams, were the first important milestones of regional energy integration, providing significant benefits to the electricity sectors of the countries involved. Additionally, contributed decisively to the development of an infrastructure for electricity transmission and constituted the starting point to begin to generate significant experience of relationship between national system operators.

In South America neighboring countries, there is a huge potential of energy resources in the form of fossil, hydro or NCRE sources, which could be used to export electric generation; however, today´s limitations to exchange these resources between countries at the technical level are the lack of installed generating and transmission capacity to accomplish it. Therefore, to realize any initiative would require significant investments in both segments.

At the moment there are many countries in the region with bilateral energy transaction agreements, due to the potential benefits to be gained by interconnecting their electrical systems, such as: take advantage of complementarities, exploiting differences in time zones (shift in peak demand of systems) and seasonal climate, diversification of the energy mix, more efficient use of electricity infrastructure, enable better utilization of generation resources, support in emergencies or crises, and improving the reliability and quality of supply [11].

In the case of Argentina and Chile, in addition to the possible option of restarting operation of the 345 kV transmission line focused of this work, Argentina sustains commercial relations with Brazil, Paraguay and Uruguay. On the other hand, in Chile, some alternatives are being studied, such as geothermic projects with Bolivia and electrical interconnection with Peru.

There is a significant potential for exchanging energy resources, as measured in gross terms, there is demand, there are potential resources, the necessary technology exists to make compatible the electrical systems, and there are stakeholders interested on both sides of the borders; all this would theoretically support the conformation of mutually attractive prices.

Due to the strategic nature of the electrical service and aspects involving issues of sovereignty, the sought for electrical systems reaching the highest degree of self-sufficiency in the supply by avoiding a significant dependence on other countries, had to be taken always as priority. Nonetheless, this was not always the case, and problems such as the gas shortage from Argentina to Chile occurred.

At some point, several projects of electricity and gas interconnection, that enabled the realization of energy exchanges at regional level materialized. Among others, Argentina exported electricity and gas to Brazil, Chile and Uruguay, Colombia and Peru exporting electrical energy to Ecuador, Central America with firm and opportunity electricity exchanges, and Bolivia exporting gas to Brazil and Argentina.

It was foreseen and argued that a breach of contractual conditions, shortages or rising future energy resources, could affect national interests; not exclusively private, hurting the integration process. For this reason, it is also necessary to mention the actual existing obstacles that are not technical or economic, but political, institutional and regulatory. In fact, the main barrier existing today to advance in new electric integration initiatives has to do with the will, the safety-regulatory framework and political stability required. Figure 6 shows some of the most important electrical interconnections between countries in South America together with the one of interest for this work, between Chile and Argentina.

Figure 6 – Relevant electrical interconnection in South American countries

2.2.4. Incentives for large scale Renewables in Chile

In Chile, the concept NCRE refers to electricity generated using renewable non-conventional generators, which use as primary source of energy biomass, geothermal, marine, solar, wind and hydraulic energy lower than 20MW.

On March 2008, Law 20.257 was enacted and established that at least 5% of power traders´ withdraw electricity to supply consumers must come from NCRE, either self-produced or bought from other generators; this last option is known as NCRE attribute. The law applied to contracts signed after August 1, 2007 and the percentage should increase 0.5% each year from 2015 until reaching 10% in 2024.

At the moment, there are about 300 MW of wind energy installed in Chile; this technology had a high growth especially between 2008 and 2009, following the enactment of Law 20.257. Considering the projects currently under construction, is expected that in coming years wind power can become the technology with more installed capacity, and solar power increasingly could have a greater weight in the energy matrix.

Wind projects led the unbuilt project portfolio in Chile until 2012; by October 2013, solar initiatives have surpassed wind, accounting for 57% of the portfolio compared to 38% of wind projects **[12]**.

From August 2011 the required obligation of Law 20.257 was exceeded, reaching by August 2013 already more than 8% of the NCRE injections. Therefore, in October 2013 the Law 20.698 set a new obligation of NCRE penetration applying to new supply contracts; establishing a quota of 6% in 2014, which increases reaching 20% in 2025.

Another incentive introduced is the existence of public tenders conducted by the Ministry of Energy, in which the energy blocks needed to meet the requirement are to be tendered, with a maximum of two calls a year. For this, a special payment scheme is provided in order to promote stability in the flow of income for NCRE projects.

2.2.5. Incentives for large scale Renewable in Argentina

There have been couples of attempts to boost the renewable energy industry in Argentina; incentives such as creating laws to reach certain amount of green energy penetration, tenders organized by the government and even the implementation of a feed-in-tariff system were executed. However, due to delays in the regulatory framework, lack of economic stability involving high risks for investors, as well as low electricity price, have made difficult to build up a feasible financial/policy environment for renewables.

In 2005 the “Strategic Wind Energy National Plan” was published in which main objectives were to promote the development of wind energy infrastructure for the country´s electricity generation, elaboration of a wind energy resource map and installation of 300 MW by 2012.

At the legislative level, the most important change came in December 2006 from the hand of the Law 26.190 "National Development Scheme for the Use of Renewable Sources of Aimed to Energy Electricity Production". Even though, Law 25.019 (1998), "National System of Wind and Solar Energy" and a series of regional laws supporting the generation of energy through renewable sources were already established and valid, the compensation provided in such instruments were insufficient as incentives.

It was only with the Law 26.190 that a clear public policy guideline was set to diversify the current energy mix from renewables. It declared of national interest the generation of electricity, destined for public service, delivered through the use of renewable sources; and set the aim of 8% contribution in the national electricity consumption in ten years; this implied reaching the target in 2016.

Law 26.190 also defined a feed-in-tariff according to the type of renewable energy generating and some other benefits as accelerated depreciation and VAT exemption. Despite the fact that the law was based in one of the worldwide most successful schemes such as the feed-in-tariff, the system failed in Argentina. Law´s regulation came almost three years late and the low premium due to the feed-in-tariff, are some reasons for its miscarriage.

Finally, in May 2009 the Ministry of Federal Planning launched the Renewable Energy Generation Program (GENREN) in which the public utility ENARSA implemented tenders for a total of 1000 MW of electricity to be produced from renewable sources and having fix contracts for 15 years. 500 MW were tendered for wind energy, 1000 MW were received as proposed projects and in July 2010, 754 MW were awarded **[13]**. What could have been more than 4% of renewable energy generation for the country (more than half the 8% target), it ended up being only less that 3%. However, payments for renewable energy generation that would arise from the program, continue to contribute at a rate that is only representative and do not have the weight to encourage investment that would drive a real large-scale change of the energy matrix.

2.2.6. Commercialization Schemes in Chilean Electrical Market

The Chilean electricity sector is closely linked to different public and private sector institutions. These institutions and market agents may inter-relate through coordination, direct dependency, contractual, property or binding relationships, among others. The stakeholders are: Governmental Institutions, Customers, System Operators, Generators, Transmission System Operators (TSO), and Distributors.

The main governmental institutions linked to the Chilean electricity sector are:

- Ministry of Energy (ME)
- National Energy Commission (CNE)
- Superintendency of Electricity and Fuels (SEC)
- National Environmental Commission (CONAMA)

The decision as what are the technologies to develop essentially relies in the private capital investment evaluation. The government is solely limited to generate the conditions so that it is possible to reach economic efficiency; thus, the government through its institutions influence the sector mainly by regulation functions, control, of indicative expansion planning for generation and compulsory for trunk transmission, as well as to the fixation of the electrical tariffs for regulated clients; which lately have been also influenced by the tendering process in distribution.

Electricity consumption in Chile is grouped into two main segments: regulated customers and non-regulated customers. The regulated customer is the one that pays a tariff defined by the authority, calculated on the basis of an ideal distribution company operating efficiently and at a purchase price paid by the distribution company. The term non-regulated customer ("free client") is applied to customers that consume electricity over a specific minimum level and freely agree prices with their suppliers; these are usually industrial users or mining companies, which in SING represent about 90% of the costumers [4].

Economic Load Dispatch Centers (CDEC) are private organizations in charge of coordinating the operation of the electrical system; therefore, they play a very important role as system operators. Each interconnected system possesses its own CDEC; hence CDEC-SING is responsible for:

- Preserving the overall security of the electricity system
- Ensuring the most economic operation of all electricity system installations
- Ensuring open access to the transmission systems
- Determining marginal costs of energy and economic transfers between CDEC members

In the generation segment a competitive system has been established based on marginal cost pricing, which is the cost of the system of providing an additional unit of electricity; while the transmission (except in the additional systems) and distribution companies have regulated tariffs.

Agents in the generation market compete to supply power to consumers, operating under a short run marginal cost (SRMC) pool-dispatch regime, coordinated by CDEC-SING. Moreover, consumers pay a price for energy and a price for capacity (power) associated with peak demand hours. The system ensures that, whenever the structure of the pool of generators is adequate to meet demand, revenues from electricity sales at the marginal cost plus revenues from the sale of capacity at the cost of developing peak power, exactly cover investment and operational costs of producers.

The operation is characterized by the existence of a spot market, where the price of electricity represents the short-term marginal cost resulting from the instantaneous balance between supply and demand. The market is a mandatory pool type with audited generation costs and a wholesale (hourly) spot market restricted to generators. In other words, it is a short term electricity market where sellers offer prices and amounts of electricity in the pool, and generator units are dispatched to supply demand.

It is also available contract financial-type market with agreements freely decided between the parties, which are usually called Power Purchase Agreement (PPA). The contracts are of a financial nature because the CDEC-SING performs the physical dispatch hour by hour, based on the operational cost information provided by each generating unit. The contract market has the following characteristics:

- Generators can enter into contracts with distribution companies and non-regulated customers.
- The contracts with distribution companies can be established for the supply of regulated customers or for non-regulated customers.
- Supply and a purchase obligation are established at a predetermined price.
- Contracts are financial, hence generators always buy in the spot market to sell at the contract market, whether dispatched or not. The financial contract provides price stability to purchasers and sellers, in accordance with their expectations of the evolution of marginal costs.

Summarizing the existing schemes, for a large NCRE project (over 9 MW) to trade its energy in SING, are:

1. **Spot market** → Participation in the energy and power transfers in the spot market, where their energy injections are valued at marginal cost, while the power is valued at node price.

CDEC-SING will perform a monthly balance of energy and power transferred, in order to identify surplus and deficit companies; according to the energy injected by each generator, transfers between companies are weighted and settled.

2. **Spot and Contract market (PPA) →** Interaction with the Spot market, and simultaneously maintains a PPA with another generating company, a free client or a distributor. The PPA is secured by a bilateral negotiation between the companies with a selling price that can be fixed or variable. PPA must be reported to the CDEC-SING to be included in the monthly balance, thus energy consumed by the client will be deducted and multiplied by the marginal cost calculated for the consumption [12]. In the event that the generator is not capable to fulfill the PPA, it will be supplied by other generators through a spot market transaction between generators.

3. **Spot and Contract market with distributor (tender) →** Generator not only interacts with the spot market, but also maintain a contract with a distribution company supplying regulated customers. The contract price is set through a competitive bidding process through auctions; blocks of energy are presented to be supplied during a fixed period. Generators submit bids and the blocks of energy are assigned to the best offer submitted.

2.2.7. Commercialization Schemes in Argentinian Electrical Market

The Argentinian Electricity Sector is established on the basis of creating an electricity market (MEM), a system of pricing and a market administrator. Therefore, the electricity market in the SADI is managed by the MEM which operation is based in two aspects: supply by generation, transportation and distribution activities; and consumption represented by customers that according to their contracted power can buy directly to the MEM or from the distribution companies.

The main institutions and organizations involved in the MEM are the Energy Secretariat (SENER), responsible for policy setting, while the National Electricity Regulator (ENRE) is the independent entity within the Energy Secretariat responsible for applying the regulatory framework and overall supervision of the sector under federal control. CAMMESA (System Administrator Company of the Argentinian Electrical Market) main functions include the operation and dispatch of generation and price calculation in the spot market, the real-time operation of the electricity system and the administration of the commercial transactions in the MEM.

MEM ´s structure has the following main characteristics:

- Consumers are classified as Electricity Market Agents and end-users
- The state drops its entrepreneur role to become regulator
- Existence of a contract market and spot market for buying and selling energy
- Distributors acquire energy from the market at stabilized prices reviewed quarterly
- Generators can sell energy to the market through a scheduled spot price
- The generation required to supply the demand is set, based on the economic cost of the power system operation
- Spot prices are set marginally with the cost needed to meet demand´s next unit
- Transportation is paid by fixed connection charges and transport capacity, as well as considering variables depending on the losses and fault probability in the lines; being the total amount fixed
- MEM open to trade with neighboring countries, enabling the export or import of energy through contracts between private companies that meet the requirements of the regulatory framework

The tariff scheme in the spot market determines a market price (PM) at each hour, obtained at the load center of the electric system which is defined at the Gran Buenos Aires area. Afterwards, the PM is scaled via regional factors in order to assign the corresponded value to the different areas.

The generation cost is given by the operating cost, plus the cost of transportation from the connection node to the market. The generator also receives remuneration for the power available to the system; additional services such as frequency regulation and voltage control are also remunerated. Generators with any kind of contract sell their entire production to the spot market, perceiving ongoing rates. On the other hand, in the existence of a contract the generator hourly trades its generation, up to the agreed amount, following the contract market; when the generation is over or under contracted values, the differences are traded in the spot market.

The industrial customers are classified according to their power demand; Heavy users (GUMA) above 1 MW, Light users (GUME) between 30 kW – 2 MW, and Particular users (GUPA) between 30 kW – 100 kW. GUMA are of interest as they need to keep contracts with generators for at least 50% of their demand; the contracted demand will be traded in the contract market and the differences (missing or surplus) will be trade hourly in the spot market. GUME and GUPA need to agree contract for their entire demand **[14]**.

The commercial schemes available, to interconnect in SADI a large renewable energy project and trade its energy at MEM, are:

1. **Spot Market** → Energy is not subject to supply contracts, and the price of electricity is defined in terms of marginal cost representing the economic cost of generating the next kWh. Generation units are dispatched regardless existing demand contracts; as a result, deviations between the actual output of the generator and the agreed supply mount must be sold in the spot market.

2. **Contract Market (PPA)** → Freely supply contracts made between a generator and a distributor, or between generator and GUMA/GUME/GUPA. The limit for entering into a contract with a generator is the generator´s capacity itself.

3. **Contract Market (PPA) between MEM and generator** → Through the Secretary of Energy´s resolution 108/2011, renewable energy generators have priority of dispatching except when limitations on transmission capacity occur or when affecting the quality of service. The validity of the PPA is 15 years, where the generator´s offer has been approved by the Secretary of Energy and the buying part will be MEM, represented by CAMMESA **[15]**. The remuneration shall be determined on the basis of costs and revenues and has to be accepted by the Secretary of Energy; the average energy price which is currently being accepted is: USD$100 – USD$105 per MWh.

4. **Distributed Auto-Generator (PPA)** → Though the Secretary of Energy´s resolution 269/2008, a distributed auto-generator is a figure in the MEM, which plays the role of electrical consumer, and at the same time, also generates electricity. It has the particularity that the points of consumption and generation are at different connection nodes in SADI. The auto-generator must have two or more points of electrical exchange, which might be either generation or consumption associated to the same company. The auto-generator is able to sell energy surplus to the MEM and also to obtain its needs. The energy to sell will be only the one not compromised by other types of commercialization schemes or contracts. This will be acquired by CAMMESA at a variable cost (CVP) and without receiving compensation from the electrical power injected to the Spot Market. Regarding the possibility of acquiring energy, the auto-generator will be treated as a GUMA; the energy will be invoiced according to the hourly price at each of the consumers' nodes and there will be also a fix monthly power payment involved **[16]**. Such a scheme was created as a measure to increase the

electrical supply offer as well as serving to enhance the economic situation of the country. However, so far the resolution hasn't had the expected impact.

2.2.8. Exporting/Importing Policies

Part of the evaluation, to start up the operation of the 345 kV transmission line between Chile and Argentina, includes the policy frameworks to enable this. Chile does not have such a background; therefore, this is a crucial issue being at the moment analyzed. Argentinian policy regarding exporting and importing policies are based in an official document known as annex 30, thus an overview of this is provided in this section.

Import and export of electricity can be performed between companies from other countries and market agents, or trading companies belonging to MEM. Importing is considered as generation added to the MEM, whereas export is considered as an additional demand in MEM at the border; both of them need to pay the applicable transmission charges. Therefore, import/export can be executed by the following entities which also need a required permit from the Energy Secretariat:

- Generators, co-generators or trading companies holding plants can be the seller of an export agreement in the contract market
- Generators, co-generators or trading companies dealing with energy transactions can perform spot exporting operations
- Distributors, GUMA or trading companies dealing with demand may be the purchaser of an import agreement in the contract market
- A trading company can perform spot importing operations

It is set that in any import or export operation, the MEM agent or trading company involved is the entity in charge of covering and doing the related payments for the transaction. Moreover, to ensure transparency of these operations is needed to establish minimum conditions of reciprocity and symmetry between the MEM and the electricity market of the other country, such as:

- Generation market and offer dispatch based on economic costs
- Open access to remaining transmission capability
- Non-discriminatory conditions for buyers and sellers of both countries

It is called International Transmission Interconnection to the equipment (lines, substations, converters, transformers, etc.) dedicated to connect the exchanging nodes; thus, its primary function is to transport electricity exchanges between the MEM and the electricity market of the other country. **[18]**

Two types of import and export operations can be performed:

- Firm exchanges of power agreed between parties to be delivered in a boundary node during a certain term, and specified through a signed deal in the contract market.
  For instance, in the case of a GUMA, it can only celebrate a firm import contract for the share of its demand that is not subjected to be interrupted **[17]**. Among other things, the contract must specify term, boundary node, international transmission interconnection to be used, firmed power agreed, generation units compromised, associated energy and price to be paid.
- Opportunity exchanges, through discontinue or interruptible transactions in the spot market. This type is in function of surpluses and shortages arising in each country and their energy prices; there is no power transaction involved. Consequently, it consists in selling to the spot market, on a boundary node, the additional supply of another country.

Finally, it is important to mention that any implementation of import and export operations, between Chile and Argentina, require high degree of coordination between the system operators, CDEC-SING and CAMMESA respectively; not only in the case of offers compatibility and acceptance, but they have also to be capable to interrupt the exchange in case of arising a condition that may jeopardize the supply and demand of any of the systems.

Chapter 3

3. Networks descriptions and Modeling

3.1. SING Network in DSPF

CDEC-SING has created a complete model of SING in DSPF, which is used for planning and assessing the system under a wide range of operational conditions. It is offered as an open resource for other companies, organisms or entities interested in analyzing and studying the grid through simulations of different operation scenarios or infrastructure variations. Therefore, SoWiTec makes use of this resource to evaluate in steady state the technical feasibility to interconnect wind and solar projects into the grid. CDEC-SING is in charge of updating the model in order to keep its data base, parameters and structure as real and actual as possible. Hence, it is important to mention that the version used for this work, corresponds to February 2014. Table 3 presents a general overview of the electrical infrastructure included in the DSPF model of SING.

Type of infrastructure	Total
Generators	215
2-Wnding Transformers	319
3-Winding Transformers	44
Transmission Lines	132
Loads	241
Busbars	308
Shunts Reactors/Capacitors	46
Series Capacitors	1

Table - 3: SING infrastructure in DSPF

As a matter of fact, even though the model contains the entire electrical infrastructure conforming SING, it is important to mention that part of the equipment can be set out of service according to the different dispatches, load levels and operational conditions. These settings and parameters of the system are defined as default by CDEC-SING, and correspond to a range of load levels where the balance between generation and demand is accomplished; varying from high, average and low demand. The complete SING diagram in DSPF can be checked in Appendix A.

3.2. SADI Network in DSPF

CAMMESA as the administrator and operator of SADI is responsible to create a simulation model representing the entire grid; it is originally built in PSS/E which is a SIEMENS power system tool widely used in the industry. SoWiTec, due to its activities and involvement in the MEM, was able to obtain the complete model and afterwards transform it into the DSPF platform. For the purposes of this project, it has been used the most updated version which corresponds to February 2014.

Type of infrastructure	Total
Generators	700
Transformers	2000
Transmission Lines	2100
Loads	1100
Busbars	3100
Shunts Reactors/Capacitors	350
Series Capacitors	18

Table - 4: SADI infrastructure in DSPF

In the case of SADI, the existing model only contained the scenario knows as peak summer demand, which is equivalent to the high demand model available for SING. For further reference, regarding DSPF models of both SADI and SING, such as detailed electrical parameters of the infrastructure or operational conditions included, it will be necessary to contact SoWiTec group, in order to obtain approval about this possibility. The diagrams in DSPF representing SADI 500 kV infrastructure can be checked in Appendix A.

3.3. Line Parameters and Model in DSPF

The 345 kV line, as it was mentioned before, it is owned by the private company AES GENER which holds transmission and generation activities in both countries. According to the construction and operation information provided by this company to CDEC-SING, the transmission line has the following characteristics:

Chilean Node	Argentinian Node	Nominal Voltage [kV]	Length [km]	Thermal Capacity [A]	Conductor Temperature [°C]	Transmission Limit [A]	Transmission Limit [MVA]
Andes Substation	Cobos Substation	345	408	1300	75	1200	717.07

Table - 5: Characteristics and capabilities of the 345 kV line between Chile and Argentina

It is of significant importance to indicate that the transmission limit stated in Table 5 is due to the current transformers the line is equipped with. Two conductors per phase are installed, each one with a cross section area of 524 mm^2.

The line is incorporated in the SING model and has the following electrical parameters:

Parameter	Value
Length	408 km
Rated Current	1.2 kA
Max. Operational Temperature	80 °C
Conductor Material	Aluminium
Nominal Frequency	50 Hz
Inductance (L)	1.039 mH/km
Capacitance (C)	0.0109 µF/km
AC-Resistance at 20°C (R)	0.0311 Ohm/km
Surge Impedance Loading (SIL)	385.5 MW
Zero Sequence Resistance (R0)	0.2877 Ohm/km
Zero Sequence Reactance (X0)	0.8196 Ohm/km

Table - 6: DSPF electrical parameters of the 345 kV line

Figure 7 shows the DSPF representation of the line, including the 345 kV busbars at each side of the line; as well as the reactive power compensation equipment consisting of shunt reactors at sending/receiving end, a series capacitor located in the Chilean side and a by-pass interrupter for the series compensation. Rated values of the reactors and capacitor are shown in Table 7.

Figure 7 – DSPF diagram of the 345 kV line

Reactive Compensation Equipment	Type	Rated Power
Shunt Reactor	R-L	42.0286 Mvar
Series Capacitor	C	490 MVA

Table - 7: Rated Power of the Reactive Power Compensation in the 345 kV line

It is important to clarify that even though Figure 7 shows the line being connected at both sides, the original model of SING does not include other SADI´s infrastructure rather than the combined cycle Salta power plant described in section 1.2. Moreover, the infrastructure in Figure 7 is completely set out of service in the SING DSPF model.

3.4. Andes and Cobos Substations

It has been stated before that the electrical substations where the 345 kV transmission line is connected to, are Andes at the Chilean side and Cobos at the Argentinian side. Therefore, it is essential to assess and monitor the loading and voltage permissible levels within this related infrastructure; as its influence in the performance of the transmission line can be significant.

Andes Substation in DSPF is composed by a 220 kV busbar and the 345 kV busbar where the transmission line is connected to. A 3-winding transformer is installed for each phase with a voltage level of 23 kV in the tertiary. The rated power is 250/250/85 MVA corresponding to the voltage levels 345/220/23 kV respectively. The tap changer installed provides additional voltage of 1.25% per tap, having for maximum and minimum 8 positions available. Figure 8 shows the substation, together with the Chilean end of the line.

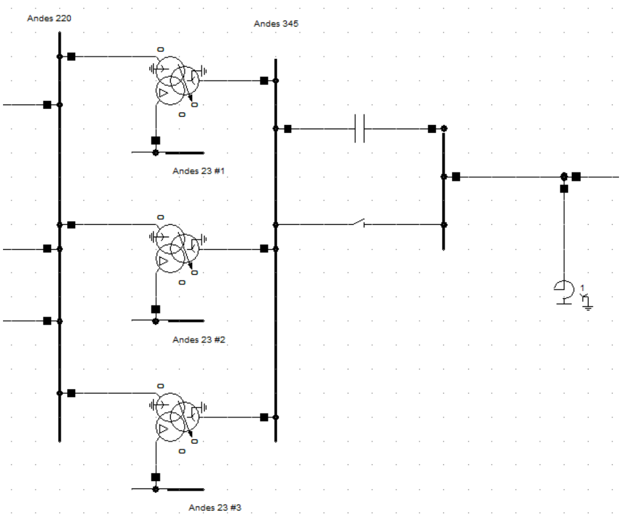


Figure 8 – Representation of Andes Substation in DSPF

Cobos substation´s infrastructure is represented in DSPF as two busbars, the 345 kV "8120 COBOS" and the connection with the rest of SADI established through the 500 kV busbar "8007 COBOS". The diagrams enclosed transformers connecting with other substations as well as 500 kV transmission lines linking "8007 COBOS" with other parts of the system. Shunt and neutral earthing compensation equipment is also inserted.

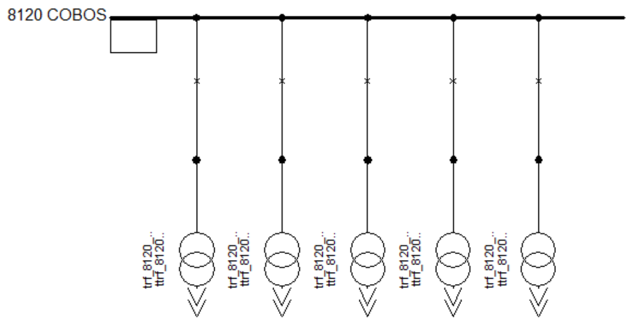


Figure 9 – 345 kV busbar and infrastructure at Cobos Substation, DSPF

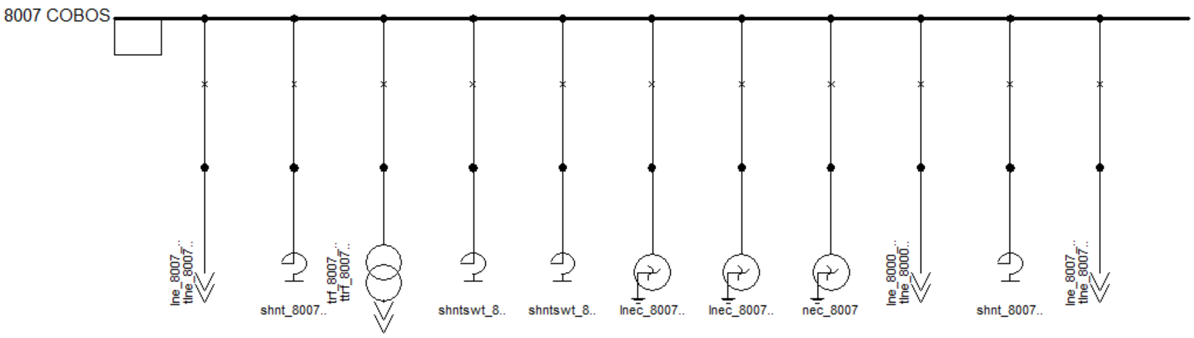


Figure 10 – 500 kV busbar and infrastructure at Cobos Substation, DSPF

For further reference, the detailed single line diagrams of Cobos and Andes substations can be found in Appendix B; they have been elaborated by Transener and AES GENER, respectively.

3.5. Wind Projects Descriptions

The SoWiTec´s projects that are being included into this work have been selected together with the management and specialists of the company. They correspond to what the company considers relevant to be analyzed and incorporated to this work in order to cover the company´s interests, as well as complement its business strategy.

These wind projects are all located at different geographical locations within SING area; general features about their development process and electrical interconnection are specified in the next tables.

Project Name	Parque Eolico Lickan Antai
SoWiTec internal code	CL021
Current Status	On-Going
Expected Ready to build year	2015
Power Capacity projected	115 MW
Straight line distance from Andes Substation	Approximately 170 km
Substation to Interconnect	Encuentro
Distance to Interconnection substation	Approximately 60 km
Interconnection Voltage Level	220 kV
Average Wind Speed Estimated at 100 m	6.95 m/s
Comments	Project with good stage of development, Currently waiting to be awarded the land right to move forward in the development.

Table - 8: Lickan Antai Project Overview

Project Name	Parque Eolico Los Vientos del Desierto
SoWiTec internal code	CL018
Current Status	On-Going
Expected Ready to build year	2016
Power Capacity projected	154 MW
Straight line distance from Andes Substation	Approximately 150 km
Substation to Interconnect	Escondida
Distance to Interconnection substation	Approximately 120 km
Interconnection Voltage Level	220 kV
Average Wind Speed Estimated at 100 m	8 m/s
Comments	Project waiting for government tendering call and basis for bidding

Table - 9: Los Vientos del Desierto Project Overview

Project Name	Parque Eolico Wayra
SoWiTec internal code	CL050
Current Status	On-Going
Expected Ready to build year	2016
Power Capacity projected	150 MW
Straight line distance from Andes Substation	Approximately 150 km
Substation to Interconnect	Domeyko
Distance to Interconnection substation	Approximately 110 km
Interconnection Voltage Level	220 kV
Average Wind Speed Estimated at 100 m	8 m/s
Comments	Conditions for development look promising and with further steps in the development process, it would become a leading project for the company.

Table - 10: Wayra Project Overview

Project Name	Parque Eolico Llasa Amuki
SoWiTec internal code	CL034
Current Status	Stand-by
Expected Ready to build year	2020
Power Capacity projected	318 MW
Straight line distance from Andes Substation	Approximately 11 km
Substation to Interconnect	Andes
Interconnection Voltage Level	220 kV
Average Wind Speed Estimated at 100 m	5.78 m/s
Comments	Due to the low wind speed obtained during the measuring campaign, only a stable and interesting agreement to trade the energy would make the project feasible.

Table - 11: Llasa Amuki Project Overview

These projects will be taken into account in the DSPF model as part of the scenarios to be described in the following chapter.

3.6. Wind Farm model in DSPF

The wind farm model used during the DSPF simulations corresponds to the one implemented by CDEC-SING to represent the first wind farm integrated to the system, "Valle de los Vientos", which was also a SoWiTec´s development, currently interconnected to SING and fully operational. The decision to employ this model to simulate the other wind projects previously described, was mainly due to the fact that it has been accepted and currently being used by CDEC-SING to electrically characterized the wind park. Moreover, it has the sufficient and appropriate electrical infrastructure to schematize a real wind power plant.

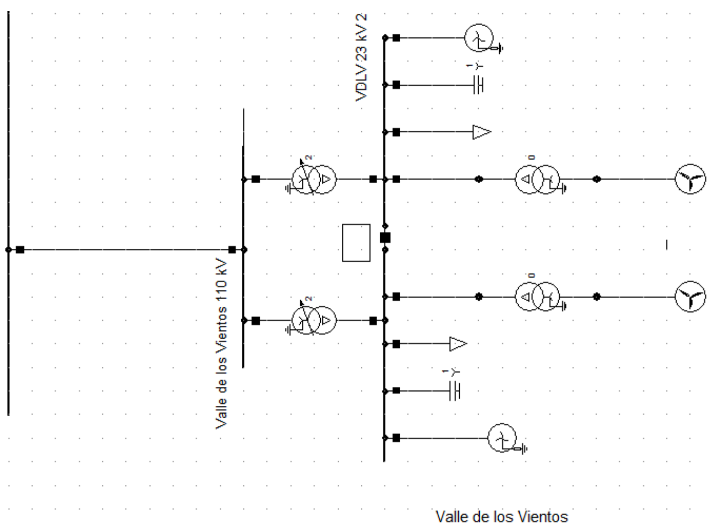


Figure 11 – Wind Farm model in DSPD, based on Valle de los Vientos project

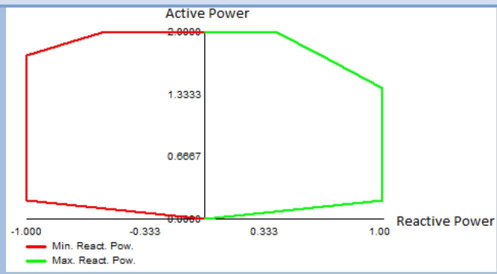
Generator Type	Static Generator, PQ bus, 2MW
Generator Capability Curve	
Step-up transformer	0.69/23 kV - 2.1 MVA
Voltage Level Busbars Collector System	23 kV
Reactive Power Equipment	Two Shunt Capacitors, 7Mvar per step
Power Transformer	Two units, 23/110/220 kV

Table - 12: Infrastructure included in the Wind Farm model in DSPF

The power transformers´ rated power is adapted depending on the nominal capacity of each wind farm, which at the same time is modified according to each project´s characteristics by adjusting the number of parallel machines; this also applies to the number of step-up transformers included in the model. The interconnection voltage level can vary between 110 and 220 kV, depending on the PCC where the project interconnects to SING at.

The model also comprises two general loads to simulate the wind farm´s own power requirements. However, in the original model they are set up with zero active power required; hence, for the purposes of the simulations in this work, the same setting will be kept. Neutral earthing equipment to limit earth faults can be also appreciated in Figure 11.

In order to emulate the wind behavior and not only representing the wind generation as a fixed static power injection, in some simulations the power delivered by the wind farms has been scaled down from full power (100%) until no wind condition (0%), passing through an intermediate step of 50% wind. However, these three step conditions are further explained in chapter 4 where the simulation scenarios and results are explicated.

3.7.Power Factory model description of the Interconnection SING-SADI

A crucial step in this work was to interconnect the power systems together. It was necessary, that once having obtained the two separate systems model, to merge and combine them into a single data base. Even though DSPF provides a merging tool, it was a difficult task to achieve; it implied a great effort to successfully merge SING and SADI into one project. This was merely due to the fact of handling such large networks where proper insertion and compatibility of parameters, equipment type libraries, diagrams, grids, default operation scenarios and study cases was required.

The 345 kV transmission line, originally represented and connected in one end at Andes substation in SING model, was interconnected to Cobos 345 kV busbar in SADI model. This can be depicted in the next figures.

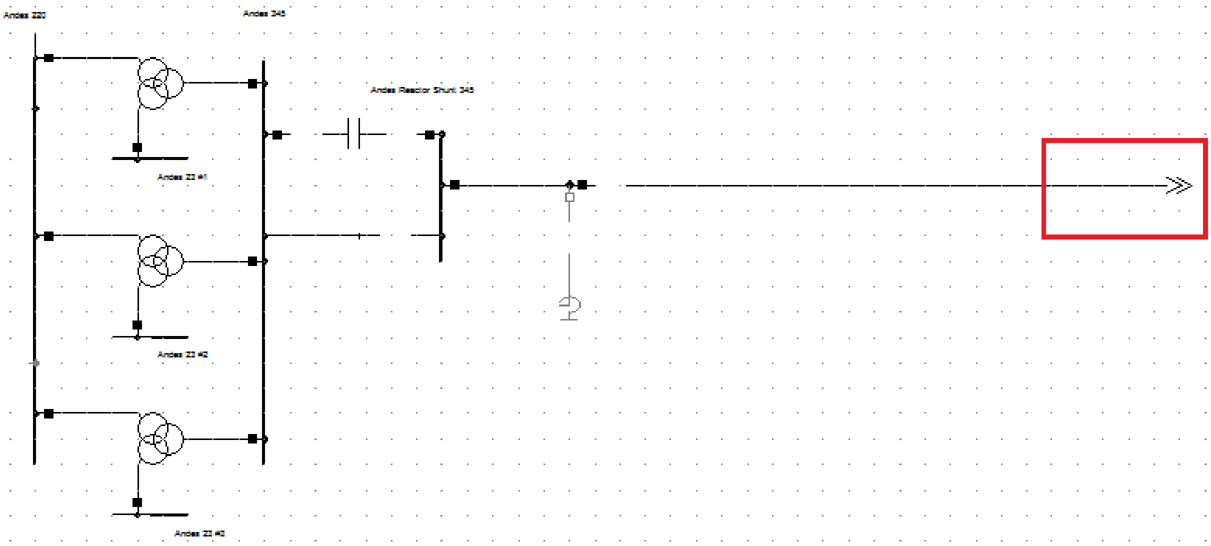


Figure 12 – Representation at the Chilean side of the 345 kV Transmission line interconnection

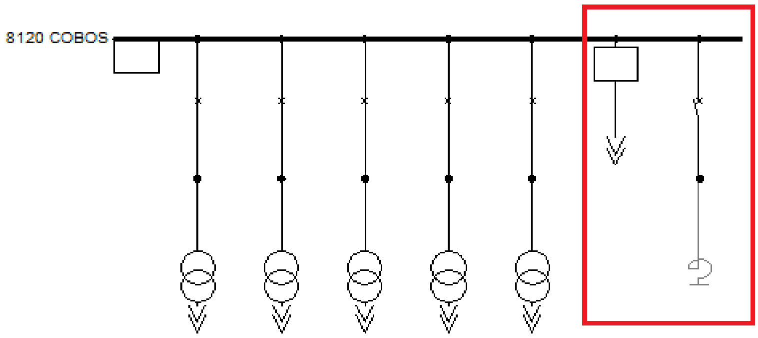


Figure 13 – Transmission line added to 345 kV busbar in Cobos Substation

Table 13 is shown in order to have a better understanding of the electrical parameters that are being considered, during the load flow calculation, for each major element in the interconnected model SING-SADI.

Element	Electrical Parameters included in DSPF
Generator Units	Bus Type, Nominal Apparent Power, Nominal Voltage, Power Factor, Synchronous Reactances, Dispatch values (Active power, Reactive Power, Voltage setting), Active and Reactive Power Operation Limits (Capability Curve).
Transmission Lines	Rated Voltage, Rated Current, Nominal Frequency, Resistance, Reactance, Maximal Operational Temperature, Conductor Material, Susceptance, Conductance, Length.
Power Transformers	Rated Power, Nominal Frequency, Rated Voltages, Positive Sequence Impedances, Zero Sequence Impedances, Vector Group, Magnetizing Impedance, Tap changers.
Loads	Operating Point (Active Power, Reactive Power, Voltage)
BusBar	Nominal Voltage
Shunt Reactive Compensators	Nominal Voltage, Shunt Type, No. of steps, Rated Reactive Power per step
Series Reactive Compensators	Rated Voltage, Rated current, Reactance

Table - 13: DSPF Electrical Parameters for each element

3.8.Simulation General Conditions and Considerations

Regarding each simulation scenario to be reported on Chapter 4, considerations are commented individually for every specific case. However, this section states the load flow simulation conditions prevailing unchanged within all the scenarios. They mainly refer to DSPF settings to be considered when running and solving the load flow calculation; these conditions are listed next:

Basic Options:

- Calculation Method → AC Load Flow, balanced, positive sequence
- Reactive Power Control → Automatic Shunt Adjustment → Activated
- Temperature Dependency: Line Resistances → 20°C
- Load Options → Consider Voltage Dependency of Loads and Consider Coincidence of Low-Voltage Loads → Activated

Active Power Control:

- Active Power Control → As Dispatched
- Balancing → Distributed Slack by Generation

Advanced Options:

- Load Flow Method → Newton-Raphson (Power Equation, classical)
- Load Flow Initialization → Consideration of Transformer winding ratio → Activated

Iteration Control:

- Max. Number of Iterations for
  - Newton-Raphson Iteration → 50
  - Outer Loop → 40
  - Number of Steps → 1
- Max. Acceptable Load Flow Error for
  - Nodes → 0.01 kVA
  - Model Equations → 0.001%
- Convergence Options
  - Automatic Model Adaptation for Convergence → Activated

As it was stipulated in section 2.1.4, in order to have a more realistic representation, this work takes a distributed slack approach. Defining a slack bus to balance the reactive power is still necessary; hence the SING-SADI slack bus for all the simulations was selected as a nuclear power unit in Argentina. This unit was the original slack bus for the SADI model alone; thus its active and reactive powers were calculated automatically by DSPF as its dispatch settings were set to zero. For this reason, the active power parameter of the nuclear plant, while using the distributed slack approach, needed to be adjusted. This was done according to the indication from CAMMESA to keep the value of active power between 600 and 640 MW, Table 14 shows the parameters of the slack bus:

Name	**Sym_6600_1**
Location	CENTRO
Type	Synchronous Machine
Nominal Apparent Power	763.5 MVA
Nominal Voltage	22 kV
Dispatch Values	P = 610 MW, Q = 0, V = .99 pu
Active Power Operational Limits	Min: 129.8 MW, Max: 649 MW
Reactive Power Operational Limits	Min: -267.53 Mvar, Max: 409.9 Mvar

Table - 14: Slack Bus Parameters

Finally, considerations are taken regarding the selected nodes to monitor during the simulations, this limitation is again due to large size of the grids. Special attention will be paid to the nodes directly linked or relatively near to the 345 kV transmission line, as well as to the nodes were the wind generation is being interconnected; this will be stated more in detail on each simulation scenario. Nevertheless, reliability of the two systems interconnected will be achieved by attending critical warnings or alarms provided by DSPF in other sections of the grids.

3.9.Permissible voltage levels and loading

In order to evaluate the impact, not only of the transmission line establishing the interconnection SING-SADI, but also of the wind generation integration; grid connection requirements and permissible voltage variation and loading limits are specified generally in grid codes. The objective is to set limits in which an operation of wind generation is considered safe for system operators. If these limits are exceeded, it means that in some circumstances the power system can become unstable or its operation could become compromised. Table 15 contains the applicable technical levels according to technical norms.

Country	Parameter	Permissible Level [19] [20]
Chile	Voltage Levels in Busbars under normal operation	• 0.97 – 1.03 pu → For 500 kV or higher • 0.95 – 1.05 pu → From 200 kV and lower than 500 kV • 0.93 – 1.07 pu → For lower than 200 kV
	Voltage Levels in Busbars under contingency	• 0.96 – 1.04 pu → For 500 kV or higher • 0.93 – 1.07 pu → From 200 kV and lower than 500 kV • 0.91 – 1.09 pu → For lower than 200 kV
	Thermal overloading of elements (current)	100% as Maximum
Argentina	Voltage Levels in Busbars under normal operation	• 0.97 – 1.03 pu → For 500 kV or higher • 0.95 – 1.05 pu → From 132 kV and lower than 500 kV
	Voltage Levels in Busbars under contingency	• 0.95 – 1.05 pu → For 500 kV or higher • 0.90 – 1.10 pu → From 132 kV and lower than 500 kV
	Thermal overloading of elements (current)	100% as Maximum

Table - 15: Chilean and Argentinian Grid Code applicable parameters

Chapter 4

4. Technical Simulation Scenarios and Results

4.1.SING – High Demand

This simulation shows the **current operational condition of SING at high demand**. It serves as base case and reference to compare for simulations involving the interconnection SING-SADI when completed. As it was stated before, due to the large amount of infrastructure in SING, **specific nodes have been selected** and the results of the load flow calculation can be checked in Appendix C, Tables A.1 to A.5. Some of this **infrastructure closely surrounding Andes substation**, includes elements such as busbars, transmission lines, transformers and shunt/series compensators, linking for instance Laberinto and Nueva Zaldivar substations. The selected nodes´ information corresponds to what in **Figure A.1 is encircled in color yellow**.

The high demand condition in SING is successfully supplied by only **21 power plants** activated. They are generating almost **2300 MW** for a required demand of 2232 MW, which implies roughly **70 MW in losses**. In this case, as the interconnection **SING-SADI hasn't been established** yet, SING has its own slack bus but the approach distributed slack is still being performed. As it can be seen in Table A.1, the **slack bus corresponds to ANG2** unit with a nominal apparent power of 330 MVA.

It can be appreciated that the **345 kV transmission line is out of service**, therefore there is no power flow on it, and even the transformers at Andes substation are loaded at a very low level. There are **no major limits being overpassed within the selected nodes**, rather than the values marked in red on Tables A.2 and A.3. They correspond to elements in 110 kV or below that the **operator is allowing them to work under those conditions**. Moreover, in some other far away sections of SING, something similar happens to some busbars exceeding the voltage limits; for instance where generation units U12 and U13 are connected (**Tocopilla node**), the 110 kV busbar is having **1.08 pu voltage** level instead of the allowed maximum level of 1.07 pu. At this point, this will be considered as an acceptable operation condition in the system.

4.2.SING – Low Demand

This simulation, as the previous case presented in section 4.1, shows the **current operational condition of SING but this time at low demand**, serving also as base case and reference. The results of the load-flow calculation can be checked in Appendix D, Tables A.6 to A.10. The selected nodes are the same as section 4.1.

The low demand condition in SING is **successfully supplied by only 20 power plants** activated. They are generating almost **2085 MW** for a required demand of 2030 MW, which implies roughly **55 MW in losses**. The slack bus corresponds to ANG2 unit with a nominal apparent power of 330 MVA.

There are **no major limits being overpassed within the selected nodes**; the infrastructure related to the 345 kV transmission line remains out of service. There are again some busbars in voltage levels lower than 200 kV exceeding the voltage limits such as the connection busbar of the generation units U12 and U13, having a voltage level of 1.08 pu. In this low demand scenario there some **busbars**, particularly concentrated in the **north of the system** and with voltage level lower than 200 kV, such as **Pozo Almonte in 24 kV, that reached levels as high as 1.16 pu**. Nevertheless, they will be taken as an operation condition allowed by CDEC-SING.

4.3.SADI – High Demand

The **high demand condition in SADI** is successfully supplied by **400 generation units activated**, generating about **25,450 MW**. This simulation shows the actual operational condition of SADI at high demand and sets the reference for further simulations. In the case of SADI, the **selected nodes** are the ones corresponding to **Cobos substation infrastructure** and Figure A.5 can be checked for additional details.

The results of the load flow calculation are in Appendix E, Tables A.11 to A.14. It is important to mention that the results show also Transnor´s infrastructure, which is the owner and operator of most of the electrical northern infrastructure in 500 kV; therefore, the **tables contain infrastructure in 132, 345 and 500 kV level**, together with the Salta combined cycle power plant units, the slack bus with the parameters in Table 14, transmission lines, transformers and shunt compensators**. Limits are being exceeded in lines of 132 kV**, not in their loading but in the voltage at each of the terminals; they are highlighted in red for a better reference.

Moreover, other 500 kV infrastructures depicted in Figure A.2 Appendix A, corresponding to Centro, Cuyo and NOA areas, stands within the limits. However, **some elements**, in the diagrams of Figures A.3 and A.4, are **beyond the acceptable voltage and overloading limits**. For instance, there are series **capacitors and transmission lines with overloading above 150% and 180%,** respectively.

As the **operation conditions** of this scenario have been **set by CAMMESA**, it will be **assumed that reliability of the system is not compromised** and that SADI can handle the overloading and voltage level conditions mentioned before.

4.4.SADI – Low Demand

In this particular case, as the **SADI model for low demand was not available**, CAMMESA was consulted in order to **obtain a factor to adjust** the high demand scenario into a close representation of how **a low demand scenario** would behave. Thus, it was indicated to equally reduce loads´ demand and generation from power plants by a factor of **32% lower than the high demand scenario**. The low demand adaptation in SADI is being supplied by the same 400 generation units as in the high demand scenario, **generating about 17,150 MW**.

Similarly to the previous case, the selected nodes are the ones corresponding to Cobos substation infrastructure in 132 and 345 kV, Transnor equipment in 500 kV is also being added; the results are shown in Appendix F, Tables A.15 to A.18. In this case, not only the **voltage limits** in the 132 kV transmission lines are **being exceeded**, but also many of the voltage levels in the 132 and 500 kV 2-winding transformers. These results will be taken into consideration for comparing the outcomes to be obtained once the interconnection between the systems is established in the coming scenarios.

The 500 kV infrastructures depicted in Figure A.2 Appendix A, corresponding to Centro, Cuyo and NOA areas, stands within the limits. However, some elements in neighboring areas such as NEA and litoral, in the diagrams of Figures A.3 and A.4, remain beyond the acceptable voltage and overloading limits. For example, some **series capacitors and transmission lines** have considerably **reduced their overloading** but they are **still over the maximums**.

4.5.SING – SADI/High Demand/Null Transfer

It is important to state at this point that due to the unavailability of a SADI low demand scenario, the adaptation presented in section 4.4 does not take into account the real changes in the generation units being dispatched nor the loads being put out of service. Therefore, the load-flow calculations in the Argentinian side in low demand might not be realistic; hence, for coming simulations regarding the interconnection of both systems, **only the high demand operation scenarios will be considered**.

This section presents the **first scenario** in which the interconnection **SING-SADI is achieved**. SING and SADI high demand operational parameters and **conditions have been kept unchanged on each side**. Therefore, this scenario introduces a condition in which ideally no power flow will be transferred between the systems as their own generations and demands are in balance; in other words, **a null transferring condition is described**.

The 345 kV transmission line has been connected as section 3.7 explains, however, the **reactive power compensation equipment in the line has not been activated**. In this case, the results in Appendix G Tables A.19 to A.24, include the selected nodes from SING and SADI together. Infrastructure from Andes and Cobos substations are gathered in the mentioned tables as well as the surrounding infrastructure which has been incorporated until this point.

A very **important outcome** from this scenario is the fact that the load flow calculation converges, meaning that **both systems are able to work interconnected in steady-state**. Regarding voltage levels at nodes and loading of the elements, the **results are very similar to the condition when both systems are operating independently**. For instance, there is a slightly **increase** in the **voltage** at the terminals of the **132 kV transmission lines**, with a higher impact in the voltage levels of the **2-winding transformers at SADI**, this comparison can be appreciate on Tables A.13 - A.21.

The **generator units at Salta power plant** are operating under **perfect conditions** as well as the infrastructure in **Andes substation**. Some remarks regarding the performance of the 345 kV transmission line are shown in Table 16.

Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	1.037	1.057	9.45	9.59	14.74	187.80	-4.02	4.26	-109.49	-75.70	0.25	0.18	0.12

Table - 16: 345 kV transmission line, SING-SADI/High Demand/Null Transfer

It can be seen that the **voltage level in SADI side is slightly above the permissible level**; however, this must not imply any operational inconvenience. The active power flow can be indeed neglected, as the **null transferring operation condition is achieved** by 4.26 MW being sent from Argentina and **receiving 4.02 MW in Chile**; which is also supported by the low and similar power angles at each terminal. Even though the **thermal loading of the line is only 14.74%**, the line is highly capacitive loaded which makes the **line behaves as a source** injecting reactive power at both terminals of the line.

In general, **both systems are performing correctly**, under the limits and similarly to what was reported in sections 4.1 and 4.3; however, **Tocopilla node** at SING side, where some **Gas units** are connected and due to the predefined settings of the machines, they are i**njecting too much reactive power** into the system which at the same time, makes them **exceed their operational limits**. This issue will be covered and further discussed in next simulations.

4.6.SING – SADI/Maximum Transfer

This scenario was performed in order to evaluate the **maximum transmission capabilities of the 345 kV line** with none of its reactive power compensation equipment active. Moreover, this scenario assesses the performance of the interconnection SING-SADI, once **altering the dispatch units that were normally on service in SADI** to supply its high load demand scenario.

As it was mentioned before in this work, SADI currently supplies part of its demand with **diesel and small thermal units**, which are **economically expensive** to generate power with due to the fuel cost and efficiency itself; these units are **highly concentrated in northern SADI**. Therefore, **diesel units were shut down** not only to enhance power flow through the line, but also to technically analyze the feasibility to substitute generation of these costly power plants by **less expensive energy generated in SING**.

For this particular simulation and to focus the objective in reaching the maximum capabilities of the 345 kV transmission line, the **new generation at SING comes from a fictitious power plant interconnected directly to the line**. The **diesel units were chosen according to the indication from CAMMESA** experts and are listed in Table 17. Likewise, the DSPF representation of the new power plant connected to the line can be seen in Figure 14, marked in red.

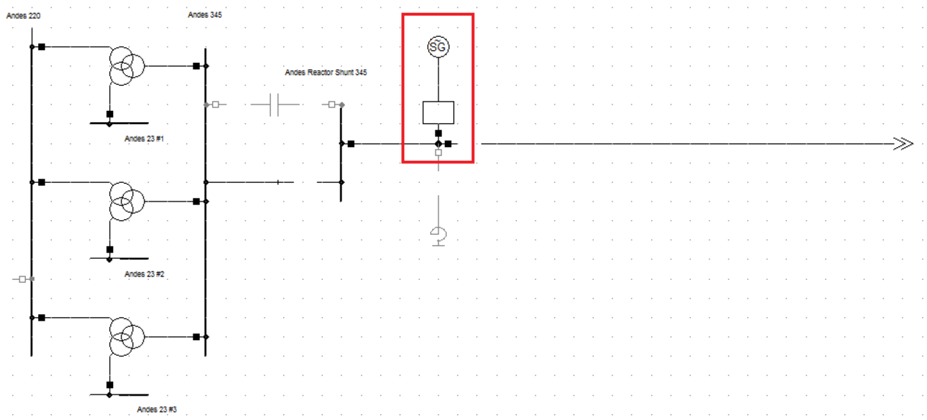


Figure 14 – Maximum Transfer with a generator connected directly to the 345 kV transmission line

Thermal Unit	Grid	Active Power [MW]	Voltage Terminal in pu, SADI High Demand	Voltage Terminal in pu, SING-SADI Maximum Transfer
sym_8609_1	NOA	20	1.05	0.99
sym_8618_1	NOA	12	1.05	0.98
sym_8631_1	NOA	30	1.05	0.96
sym_8632_2	NOA	30	1.05	0.96
sym_8633_3	NOA	30	1.05	0.96
sym_8658_1	NOA	15	1.02	0.91
sym_8659_1	NOA	20	1.04	0.96
sym_8663_1	NOA	30	1.05	0.94
sym_8671_1	NOA	20	1	0.86
sym_8673_1	NOA	15	1.03	0.89
sym_8683_1	NOA	10	1.05	0.99
sym_8686_1	NOA	30	1.02	0.87
sym_8695_1	NOA	15	1.05	0.92
sym_6613_3	Centro	20	1	0.96
sym_6631_1	Centro	30	1.05	1.02
sym_6632_2	Centro	30	1.05	1.02
sym_6651_1	Centro	25	1.08	1.03
sym_5629_1	NEA	20	1.05	1
sym_7621_1	Cuyo	20	1.05	1.03
sym_7622_2	Cuyo	20	1.05	1.03
sym_7641_1	Cuyo	24	1.03	1.01
sym_7642_2	Cuyo	24	1.03	1.01
sym_7643_3	Cuyo	20	1	1.01
sym_7644_4	Cuyo	20	1	1.01
sym_7654_4	Cuyo	28	1.03	1.01
sym_7665_1	Cuyo	25	1.02	0.99
sym_7666_2	Cuyo	25	1.02	0.99
sym_7677_1	Cuyo	20	1.02	0.99
sym_7680_1	Cuyo	20	1.05	1.03

Table - 17: Thermal units disconnected in SADI

The power plant is injecting purely **648 MW** directly connected to the transmission line with no reactive power generation, it is simply a source of active power; hence, no further characteristics need to be commented. On the other hand in SADI, this very **same amount of nominal capacity is being disconnected** through the thermal units in Table 17.

It is important to emphasize that the purpose of connecting a generator directly to the line is merely to **stress the 345 kV transmission line and reach extreme operation conditions**. However, this option is technically possible and according to comments from CDEC-SING, there are some NCRE projects (geothermal) analyzing this possibility.

The results are shown in Appendix H Tables A.25 to A.30; selected nodes consider infrastructure from Andes and Cobos substations as well as surrounding infrastructure. **Voltage levels in SADI 132 kV infrastructure get back to permissible levels** in comparison with the null transfer case; however some of the **infrastructure linked to Andes substation exceeds the limits, including the 3-winding transformers**. On the other hand, the 2-winding transformers in Table A.27 operate under perfect voltage levels but at the same time it can be easily appreciated the **excessive overloading**, over **150%**, that the **power transformer at Cobos substation** (500/345 kV) gets.

Although no norms apply to generator power factors (PF), it is important to notice that the PF of Salta power plant decrease substantially as its units are providing reactive power needed in the interconnected system to maintain the balance.

Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	0.913	0.991	78.19	28.20	100.45	141.25	650.01	-594.83	99.82	338.09	55.18	1.21	1.16

Table - 18: 345 kV transmission line, SING-SADI Maximum Transfer

It can be seen from Table 18 that the **voltage level in SING side**, of the 345 kV transmission line, is **below the permissible level** and measures to correct it have to be taken. The maximum transmission capacity is reached by obtaining a **flow of 650 MW in the sending side (SING)** and almost **595 MW in the receiving side (SADI)**, implying 55 MW in losses. Although the **thermal loading of the line reaches slightly more than 100%**, from these results it can be seen that **in steady state the systems can be interconnected while establishing a power flow from Chile to Argentina and using the total transmission capacity of the line**. Furthermore, the line behaves as a **sink** of reactive power as the flow is going into the line from both terminals.

Lastly, as the **thermal units** are being disconnected in SADI, then it is essential to pay attention to the **voltage variation at their terminals** in order to have an insight in whether the impact of this disconnection is at local level or if the entire system is in charge of balancing and improve the voltage levels. In the two last columns of Table 17, a comparison is shown between the voltage level of the units, in normal high demand operation scenario (Section 4.3) and the level reached once being disconnected in this current scenario. It can be seen that the **major variations are on units located in NOA**, which is at the same time the electrical area where the interconnection SING-SADI is established.

Comments and approach will be given in further simulations about the voltage levels of the thermal units, the overloading in the power transformer at Cobos substation and the reactive power issue in the Tocopilla node, which also appears during this scenario.

4.7.SING – SADI/Maximum Transfer/Reactive Compensation

This scenario attempts to also show the **maximum transfer capability of the 345 kV transmission line** but, differently from the last simulation scenario, in this case the **shunt and series reactive compensation of the line were included**. A range of different simulations were performed as activating both shunt reactors, or activating only one at the time, as well as one of the shunts together with the series capacitor and finally only the series capacitor active.

The condition, in which the **maximum power flow** was encountered and also the related **infrastructure showed the best voltage levels**, was when **only the series capacitor operates**. The load flow results of the line itself can be found in Table 19.

Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	0.954	0.993	78.05	28.98	100.24	148.18	674.16	-618.70	125.17	308.72	55.46	1.20	1.17

Table - 19: 345 kV transmission line, SING-SADI Maximum Transfer with Reactive Compensation

The **voltage levels at the terminals of the 345 kV transmission line operate under permissible levels**, however, it is important to remark that the 0.954 pu voltage is at the sending terminal of the series capacitor and not at the 345 kV bar of Andes substation. The **maximum transmission capacity is increased to 674 MW** being sent from Chile and almost 619 MW being received in Argentina, with losses in the range of 55 MW. Hence, it is relevant to state **that improvement in the transmission capacity of the line was achieved through the employment of the series capacitor**. Additionally, the results show that such maximum condition can be technically feasible to maintain while the systems operate in steady state. Moreover, the line again is consuming important amounts of reactive power.

In this case the **active power generation of the fictitious power plant** connected directly to the line was increased to **675 MW**. The **same thermal units** as in the previous case are kept **deactivated**, so the same 648 MW were disconnected from SADI. The **voltage levels at the terminals of these units behave in same manner** as the maximum transfer case depicted in last column of Table 17.

The results of the selected nodes are shown in Appendix I Tables A.31 to A.36. The most **significant outcomes** are the **low voltage levels** at the infrastructure of Andes substation, which at the same is being reflected in the voltage levels of **220 kV transmission lines in SING**. The **overloading** of the power transformer at Cobos substation (500/345 kV) appears again with a value **of 162%.**

4.8.SING – SADI/Wind Scenario 1

This section covers the simulation where **project Lickan Antai** is connected to SING. The description of the project was previously stated in Table 8, section 3.5 of this work. Moreover, the DSPF wind farm model in Figure 11, section 3.6 was adapted to the characteristics of Lickan Antai in the sense of having adequate number of parallel machines to **generate 115 MW**, enough transformation capacity in the wind farm and a suitable transmission line to **interconnect at 220 kV in Encuentro substation**.

In Figure A.1 of Appendix A, the **location of this interconnection can be depicted in color green**. Additionally, a detail of some infrastructure including the 220 kV busbar at Encuentro substation, the wind farm interconnection transmission line and Lickan Antai project itself, can be appreciated in Figure 15.

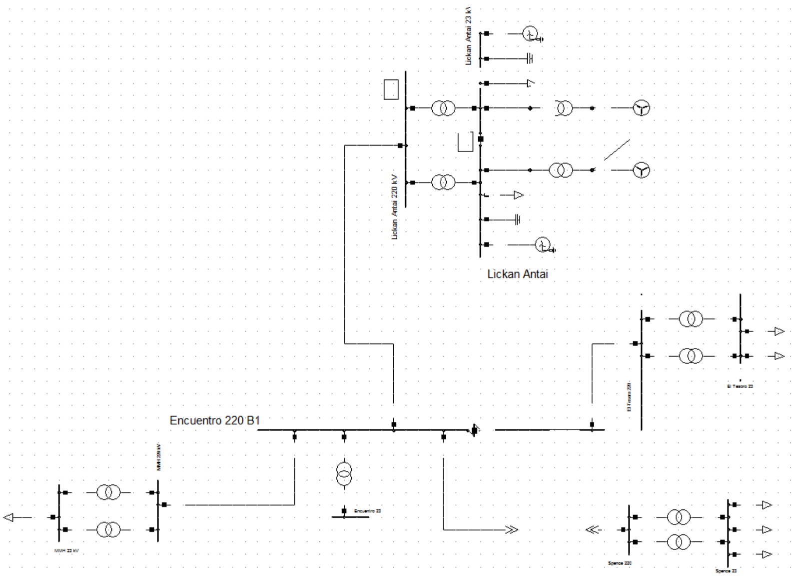


Figure 15 – Lickan Antai Project connected at Encuentro substation

The following features and conditions are essential for the understanding of the parameters included in this simulation:

- As it was proved earlier, the **series capacitor** improves the transmission capability of the 345 kV transmission line, therefore it is **kept active**.
- The **shunt capacitors** within the wind farm infrastructure are **activated** in order to emulate the wind farm capacity to produce reactive power.
- During the maximum transfer scenarios it was identified that the power transformer (345/500 kV) at Cobos substation gets overloaded; therefore, **a second power transformer**

with identical characteristics has been added. The additional transformer giving a new configuration to Cobos substation can be seen in Figure 16.

- Only **five thermal units**, with a combined **capacity of 122 MW**, have been **shut down** in SADI. Table 20 shows a comparison between the terminal voltages obtained in this simulation and the original scenario of SADI in High Demand.
- In Appendix J, Tables A.37 to A.42, the load flow results of the selected nodes are gathered, as well as the new important infrastructure to report such as the 220 kV line connecting to Encuentro substation, the second transformer at Cobos substation and wind farm´s shunt capacitors. This **new infrastructure is highlighted in light green** for better identification.

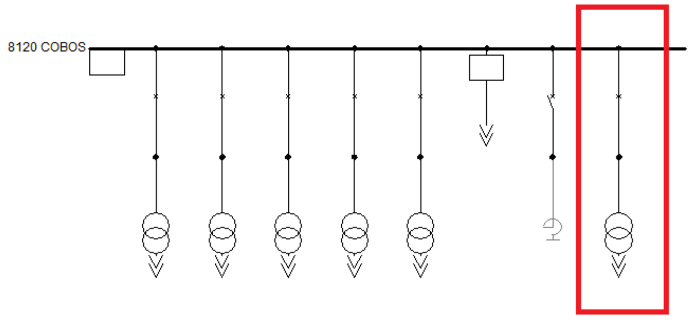


Figure 16 – Configuration of Cobos substation with additional 345/500 kV transformer

Thermal Unit	Grid	Active Power [MW]	Voltage Terminal in pu, SADI High Demand	Voltage Terminal in pu, SING-SADI Wind Scenario 1
sym_8609_1	NOA	20	1.05	1
sym_8618_1	NOA	12	1.05	0.99
sym_8631_1	NOA	30	1.05	1
sym_8632_2	NOA	30	1.05	1
sym_8633_3	NOA	30	1.05	1

Table - 20: Thermal units disconnected in SADI, Wind Scenario 1

From Appendix J, it can be conclude that the **related infrastructure** of the 345 kV transmission line as well as the PCC (Encuentro Substation) **operate under permissible levels**. The interconnection of **Lickan Antai project is feasible** from the steady state point of view. Table 21 shows load flow results specifically for the 345 kV transmission line with outstanding performance regarding voltages and loading levels. About **105 MW are being received in Argentina**, with a line´s thermal **loading** of only **24.6%**. The transmission line is now generating reactive power and in-feeding it into both systems, instead of consuming.

Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	0.987	1.044	14.35	7.54	24.62	176.59	106.84	-105.14	-137.60	-21.07	1.71	0.30	0.17

Table - 21: 345 kV transmission line, SING-SADI/Wind Scenario 1

The purpose to generate **wind energy in SING** and transmit the equivalent amount to SADI has been **successfully evaluated** for the case of Lickan Antai. Furthermore, the additional **power transformer at Cobos** is having a **positive impact** in the performance of the interconnection. Likewise, the **reactive power generated** in the wind farm through the shunt capacitors help to **keep the voltages at the PCC in a good level**.

As a final point, the five thermal units disconnected from SADI do not display problems with the voltage levels at their terminal; in general **the two power systems satisfactory tolerate this scenario**.

4.9.SING – SADI/Wind Scenario 2

This section covers the simulation where **projects Los Vientos del Desierto and Wayra** are connected to SING. The descriptions of the projects were previously stated in Table 9 and 10, section 3.5 of this work. The DSPF wind farm model has been also adapted as in the previous case, in order to fulfil the characteristics of both projects; thus, **154 MW and 150 MW** are simulated together with suitable transmission lines to **interconnect at 220 kV in Escondida and Domeyko substations**.

In Figure A.1 of Appendix A, the location of this **interconnection can be depicted in color blue**. A detail representation in DSPF of these two projects is illustrated in Figure 17.

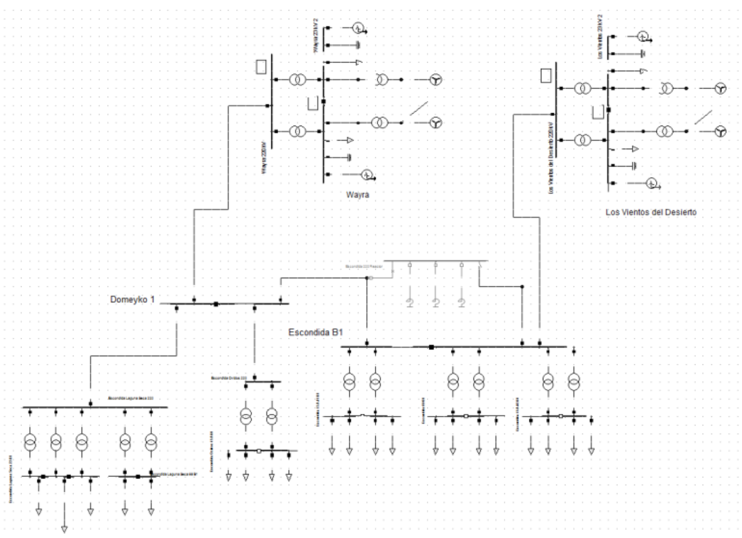


Figure 17 –Los Vientos del Desierto and Wayra Projects connected at Escondida and Domeyko substations

Similarly to the previous scenario, next features and conditions are essential for better understanding this simulation:

- Due to the improvement in the transmission capability of the 345 kV transmission line, the **series capacitor is kept active**.
- **Shunt capacitors** within the wind farms´ infrastructure are **activated**.
- The **second power transformer (345/500 kV) at Cobos** substation has been kept **installed**.
- **Thirteen thermal units**, with a combined capacity of **297 MW**, have been **shut down in SADI**. Table 22 shows a comparison between the terminal voltages obtained in this simulation and the original SADI High Demand scenario.
- In Appendix K, Tables A.43 to A.48, load flow results of the selected nodes are shown, as well as the new **important infrastructure to report** such as the **220 kV lines connecting to Escondida and Domeyko substations**, the second transformer at Cobos substation and wind farm´s shunt capacitors. This **new infrastructure is highlighted in light green** for better identification.

Thermal Unit	Grid	Active Power [MW]	Voltage Terminal in pu, SADI High Demand	Voltage Terminal in pu, SING-SADI Wind Scenario 2
sym_8609_1	NOA	20	1.05	1
sym_8618_1	NOA	12	1.05	0.99
sym_8631_1	NOA	30	1.05	0.99
sym_8632_2	NOA	30	1.05	0.99
sym_8633_3	NOA	30	1.05	0.99
sym_8659_1	NOA	20	1.04	0.99
sym_8683_1	NOA	10	1.05	1
sym_6613_3	Centro	20	1	0.96
sym_6631_1	Centro	30	1.05	1.02
sym_6632_2	Centro	30	1.05	1.02
sym_6651_1	Centro	25	1.08	1.03
sym_5629_1	NEA	20	1.05	0.99
sym_7621_1	Cuyo	20	1.05	1.05

Table - 22: Thermal units disconnected in SADI, Wind Scenario 2

From Appendix K, it can be conclude that the **related infrastructure** of the 345 kV transmission line as well as both PCCs **operate under permissible levels**. The **interconnection of Los Vientos del Desierto and Wayra projects is feasible** from the steady state point of view. Table 23 shows load-flow results specifically for the **345 kV transmission line** with **acceptable performance** regarding voltages and loading levels; **288 MW flow from Chile to Argentina**, where due to the losses about 280 are received. With a **loading of 44%**, now there is a reactive power flow through the transmission line from SADI to SING.

Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	0.977	1.033	31.41	13.07	44.07	171.09	288.20	-279.08	-110.97	35.61	9.12	0.53	0.46

Table - 23: 345 kV transmission line, SING-SADI/Wind Scenario 2

It can be stated that the main goal of **generating energy in SING by means of this wind scenario** and transmit it to Argentina has been **successful**. Furthermore, the additional **power transformer at Cobos** is still having a **positive impact** in the performance of the interconnection. Likewise, the reactive power generated in the wind farms through the shunt capacitors help to keep the voltages at the PCC in a good level. Moreover, the **thermal units disconnected** from SADI **do not exhibit problems** with the voltage levels at their terminals; in general the two power systems satisfactory tolerate this scenario.

4.10. SING – SADI/Wind Scenario 3

Wind scenario 3 presents the simulation in which the **project Llasa Amuki** is connected to SING. The project is described in Table 11, section 3.5. The DSPF wind farm model adaptation for this case was performed to obtain **318 MW** as output from the wind farm; the particularity of Llasa Amuki is that due to its location, the intention is to **connect directly at the 220 kV busbar of Andes substation**. In DSPF, this interconnection together with the 345 kV transmission line is shown in Figure 18.

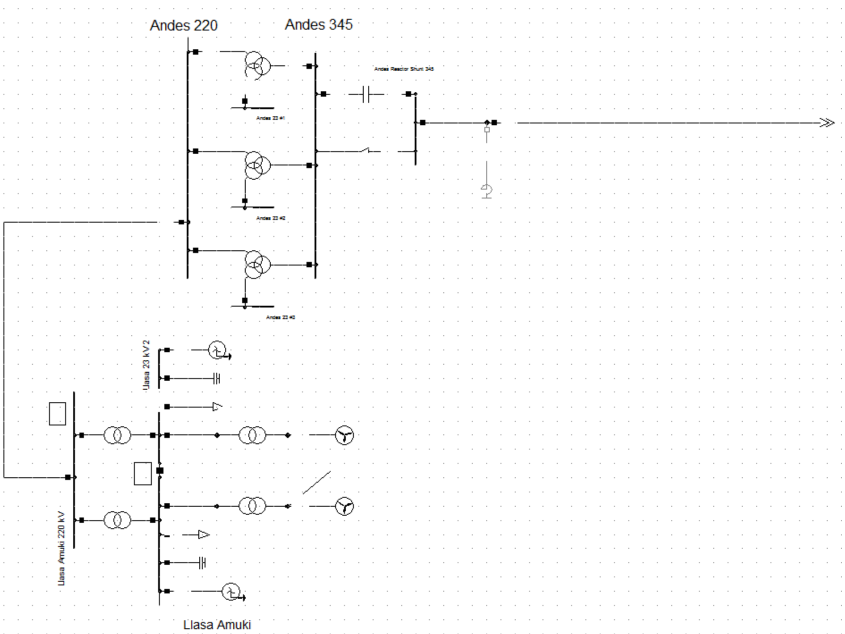


Figure 18 – Llasa Amuki Project connected at Andes substation

Features and conditions necessary to understand this simulation are listed below:

- Due to the improvement in the transmission capability of the 345 kV transmission line, **series capacitor is kept active**.
- **Shunt capacitors** within the wind farm´s infrastructure are **activated**.
- **Second power transformer** (345/500 kV) at Cobos substation **installed**.
- **Fourteen thermal units**, with a combined capacity of **317 MW**, have been **shut down** in SADI. Table 24 shows a comparison between the terminal voltages obtained in this simulation and the original SADI High Demand scenario.
- In Appendix L, Tables A.49 to A.54, load flow results of the selected nodes are shown. **Highlighted in light green**, for better identification, is reported the new infrastructure such as the 220 kV line from Llasa Amuki to Andes substation, second transformer at Cobos substation and the reactive power provided by the shunt capacitors in the wind farm.

Thermal Unit	Grid	Active Power [MW]	Voltage Terminal in pu, SADI High Demand	Voltage Terminal in pu, SING-SADI Wind Scenario 3
sym_8609_1	NOA	20	1.05	1
sym_8618_1	NOA	12	1.05	0.99
sym_8631_1	NOA	30	1.05	0.99
sym_8632_2	NOA	30	1.05	0.99
sym_8633_3	NOA	30	1.05	0.99
sym_8659_1	NOA	20	1.04	0.99
sym_8683_1	NOA	10	1.05	1
sym_6613_3	Centro	20	1	0.96
sym_6631_1	Centro	30	1.05	1.02
sym_6632_2	Centro	30	1.05	1.02
sym_6651_1	Centro	25	1.08	1.03
sym_5629_1	NEA	20	1.05	0.99
sym_7621_1	Cuyo	20	1.05	1.05
sym_7622_2	Cuyo	20	1.05	1.05

Table - 24: Thermal units disconnected in SADI, Wind Scenario 3

From Appendix L, it can be **conclude** that in steady-state the **related infrastructure of the 345 kV transmission line** together with the entire **Andes substation operate correctly** with the integration of Llasa Amuki wind farm. Table 25 includes load flow results of the **345 kV transmission line, voltages and loading levels** have an **acceptable performance**; in this case almost **300 MW** are being successfully **transferred to SADI**. The **loading** of the line is similar to the previous case **46.4%** and a **reactive power flow from SADI to SING**, where the **line** itself is generating about **62 Mvar**.

Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	0.98	1.03	33.39	13.74	46.45	170.81	309.10	-298.72	-103.75	41.81	10.37	0.56	0.49

Table - 25: 345 kV transmission line, SING-SADI/Wind Scenario 3

Wind Scenario 3 demonstrates that energy being generated in SING by means of a wind farm can be transmitted to Argentina **successfully**. Furthermore, the additional power transformer at Cobos has a positive impact in the performance of the interconnection. Likewise, the reactive power generated in the wind farms through the shunt capacitors help to keep the good voltages at Andes substation. Moreover, the **thermal units disconnected** from SADI **do not exhibit problems** with the voltage levels at their terminals as they behave in the same manner as Wind scenario 2.

4.11. SING – SADI/Wind Scenarios 1+2+3

The wind scenarios reported before have been simulated all together in this section. **Lickan Antai, Los Vientos del Desierto and Wayra are SowiTec´s projects with better feasibility**, more advance stage of development and better wind conditions than Llasa Amuki. Therefore, to present a **more realistic approach** and also to not exceed the maximum transmission capability of the 345 kV line, **Llasa Amuki nominal capacity has been reduced to 200 MW** and the others have been kept the same.

This simulation implies a **significant high penetration of wind power in SING**; therefore, as it should have been expected, some **technical complications appeared**:

1. **Voltage levels drops at some of the wind farms´ PCCs**. For instance, levels under permissible limits were shown at Andes substation and electrical infrastructure surrounding Escondida substation.
2. **Low voltage levels** in the terminals of few of the **thermal units** disconnected from SADI.
3. **Tocopilla node** in SING has been so far a **sensitive area** in which some of the generation units exceed dramatically their capability limits by producing **excessive amounts of reactive power** and showing high voltage levels. For instance the generation units **U12 and U13** reached **loading of 163.5%** and voltages above 1.1 pu.

Some of the **solutions implemented**, to overcome these problems, involved **modifications in the tap changers** of some transformers as well as **adjustments in the reactive power generation** of the wind farms. Hence, in order to achieve a good performance and ensure the reliability of the interconnected power systems, the measures listed below were applied.

1. To improve the voltage levels at the interconnection points of the wind farms:

    a. **Increased reactive power capabilities of Llasa Amuki**; each shunt capacitors can provide now a **maximum of 21 Mvar**. By doing this, **acceptable voltage levels are achieved** at Andes substation as well as in some other busbars such as Nueva Zaldivar 220, Tap off Oeste, Laberinto 220. This also has a positive impact in busbars at the Escondida node.
    b. **Increased reactive power capabilities of Los Vientos del Desierto and Wayra** projects; each shunt capacitors can provide now a **maximum of 14 Mvar**. By doing this, acceptable voltage levels are achieved at busbars Escondida Laguna Seca 220 kV and 69 kV, Escondida Oxidos and Escondida 69 kV.
    c. **Tap Changers** of transformers No. 1, 2, 3 **"Laguna Seca 220/23 kV"** were **adjusted** in order to provide an extra 1.875% in voltage.
    d. **Tap Changers** of transformers No. 5 and 6 "**Escondida B2 220/66 kV**" were **adjusted** in order to provide an extra -.625% in voltage.

2. There are **3 thermal units showing low voltage levels** at their terminals, thus the following modification were performed to the tap changer of their connecting transformers:

    a. For thermal unit "sym_8658_1", transformer "trf_8527_8658_1" adjusted in order to provide an **extra -5% in voltage and reach .95 pu**
    b. For thermal unit "sym_8671_1", transformer "trf_8510_8671_1" adjusted in order to provide an **extra -2.5% in voltage and reach .96 pu**
    c. For thermal unit "sym_8695_1", transformer "trf_8881_8695_1" adjusted in order to provide an extra **-5% in voltage and reach .97 pu**

3. To **improve the voltage and loading** performance of **Tocopilla node** in SING:

    a. It was **identified**, in the DSPF model of SING, an **external station controller** applied to the Tocopilla units and keeping a **voltage set point of 1.08 pu**. This caused that during previous scenarios where the Tocopilla problem was mentioned, the units were demanded to produce **excessive reactive power** to maintain the voltage setting. The **solution implemented** was to change the set point of the controller and **fix it to 1 pu**.

The milestones of this simulation are listed below:

- Nominal capacities of the projects are: **Lickan Antai – 115 MW, Los Vientos del Desierto – 154 MW, Wayra – 150 MW and Llasa Amuki – 200 MW**. Thus, a total **wind capacity of 619 MW** is being simultaneously connected to SING.
- PCCs of the wind farms are the same as previous scenarios.
- **Series capacitor** of the 345 kV transmission line is **kept online** to improve the capability.
- Wind farms´ shunt capacitors are able to provide reactive power compensation.
- Second power transformer (345/500 kV) at Cobos substation installed
- **Thermal units in SADI** have been **shut down**. In total **28 units** have been disconnected with a total capacity of **618 MW**. Table 26 shows their terminal voltages obtained in this simulation when modifying the tap changers and during the original SADI High Demand scenario.
- Appendix M, Tables A.55 to A.60, show the load flow results of the selected nodes. Infrastructure such as wind projects´ interconnection line, second transformer in Cobos substation and the reactive power equipment in the wind farms is highlighted in light green for better identification.
- In Table A.55 and **highlighted in yellow, Tocopilla units (U12 and U13)** have been included in order to monitor their operation and keep them under limits.

Thermal Unit	Grid	Active Power [MW]	Voltage Terminal in pu, SADI High Demand	Voltage Terminal in pu, SING-SADI Wind Scenario 1+2+3
sym_8609_1	NOA	20	1.05	0.99
sym_8618_1	NOA	12	1.05	0.98
sym_8631_1	NOA	30	1.05	0.97
sym_8632_2	NOA	30	1.05	0.97
sym_8633_3	NOA	30	1.05	0.97
sym_8658_1	NOA	15	1.02	0.95
sym_8659_1	NOA	20	1.04	0.96
sym_8663_1	NOA	30	1.05	0.99
sym_8671_1	NOA	20	1	0.96
sym_8673_1	NOA	15	1.03	0.96
sym_8683_1	NOA	10	1.05	0.99
sym_8695_1	NOA	15	1.05	0.97
sym_6613_3	Centro	20	1	0.96
sym_6631_1	Centro	30	1.05	1.01
sym_6632_2	Centro	30	1.05	1.01
sym_6651_1	Centro	25	1.08	1.03
sym_5629_1	NEA	20	1.05	0.99
sym_7621_1	Cuyo	20	1.05	1.03
sym_7622_2	Cuyo	20	1.05	1.03
sym_7641_1	Cuyo	24	1.03	1.01
sym_7642_2	Cuyo	24	1.03	1.01
sym_7643_3	Cuyo	20	1	1.01
sym_7644_4	Cuyo	20	1	1.01
sym_7654_4	Cuyo	28	1.03	1.01
sym_7665_1	Cuyo	25	1.02	0.99
sym_7666_2	Cuyo	25	1.02	0.99
sym_7677_1	Cuyo	20	1.02	0.99
sym_7680_1	Cuyo	20	1.05	1.03

Table - 26: Thermal units disconnected in SADI, Wind Scenario 1+2+3

It can be established, through the results in Appendix M that the **related infrastructure to the 345 kV transmission line** and to the interconnected wind projects **performs according to the permissible technical levels**. Therefore, **high penetration of wind power in SING is feasible** from the **steady state** point of view in order to export the surplus energy to SADI. **This condition has been achieved after applying the solutions described earlier during this scenario**. Moreover, major adjustments such as the additional power transformer at Cobos and monitoring the thermal units disconnected from SADI to avoid voltage problems in the systems, are having a positive impact in the performance of the interconnection SING-SADI.

Table 27 shows load-flow results for the **345 kV transmission line** with **good operation** regarding voltages and loading levels; **SADI ends up receiving 554 MW** with losses in the range of 41 MW. The **loading** of the **line** in this scenario is **87.2%** with a heavy need of reactive power consumption by the line itself.

Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	0.956	1.000	63.07	21.25	87.23	153.31	595.56	-554.10	51.28	230.54	41.46	1.05	1.00

Table - 27: 345 kV transmission line, SING-SADI/Wind Scenario 1+2+3

Lastly, it is worth to mention that the **series compensator gets saturated up to 127.6%**, however, by adjusting the tap changers of the transformers at Andes SE and injecting extra reactive power in the SING system through other reactive compensation equipment available, that would help to release some loading of the capacitor bank.

4.12. SING – SADI/Wind-Solar-Gas

Chile is expecting in the near future to improve its current situation regarding supply of LNG; condition that would allow using generation units which are nowadays out of operation. Moreover, the development of solar projects in SING has been ramping up last years with considerable amount of projects under construction and starting operation dates before the end of 2014. Therefore, this section attempts to evaluate the interconnection SING-SADI when the **power to be exported to Argentina comes from different technologies and not only wind projects**. At the same time, this share of generation provides a more realistic and probable scenario than previous simulations.

In order to **not exceed the transmission capacity of the 345 kV line** and to have a balanced share within technologies, the nominal capacity of SoWiTec´s wind projects has been modified. It is important to clarify that during the development process of a wind project, it is a common practice in the industry that the nominal capacity of projects change from a planned capacity at the beginning until it reaches a ready to build stage where the nominal capacity is fixed. This is due to different constraints such as financial, technical or environmental reasons; and in most of the cases it tends to decrease.

- The **new wind, solar and gas generation at SING is in total 555 MW** and its composed by:
  - Wind Projects
    - **Lickan Antai** – **100 MW** instead of 115 MW
    - **Los Vientos del Desierto** – **100 MW** instead of 154 MW
    - **Wayra** – **100 MW** instead of 150 MW
    - **Llasa Amuki** – Due to the low feasibility, the project has been **left out** in this case
    - **Valle de los Vientos** – **50 MW**, described in section 3.6.
    - **Total wind nominal capacity – 350 MW**
  - Solar Projects
    - The projects here considered are listed in [21] and correspond to nearly **30% of the solar projects currently under construction**. In Figure A.1 of Appendix A, the location of these projects can be depicted in color orange.
    - **La Huayca** – **9MW**, connected at Pozo Almonte 66
    - **Pozo Almonte 3** – **16 MW**, connected at Pozo Almonte 66
    - **Quillagua I** – **23 MW**, connected at Crucero 220
    - **Quillagua II** – **27 MW,** connected at Crucero 220
    - Andes – **30 MW**, connected at Andes 220
    - **Total solar nominal capacity – 105 MW**
  - Gas units
    - Due to the lack of LNG fuel, **Atacama power plant** is at the moment working only with half on its available units **TG1A, TG1B and TV1C**. According to CDEC-SING, the remaining units, such as **TG2A would possibly be the first to operate in order to export to Argentina**. In Figure A.1 of Appendix A, the location **of Atacama plant can be depicted in color pink**.
    - TG2A - **100 MW**
    - **Total extra gas nominal capacity – 100 MW**

- PCC of the wind farms are the same as previous scenarios.
- **Series capacitor** of the 345 kV transmission line is **kept online** to improve the capability.
- Wind farms´ shunt capacitors are able to provide reactive power compensation.
- **Second power transformer** (345/500 kV) at Cobos substation **installed**
- **Thermal units in SADI have been shut down**. In total **24 units** have been disconnected with a **total capacity of 553 MW**. Table 28 shows their terminal voltages obtained in this simulation and during the original SADI High Demand scenario. It is relevant to mention that **the units presenting voltage drops in previous scenarios were not disconnected** and original parameters in the busbars of these units were kept.
- Appendix N, Tables A.61 to A.66, show the load flow results of the selected nodes. Infrastructure such as wind projects´ interconnection line, second transformer in Cobos substation and the reactive power equipment in the wind farms is highlighted in light green for better identification.
- In Table A.61, Tocopilla units (U12 and U13) are highlighted in light yellow; **unit TG2A from Atacama power plant is highlighted in light blue**. This is in order to monitor their operation and keep them under limits.

Thermal Unit	Grid	Active Power [MW]	Voltage Terminal in pu, SADI High Demand	Voltage Terminal in pu, SING-SADI Wind, Solar, Gas
sym_8609_1	NOA	20	1.05	1
sym_8618_1	NOA	12	1.05	0.98
sym_8631_1	NOA	30	1.05	0.98
sym_8632_2	NOA	30	1.05	0.98
sym_8633_3	NOA	30	1.05	0.98
sym_8659_1	NOA	20	1.04	0.98
sym_8663_1	NOA	30	1.05	1
sym_8683_1	NOA	10	1.05	1
sym_6613_3	Centro	20	1	0.96
sym_6631_1	Centro	30	1.05	1.02
sym_6632_2	Centro	30	1.05	1.02
sym_6651_1	Centro	25	1.08	1.03
sym_5629_1	NEA	20	1.05	0.99
sym_7621_1	Cuyo	20	1.05	1.03
sym_7622_2	Cuyo	20	1.05	1.03
sym_7641_1	Cuyo	24	1.03	1.01
sym_7642_2	Cuyo	24	1.03	1.01
sym_7643_3	Cuyo	20	1	1.01
sym_7644_4	Cuyo	20	1	1.01
sym_7654_4	Cuyo	28	1.03	1.01
sym_7665_1	Cuyo	25	1.02	0.99
sym_7666_2	Cuyo	25	1.02	0.99
sym_7677_1	Cuyo	20	1.02	0.99
sym_7680_1	Cuyo	20	1.05	1.03

Table - 28: Thermal units disconnected in SADI, Wind-Solar-Gas Scenario

This simulation also encountered some **technical complications at SING**:

1. **Voltage levels drops at some of the wind farms´ PCCs**. Levels under permissible limits were shown at **Andes substation** and at electrical infrastructure surrounding **Escondida substation**.
2. **Tocopilla node** in SING has been so far a sensitive area in which some of the generation units exceed dramatically their capability limits by producing **excessive amounts of reactive power** and showing high voltage levels. For instance the generation units U12 and U13 reached **loading of 159% and voltages above 1.1 pu**.
3. **Overloading of the series capacitor** in the 345 kV transmission line.

The **solutions implemented** to overcome these problems, involved modifications in the **tap changers** of some transformers, adjustments in the **reactive power generation of the wind farms** and activation of some other **reactive power compensation equipment in SING**.

1. To **improve the voltage levels** at the interconnection points of the wind farms:

    a. The **solar project "Andes"** has been set up in order to have reactive power capabilities, thus **injecting 15 Mvar** help to raise the voltage levels of the busbars in Andes substation.
    b. **Increased reactive power capabilities of Los Vientos del Desierto and Wayra** projects; each shunt capacitors can provide now a **maximum of 21 Mvar**. By doing this, acceptable voltage levels are achieved at busbars Escondida Laguna Seca 220 kV and 69 kV, Escondida Oxidos and Escondida 69 kV.
    c. **Tap Changers** of transformers No. 1, 2, 3 "Andes 345/220/23 kV" were **adjusted** in order to provide an **extra 6.25% in voltage**.
    d. **Tap Changers** of transformers No. 1, 2, 3 "Laguna Seca 220/23 kV" were **adjusted** in order to provide an extra **1.875% in voltage**.
    e. **Tap Changers** of transformers No. 5 and 6 "Escondida B2 220/66 kV" were **adjusted** in order to provide an extra **-.625% in voltage**.

2. To improve the voltage and loading performance of Tocopilla node in SING:

    a. The **set point of external station controller in Tocopilla units is fixed to 1 pu**, in order to avoid the excessive generation of reactive power

3. To **reduce the overloading** of the series capacitor and **reach** the current value of **105.6%:**
    a. The 15 Mvar injected by solar project "Andes" helps to reduce the loading
    b. **Activation of shunt capacitors in other parts of SING** in order to generate more reactive power and release overloading of the series capacitor. **These capacitors are highlighted in light orange** in Table A.65

SADI network seems to be operating without major problems during this simulation scenario and no adjustments are needed. On the other hand, **attention to the south transmission system of SING was given** in order to monitor the transmission lines, as according to CDEC-SING this is a **weak point** of the grid, however, **no** further implications with **saturation or voltages were found**.

Regarding the **solar projects -La Huayca, Pozo Almonte, Quillagua I and II-**, their surrounding infrastructure **do not show any negative impact** when interconnecting at busbars Pozo Almonte 66 or Crucero 220; the **voltage levels are successfully maintained** at these nodes. The same happens with **gas unit TG2A**, as the surrounding infrastructure was designed to allow the injection of the entire Atacama power plant. Therefore the extra 100 MW generated are well received with **no major impacts,** plus its reactive power injected helps the system and other units to remain under permissible limits.

Hence, in order to achieve a good performance and ensure the reliability of the interconnected power systems, the measures reported were applied. Through the results in Appendix N, it can be **concluded that the related infrastructure** to the 345 kV transmission line, to the wind and solar projects and to the reactivation of a gas unit, **performs according to the permissible technical levels**. Therefore, this **generation scenario at SING proves to be feasible from the steady state point of view, in order to export energy to Argentina**.

Table 29 shows load flow results for the **345 kV transmission line with good operation** regarding voltages and loading levels; **SADI received almost 500 MW** with losses in the range of 28.5 MW. The **loading** of the line in this scenario is **72.1%** with reactive power consumption by the line itself.

Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	1.022	1.018	53.06	20.11	72.13	171.05	528.39	-499.92	19.68	108.02	28.47	0.87	0.84

Table - 29: 345 kV transmission line, SING-SADI/Wind-Solar-Gas Scenario

4.13. SING – SADI/Wind-Solar at 50%/extra Gas

The intermittency and fluctuation of NCRE such as wind and solar have been a real challenge for the integration of these energy sources into the power systems. Technological improvements and control techniques have been developed and applied for a better and more efficient utilization as well as for securing the supply and reliability of the electrical power system. In this work it is also important to imitate the intermittent behavior of sun and wind in some manner. Therefore, the purpose of this scenario is to **reduce the renewable generation**, presented in section 4.12, by a **fixed step of 50%**; and **substitute this sudden loss by conventional generation** units which in this case is done by turning on more gas units.

Relevant features of this simulation are:

- **The new wind, solar and gas generation at SING is in total 554.5 MW** and its composed by:
    - Wind Projects
        - Lickan Antai – **50 MW**
        - Los Vientos del Desierto – **50 MW**
        - Wayra – **50 MW**
        - Valle de los Vientos – **25 MW**
        - **Total wind nominal capacity – 175 MW**
    - Solar Projects
        - La Huayca – **4.5 MW**
        - Pozo Almonte 3 – **8 MW**
        - Quillagua I – **11.5 MW**
        - Quillagua II – **13.5 MW**
        - Andes – **15 MW**
        - **Total solar nominal capacity – 52.5 MW**
    - Gas units
        - TG1B – **5 MW** increased from previous scenario
        - TV1C – **22 MW** increased from previous scenario
        - TG2A - **100 MW**
        - TG2B - **100 MW**
        - TV2C – **100 MW**
        - **Total extra gas nominal capacity – 327 MW**
- PCC of the wind farms are the same as previous scenarios.

- **Series capacitor** of the 345 kV transmission line is **kept online** to improve the capability.
- Wind farms´ shunt capacitors are able to provide reactive power compensation.
- **Second power transformer** (345/500 kV) at Cobos substation **installed**
- **Thermal units in SADI** have been shut down. The same **24 units**, as the previous scenario, have been disconnected with a **total capacity of 553 MW**. The performance of their terminal voltages is also the same as shown in Table 28.
- Appendix O, Tables A.67 to A.72, show the load flow results of the selected nodes. Infrastructure such as wind projects´ interconnection line, second transformer in Cobos substation and the reactive power equipment in the wind farms is highlighted in light green for better identification. In Table A.68, **transmission lines related to Atacama power plant have been added and are also highlighted in light green**.
- In Table A.67, **Tocopilla units (U12 and U13) are highlighted in light yellow and units from Atacama power plant in light blue**. This is in order to monitor their operation and keep them under limits.

This simulation encounters similar **technical complications at SING** as the previous case:

1. Low Voltage levels at some of the wind farms´ PCCs.
2. Excessive amount of reactive power produced at Tocopilla node; generation units U12 and U13 reached loading of 160% and voltages above 1.1 pu.
3. Overloading of the series capacitor in the 345 kV transmission line.

The **solutions implemented** to solve the problems where in the **same line of adjusting tap changers and in-feed reactive power** by means of compensation equipment.

1. To **improve the voltage levels** at the interconnection points of the wind farms:

    a. **Reactive power capabilities of Los Vientos del Desierto and Wayra projects** were increased; each shunt capacitors can provide now a **maximum of 21 Mvar**. By doing this, acceptable voltage levels are achieved at busbars Escondida Laguna Seca 220 kV and 69 kV, Escondida Oxidos and Escondida 69 kV.
    b. **Tap Changers** of transformers No. 1, 2, 3 "**Andes 345/220/23 kV**" were **adjusted** in order to provide an extra **6.25% in voltage**.
    c. **Tap Changers** of transformers No. 1, 2, 3 "**Laguna Seca 220/23 kV**" were **adjusted** in order to provide an extra **1.875% in voltage**.

d. **Tap Changers** of transformers No. 5 and 6 "**Escondida B2 220/66 kV**" were **adjusted** in order to provide an extra **-.625% in voltage**.

2. To improve the voltage and loading performance of Tocopilla node in SING:

   a. The **set point** of external station controller in **Tocopilla units is fixed to 1 pu**, in order to avoid the excessive generation of reactive power

3. To **reduce the overloading of the series capacitor** and **reach** the current value of **104.5%:**
   a. Adjustment of the tap changers from the 3-Winding transformers at Andes Substation.
   b. Activation of shunt capacitors in other parts of SING in order to generate more reactive power and release overloading of the series capacitor. These capacitors are highlighted in light orange in Table A.71

SADI operates without major problems and the south transmission system of SING performed also with no overloading or voltage issues. Regarding the solar projects, they do not show any negative impact when interconnecting to the system. The same happens with the gas units from Atacama power plant, as the infrastructure is strong enough to operate with the nominal capacity of the whole plant, hence the extra **327 MW generated are handled without problems**.

The results in Appendix O **demonstrate that the interconnection SING-SADI in steady-state can be achieved** with power exchange purposes from Chile to Argentina, and still ensure the reliability and operation of both systems.

Finally, Table 30 shows load flow results for the **345 kV transmission line with good operation** regarding voltages, loading levels and behaving as a sink of reactive power; **SADI received almost 490 MW** and the loading of the line is not even exceeding three quarters of its total thermal limit.

Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	1.011	1.018	52.54	19.83	71.43	169.16	517.61	-489.89	8.14	113.66	27.72	0.86	0.83

Table - 30: 345 kV transmission line, SING-SADI/Wind-Solar 50%/Extra Gas Scenario

4.14. SING – SADI/No Renewables/All Gas and Coal

A **scenario without the presence of renewable resources** was also simulated. This was mainly with the purpose to evaluate the systems´ performance at certain moment when **neither wind nor sun was available**. In this situation conventional generation would have to be put on service in order to compensate the possible demand required from Argentina. The methodology for this scenario was similar as it has been described in the other cases; however, some particularities were shown up which are being briefly explained together with the conditions applied to the simulation.

- **Wind projects deactivated**, hence no wind power is being injected in SING
- **Solar projects deactivated**, hence no solar power is being injected in SING
- The **conventional generation** belongs to power plants **from Gas Atacama and E-CL**, which according to information obtained from CDEC-SING and AES GENER, these generators have the capabilities to start up generation units based in **LNG and Coal**, currently out of service.
    - Gas Atacama units
        - TG1B – Dispatch remains the same as scenario 4.13, hence the unit´s generation was increased in **5 MW**
        - TV1C – Setting remains the same as scenario 4.13, hence the unit´s generation was increased in **22 MW**
        - TG2A - **100 MW**
        - TG2B - **100 MW**
        - TV2C – **100 MW**
    - E-CL units
        - **U16 (Gas)** – Dispatch increased in **120 MW**, from 230 MW to 350 MW
        - **U15 (Coal)** – **106 MW**
        - These units are located in Tocopilla node, in Figure A.1 Appendix A **can be depicted color brown**.
    - **Total Gas and Coal extra nominal capacity – 553 MW**
- **Series capacitor** of the 345 kV transmission line is kept **online** to improve the capability.
- **Second power transformer** (345/500 kV) at Cobos substation **installed**.
- **553 MW** were **shut down** through the same 24 thermal units in SADI; the terminal voltages remained unchanged.
- As previous cases, measures were taken in order to solve similar technical troubles such as low voltage profiles at Andes substation and Escondida node, high reactive power levels at Tocopilla node and overloading of the series capacitor in the 345 kV transmission line. The

measures followed the same line of adjustments in tap changers, change voltage set points of external controllers and activating new reactive compensation equipment.

For this scenario, as most of the **voltage levels and equipment loading** were similar to previous cases and **stayed under permissible levels**, the whole compilation of results has not been included in Appendix. However, it is important to **remark** some aspects such that the **busbar at SING side of the 345 kV transmission line, presented a voltage drop down to .916 pu**. Regardless the tap changer modification at Andes substation or increasing reactive power in the surrounding infrastructure, it was **not able to obtain a permissible levels**.

Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	0.916	1.009	54.32	19.21	74.76	151.57	489.43	-460.15	-40.36	196.09	29.28	0.90	0.83

Table - 31: 345 kV transmission line, SING-SADI/No Renewables/All Gas and Coal Scenario

Despite the voltage level at one of the terminals of the 345 kV transmission line, there is an active power flow from SING to SADI and reactive power flow in the opposite direction, with the transmission line itself consuming most of the reactive power, as it is stated on Table 31.

Further measures to solve the low voltage level of the mentioned terminal will have to be analyzed; this might include connecting additional reactive power compensation or decreasing the amount of power being transferred.

Moreover, the **conventional units** added to this scenario were also showing **low performance regarding their voltage profiles**; therefore the **set point of units U16, U15, TG1A, TG1B and TV1C was changed from 1.02 to 1.04**. This allowed them to operate within the limits but also to generate more reactive power. In Table 32, the load-flow results of Tocopilla units can be seen in light yellow and Atacama units in light blue.

Generators												
Unit Name	Grid	Terminal Busbar	Bus Type	Parallel Machines	Nominal App.Pow. [MVA]	Apparent Power [MVA]	Loading [%]	Active Power [MW]	Reactive Power [Mvar]	Voltage [p.u]	Power Factor
sym_6600_1	Centro	6600 EMBANUCL	SL	1	763.5	618.03	80.95	610.99	93.04	0.990	0.99
sym_8622_1	NOA	8622 TANDESG1	PV	1	270	212.77	78.80	180.29	112.98	1.020	0.85
sym_8623_2	NOA	8623 TANDESG2	PV	1	270	212.77	78.80	180.29	112.98	1.020	0.85
sym_8624_1	NOA	8624 TANDESTV	PV	1	270	243.64	90.24	200.32	138.68	1.020	0.82
U16	SING	Tocopilla U16	PV	1	500	355.79	71.16	350.57	60.74	1.008	0.99
U15	SING	Tocopilla U15	PV	1	147	110.43	75.12	106.17	30.37	1.020	0.96
U13	SING	Tocopilla U13	PV	1	92	82.26	89.42	80.13	18.62	1.000	0.97
U12	SING	Tocopilla U12	PV	1	92	82.26	89.42	80.13	18.62	0.996	0.97
TV2C	SING	Atacama TV2C 15	PV	1	165	100.53	60.93	100.16	8.55	1.000	1.00
TV1C	SING	Atacama TV1C 15	PV	1	165	117.30	71.09	112.18	34.28	1.020	0.96
TG2B	SING	Atacama TG2B 15	PV	1	165	100.61	60.98	100.16	9.53	1.000	1.00
TG2A	SING	Atacama TG2A 15	PV	1	165	100.90	61.15	100.16	12.19	1.000	0.99
TG1B	SING	Atacama TG1B 15	PV	1	165	105.17	63.74	105.17	0.00	0.989	1.00
TG1A	SING	Atacama TG1A 15	PV	1	165	117.07	70.95	105.17	51.43	1.031	0.90

Table - 32: SING-SADI, No Renewables/All Gas and Coal (Generators, Selected Nodes)

Lastly, the load flow results for the **series capacitor** are shown in Table 33, displaying the **overloading of 109.4% and low voltage at one of its terminal**.

Name	Grid	Terminal i Busbar	Terminal j Busbar	Voltage Terminal i [p.u.]	Voltage Terminal j [p.u.]	Current, Magnitude Terminal i [kA]	Total Reactive Power Terminal i in Mvar	Total Reactive Power Terminal j in Mvar	Loading [%]	Nominal Voltage [kV]
Condensador Serie Andes 1/2	SING	Andes 345	Andes Reactor Shunt 345	0.959	0.916	0.90	-157.01	40.32	109.41	345

Table - 33: SING-SADI, No Renewables/All Gas and Coal (Series Capacitor at the 345 kV transmission line)

In general, based on the load-flow calculation, **SADI behaves correctly and SING shows no further implications than the ones described in this section**. The steady-state operation of the SING-SADI interconnection functions correctly, even with the absence of NCRE projects.

4.15. N-1 contingencies

Contingencies are necessary to be evaluated in case of a failure in the system, this in order to ensure the reliability and continuity of electric supply. The criteria N-1 is widely used to assess these conditions. **SING-SADI/Wind-Solar-Gas** reported in section 4.12 is considered very realistic as well as stresses the transmission capability in a good level; therefore, the **contingencies are applied to this scenario**.

Three contingencies were simulated, the implications found are stated below:

1. **Loss of the 345 kV transmission line**

The load-flow calculation converges meaning that **both systems are able to operate in steady-state** even when a sudden disconnection of the 345 kV line happens. In general both systems´ **infrastructures seem to work under permissible levels**. However, **Andes substation shows 1.09 pu voltage level at the 345 kV busbar**, this impact could be diminished by readjusting the tap changers of the transformers, by activating shunt rectors in the system or by employing an automatic disconnection generation system. As more generation is required at SADI and less generation at SING, the **distributed slack approach helps in this condition** to achieve a balance in the systems even when working separately due to the contingency. Further attention needs to be paid to the operations limits of the generation units.

2. **Loss of the second power transformer (450 MVA, 345/500 kV) in Cobos substation**

This represents the **most critical situation** as in the case of a contingency where the second transformer is lost, the **remaining transformer** at Cobos substation gets an **overloading of 148%;** besides this, the rest of the infrastructure operates well. However, an overloading of this magnitude will definitely **limit the transfer**. On the other hand, the 345 kV transmission line exports 528.7 MW and loaded of 72.3%, the receiving end gets 500 MW and the lines behaves as a consumer of reactive power. The series capacitor shows a loading of almost 106%. The slack bus stands within limits with only 81% overloading and 610.3 MW and 99 Mvar in-feed. The distributed slack is again balancing the active power in the systems.

3. **Loss of one power transformer (250 MVA, 345/220/23 kV) in Andes substation**

The **other two transformers at Andes substation get overloaded up to 110.5 %**, the **series capacitor presents an overloading of 106%**; these overloading levels might be acceptable but it corresponds to the operators to evaluate the condition. The 345 kV transmission line is still transmitting 527 MW with a loading of 72.5 %; furthermore, **the voltage levels of busbars in Andes, Encuentro and Escondida nodes are kept under acceptable levels**. The two power transformers (450 MVA 345/500 kV) at Cobos substation present a loading of 85% and no problem in the voltage levels. **The distributed slack is again adjusting the active power in the systems**.

4.16. Brief insight of possible Dynamic and Stability Issues

The information and data in this section was mainly collected during meetings with CDEC-SING, CAMMESA and AES GENER; it outlines some facts and technical issues related to power system stability of the SING-SADI interconnection from a dynamic perspective. It is also important to remark that SADI DSPF model does not contain dynamic parameters as stabilizers, speed or voltage regulators.

There was the believe that due to the significant different sizes between SING and SADI, in the case of any contingency, incident or fault; SING was going to receive the worst negative impact, such as a complete outage or partial blackout. Nevertheless, tests performed have proved otherwise; there have been two main power flow trails, one involving 50 MW transfer and the other with 150 MW. SING has a low frequency regulation capability, primarily due to the inertia characteristics of the thermal power plants; therefore, when interconnecting the systems, there are in fact positive dynamic implications such as the improvement of this regulation.

Recently, as the two system operators have been analyzing the interconnection option more in detail, it was noticed that an oscillatory mode of approximately 0.3 Hz appears when establishing the interconnection. The power involved in this oscillatory mode is known to be minimum; however, the problem is that the mode is continuously excited due to the variability in the demand of SING, which varies importantly for a power system of its size.

It is foreseen that due to the mode previously mentioned, adjustments will have to be performed to the power system stabilizers at some of the major generation units in SING. But before doing such arrangements, simulations are needed to evaluate the damping of the oscillation. Moreover, the installation of the second power transformer (450 MVA 345/500 kV) at Cobos substation, which is currently ongoing, is essential to achieve the SING-SADI interconnection.

Thinking about power flow from SADI to SING, the interconnection transfer could easily reach 650 MW or the total amount allowed by the transmission capacity of the 345 kV line. However, the flow from SING to SADI might have to be limited due to dynamic constraint of the oscillatory mode, which still needs to be further evaluated and studied.

Another dynamic issue, in the need of even much more better understanding, is the possibility that the steam turbine installed at Salta power plant might enter into a state of sub-synchronous resonance when operating at the same time as the series capacitor of the 345 kV transmission line.

Consequently, considering these matters to be assessed, it is being thought for a first stage to start with a power transfer of 250 MW, and once having further insight in the dynamic issues, increase it up to 450 MW as a second stage; until finally reach the total transmission thermal capacity of the line.

Chapter 5

5. Analysis of commercial feasibility

A successful and mutually convenient energetic interconnection can be a tremendous catalyst for economic integration. Potential benefits to be gained by interconnecting electrical systems, may be referred such as: contribution to the diversification of the energy mix, allowing more efficient use of electricity infrastructure, enable better use of generation resources, support in emergencies or contingencies and improving the reliability/quality of the supply.

This leads to think that in the short term, Argentina and Chile should continue moving forward to reactivate the operation of the 345 kV transmission line in order to allow the electrical interconnection SING-SADI. This should be done under certain technical circumstances where the reliability and continuity of supply of both systems is secured. Additionally, the creation of a clear and strong policy framework stating the agreements between all the parts involved is required.

In a general perspective, some of the features and points that the policy framework should enhance are:

- Point to the conformation of integrated, stable and transparent energy markets.
- Grant the possibility to the energy players to buy and sell energy, regardless of origin and destination.
- Free and non-discriminatory access of consumers and producers to the transmission and distribution systems
- Regulate and enable the possibility of transactions not only between Chile and Argentina, but also with third countries in order to enhance a wider electrical market
- Regulate the chance to operate and trade energy within the different commercialization schemes available in each country
- Regulate suitable reciprocity for the treatment of export and import, in terms of tax and subsidies
- Design of arrangements robust to non-compliance behaviors

Steps have been taken, as a first stage, to technically prove the viability and feasibility of the interconnection SING-SADI, without this nothing can be done. Once completed, the next stage would be to analyze how these exchanges can be achieved from a regulatory perspective. Most probably, it will tend to be similar to what is being hold between Argentina and Brazil, in which several modalities are currently applied and could be replicated for the case Chile and Argentina.

1. One is the emergency mode, and is based on an agreement between the operators of the system. Thus, in the presence of an emergency in Chile or Argentina, the other country helps the one in need. This is for emergency situations that last no more than five days, small amounts of energy are involved and it is fast to achieve. For example, if the system of any of these countries crashes or there is an unexpected event, the other country helps by sending energy. This would work only as an agreement between system operators, CDEC-SING and CAMMESA. There is no valuation on this case, meaning that the energy exported or imported is measured, balanced and in the long term tends to zero. Hence, there are no commercial transactions; neither of the two countries pays to the other.

2. The other modality is an agreement between countries in order to commercialize energy. This agreement has basically two variations; import with a payment or import with refund. In the case of import with payment, if Argentina imports energy from Chile, this one registers the hours that the machines generate energy in order to supply Argentina. Afterwards Argentina, based on the register received from Chile, pays the generation costs, transmission costs, losses and all the costs involved. In the case of import with refund, it could be that Argentina imports energy in winter and in spring gives it back; and if Argentina exports energy, there is a refund of it during a different time. Beyond the losses, the option with refund tends to be balanced.

The emergency mode could be one of the first ones to be applied to the interconnection between Chile and Argentina, thus an agreement between CDEC-SING and CAMMESA will be required. Moreover, as the Argentinian system is bigger than the Chilean one, it would be easier for Argentina to help Chile; but at the end of the day this will depend on the supply and available generation units of each country.

The two modalities previously described are feasible to be performed. Therefore, a two-way exchange could be carried out between the two countries, meaning that energy could be requested based on the information from generation units to be dispatched at each side. The most expensive ones would likely be assigned for the international exchange; thus, the units establishing the marginal cost would be available to export. If the countries are willing to pay the cost, the exchange would be executed; otherwise the energy would be generated with local generation units.

In the case Argentina-Brazil, everything is done through a “trading company” which performs all the commercial transactions and payments. Moreover, as Argentina and Brazil operate with different electrical frequencies, there is a power converter station which also involves costs and an extra remuneration, however all these are now regulated by law and CAMMESA only pays this extra fee when it is used. Something similar could happen in the case of the interconnection Chile-Argentina; as owner of the 345 kV transmission line, one option for AES GENER would be to collect tolls for the use of the line, remuneration that Chile or Argentina will be willing to pay whenever the transaction is done.

Moreover, depending on the type of units used to export, most likely marginal units, plus the transmission costs, tolls and trading; the exporting price could end up being high and no longer attractive. Therefore, establishing the costs involved and ensuring reasonable prices will determine how feasible this exchange could be. The more expensive it is; the less likely there would be an exchange as each country in this case would prefer to generate with its own generators.

Regarding the costs that would be probably involved in the transaction, the exporting cost would mainly consist of: tolls, transmission costs linked to what is known as “AVI-COMA” (Annuity Investment Value, Operation Cost and Maintenance) and, if involved, a trading company fee. Eventually if the exporting cost gets too high, the regulations would have to set limits and create a framework so that the costs are not excessive. Nevertheless, as the 345 kV transmission line is categorized as additional transmission system, the cost will basically depend on an agreement between the involved parts.

On the other hand, Argentinian regulation does contemplates the figure of trading company, whilst in Chile would have to be created and added in the new regulations. Nevertheless, one possibility is that AES GENER could also act as a trading company, which would only represent an extra income. According to AES GENER its main objective is to recover the investment of the 345 kV transmission line through tolls and transmission costs; without interest at the moment of exporting its energy generated in SING as this is already committed to the mining. Therefore, it is likely that other companies like Gas Atacama or E-CL would be in charge of exporting as they have currently installed capacity not being dispatched.

As it was commented earlier in this work, Argentina has an existent regulation allowing international electrical exchanges. However, Chile needs to prepare and build up a solid policy framework in order to properly manage this future transaction; and at the same time make it compatible to the current regulation in Argentina. Hence, a supreme decree from competent authorities in Chile, such as the ME and CNE, need to contemplate:

1. Definition of the cost structure in which the import or export transaction between systems will be based
2. Protocols and operation coordination between CDEC-SING and CAMMESA
3. SING commercial and economic regulation of electrical in-feeds or withdraws
4. Deficit scenarios conditions and mechanisms for conflict resolution

Additionally, there are some relevant parameters that this work recognizes necessary to be included in regulatory framework, which form part of the ideas that are being considered so far in order to constitute the policy scheme that would govern the economic transaction and rule its operation:

- Maintain or improve the security of the systems
- The import or export must not adversely affect the electricity prices of the local electrical market; hence the local in-feeds or consumption margins must remain the same in spite of the interconnection. This condition would be reached with a surplus transfer scheme, as during normal operation of the system this is not part of the dispatch.
- Imports or exports must always be considered as an opportunistic condition. The domestic supply of SING and SADI are priority; therefore, the 345 kV transmission line will have to operate in an interruptible interconnection scheme.
- Minimize risk of non-payment conditions for exporting generators.
- Possibly consider a prepayment before carrying out the exportation.
- Consider other options such as an energetic exchange in which Chile contributes with electricity and Argentina with gas.

It might be possible to have the regulatory framework ready by the end of 2014, but it also requires a high level of political will from Chile and Argentina. It is essential that the two governments get involved in creating a strong and clear agreement in which necessary details are set, final costs determined and also legally establishing the local market prices not to be affected due to the transaction.

At the present time Argentina has no surplus energy, hence any exchange is attractive, but it will all depend on costs. The exchange of energy could be even more feasible in the direction Chile to Argentina, especially because of the considerable large surplus that SING has.

Finally, as it is likely that the regulatory framework will be based in one of the methods, currently on-going, between Argentina and Brazil; there are still features that will have to be defined specifically for the case SING-SADI. Thus, as an objective of this work, a possible structure of the operative scheme to manage the transaction, in the case of exporting from Chile to Argentina, is next presented in order to gain further comprehension regarding the interconnection SING-SADI:

- In a weekly basis programming, CAMMESA might requests a volume of energy with detailed schedule or in other words, an exporting demand. The trading company asks for it to CDEC-SING, which would consider SADI as a new demand in Andes substation. This demand will have to be supplied by power plants not being involved in local dispatch at SING.

- CDEC-SING dictates whether the security of the service is affected or not, and determines the feasibility of the operation. It could be thought about a weekly pre-dispatching, with the possibility of daily and hourly checks, in case of failure units.

- CDEC-SING requests offers to the available and not dispatched generation units, hence conforming in this way the exporting offer and price.

- If CAMMESA accepts the cost conditions, the exporting demand and offer would be scheduled in a weekly planning; with neither impact on the internal economic dispatch nor in the local prices.

- CAMMESA prepays to the trading company the total exporting energy according to the prices given by the power plants involved in the transaction, including the exporting energy to cover electrical losses at SING and at the 345 kV transmission line. Transmission costs until reaching Cobos substation and tolls associated with the withdraw from Andes substation will have to be included.

- The trading company makes the necessary payments to the corresponding SING agents, and possibly receives a commercialization fee itself.

- Argentina will receive the energy at the 345 kV busbar in Cobos substation, for further transferring to SADI through the 500 kV busbar.

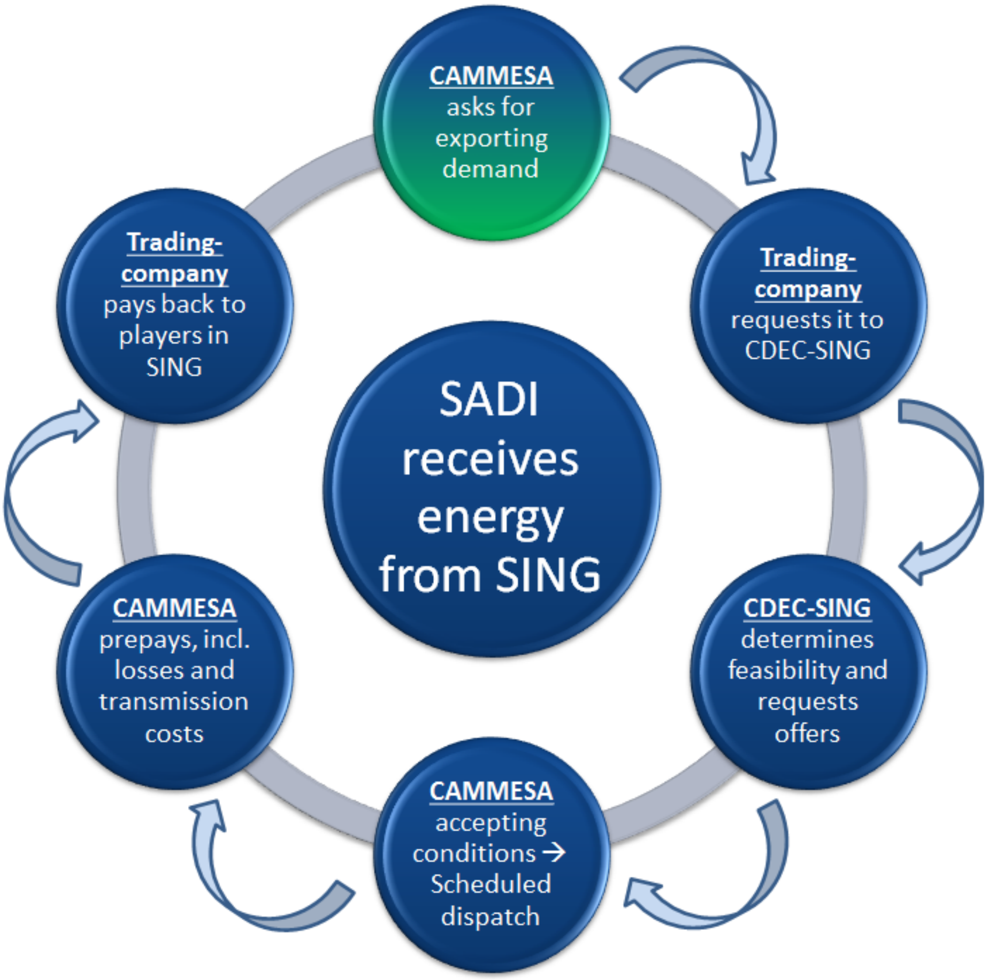


Figure 19 – Possible operative scheme to export power from Chile to Argentina

The regulatory framework would need to be eventually enriched as it seems that if this were carry out immediately, it would operate at the beginning at a spot market level. The next stage would be to have an agreement between a Chilean generator and a consumer or load located in Argentina. This would simplify the transaction operation, as there would be a contract giving the security to carry out the exchanges. Moreover, this contractual level option would also reinforce defining the interconnection as such.

At SING, in the case of commercializing in the spot market, power plants based on NCRE are generally dispatched to supply the local demand due to their low generation cost. Therefore, the contract alternative would open another option for these technologies to trade their generated energy with possibly a higher price. For this reason, it would be ideal that the regulatory framework could integrate the option, for instance for wind developments such as Llasa Amuki in the need of better commercial conditions to become a feasible project, to hold contracts not only in the local market but also in Argentina. This could be achieved by making use of the current commercialization schemes at each country, described in sections 1.2.6 and 1.2.7, and include in such a way that a heavy user in SADI could hold a PPA with a wind or solar power plant in SING or a distributed auto-generator having its demand in Argentina while generating in Chile.

Moreover, it would be also desirable that the NCRE attribute available in Chile, could be extended and apply it also in the case of exporting to Argentina; this would not only boost the NCRE projects in the zone, but would support both countries in achieving their renewable energy targets.

Finally, thinking in future scenarios in which the framework to be done enhances a real integration of the power systems, SoWiTec´s projects interested in trading energy locally or exporting to Argentina through an interconnection at Andes substation, should comply with AES GENER requirements, which among other the following is needed:

- A connection agreement that involves impact studies such as protections and short circuit, deadlines to complete the interconnection, construction conditions as well as experts involved in supervising the construction.
- Required reinforcements to the substation would need to be paid.
- If the interconnection is through a transmission line, the interconnection busbar has to be transferred. This is for operation, maintenance and reliability reasons.
- Hold the necessary property or land lease agreement for related infrastructure
- Establish and sign toll agreement
- Initial contributions in order to cover start-up expenses

Chapter 6

6. Conclusions & Further Work

6.1. Conclusions

The interconnection SING-SADI has been evaluated through load flow calculations in DSPF computational tool, this in order to assess the technical capabilities of the line to transmit power from Chile to Argentina.

Moreover, it can be stated that the research questions and sub-questions have been answered trough out this work development. From the technical part of this work, it is concluded that **the 345 kV transmission line is technically capable from a steady-state condition to transmit SING´s surplus energy to SADI**, without compromising the reliability of the two power systems.

The active power flow was of **4 MW from Argentina to Chile** in the **null transferring case** where both power systems are supplying their own demand but interconnected through the 345 kV transmission line connected. Furthermore, it **reached up to 618 MW transfer from Chile to Argentina** when stressing the line until **maximum thermal transmission capabilities**, implying an **overloading of 100.2%** in the line. This maximum power was achieved by **employing the series reactive power compensation** installed in the line, which indeed improved the transmission capacities of the line itself.

Simulation scenarios were created in which the interconnection was assessed not only on extreme conditions, but also with **different penetration levels of wind power** being generated by **SoWiTec´s projects**. Lickan Antai, Los Vientos del Desierto , Wayra and Llasa Amuki projects were simulated on separate scenarios but also **combining their projected capacity** to reach a receiving power in Argentina of **554 MW**. In this case of high wind power penetration, technical **complications** had to be faced such as **drops in voltage levels of the PCCs and surrounding infrastructure**; however this was mitigated by increasing the reactive power capabilities of the wind farms. Therefore, each wind project will have to be capable to **supply reactive power to the grid in the range of 28 – 41 Mvar**. SoWitec can take this into account for the current developing phase and further stages of the projects, as it could have an impact in the type of wind turbines to use or the reactive compensation equipment to install.

In addition to wind power, **solar power was also included** in this work according to the official Chilean energetic planning. **Conventional sources based on gas and coal**, which according to CDEC-SING would possibly be the **first units to generate for exportable purposes**, were as well included and evaluated. These scenarios made the study more realistic and complete in order to be taken as a reference for the future realization of the interconnection.

The **availability of the renewable resource** was considered in the simulations by setting three fix steps of penetration levels **100%, 50% and 0%**; where the conventional energy contributed with extra power in order to satisfy the demand. For instance, **wind power was scaled from 0 to 350 MW**, **solar power from 0 to 105 MW** and **conventional energy from 100 to 553 MW**. Some of the **technical problems to overcome** during these simulations were **low voltage levels at Andes substation** which was **solved by injecting 15Mvar**, and/or by **adjusting the tap changers** of the 3-winding transformers at the substation in order to allow **6.25% voltage regulation**. Slight **overloading** of the series capacitor was shown and **reduced until avoid exceeding more than 105%,** which could be a permitted by CDEC-SING under certain circumstances.

Active power flow was successfully established from SING to SADI; whereas the **reactive power performance of the 345 kV transmission line**, also part of the research sub-questions, **changed throughout** the simulated scenarios from being both **source and sink** of reactive power, as well as allowing an actual flow in the opposite direction than the active power, meaning from Argentina to Chile. This was **due to the voltage magnitude differences** presented at the terminals of the transmission line and the **ratio of active power being transferred/surge impedance loading (SIL)**.

An **important part of this research** and study was to **monitor the electrical infrastructure** linked to the interconnection nodes in order to make sure that **voltage levels and loadings** were **kept under permissible limits** according to the technical policies on each country. There were some situations in which even applying the proposed **corrective measures**, voltage levels remained out of limits. This is the **case of the simulation where there is no availability of renewable resources**, so the voltage level at **Andes substation terminal** of the 345 kV transmission line shown a voltage drop down to **.916 pu**; which was not able to correct. Despite this specific case, **permissible levels in the selected nodes were reached** in most of the simulations by **adjusting tap changers** of some transformers or by **increasing the generation of reactive power** in the system through compensation equipment in the wind farms or already installed in SING.

It was also appreciated that **through the interconnection SING-SADI** and the adjustments, part of the solutions implemented, **voltage levels from selected nodes can be improved in comparison to the base cases or null transferring scenario**. For instance when stressing the line to maximum capabilities, voltage levels in SADI 132 kV infrastructure get back to permissible levels. **Results of the selected nodes were documented** and presented in appendixes.

A **maximum of 100% thermal loading** in the infrastructure was **targeted**, however in some cases overloading occurred. This lead to an **important finding** regarding the power transformer in Cobos substation, were excessive **overloading up to 162%** occurred; hence the **need of a second power transformer** (345/500 kV, 450 MVA) was confirmed and **installed** in order to split the load and reach a maximum loading on each transformer of **90%**. In the absence of this new installation the interconnection gets compromised and the power able to be transferred decrease substantially. In the case of the **345 kV transmission line**, the thermal load varied from **25% to 100.45%**; therefore this support that the steady-state operation of the transmission line is acceptable.

Furthermore, the **distributed slack** is considered to be satisfactory in order to simulate the systems interconnected with a **more realistic approach** and have an integrated power control where all the generation units available are involved in the power balance. The advantage of this approach was even more evident when performing the contingencies; as for example when the 345 kV transmission line fails and the systems are interconnected, SADI has a significant large demand needing to be supplied. Therefore the distributed slack **contributes by adjusting extra power from the available units**; however further insight in this condition is needed as capability limits from some units might be exceeded and transient stability or start-up time of reserves might be also an issue.

Finally, the **thermal units switched off in SADI were monitored** in all simulations were modification to the original dispatch was performed. During the **maximum transfer scenario**, there were in fact some **units located in NOA** with important voltage **drops down to .86 pu**; this was **solved** by **adjusting the tap changer** of their connection transformer. Subsequently, the **five thermal units** showing voltage issues were **left on service** and **no major problems** were detected afterwards in the **other 24 units** with a combined capacity of **553 MW**. Therefore it is believed that this issue could be indeed a local problem related to the SING-SADI interconnection, but only for the five thermal units identified and under certain operational conditions. **Disconnecting the rest of thermal units seems feasible and viable to substitute their generation by imported power from SING**.

Second objective of this work was to **obtain comprehension about the commercial structure** that the interconnection SING-SADI will get. Meetings organized and communications with staff from CDEC-SING, CAMMESA and AES GENER were very important to guide and achieved this goal. From a regulatory a policy perspective, **everything points towards Chile and Argentina keep moving forward to reactivate the operation of the 345 kV transmission line and make the interconnection possible**.

An **overview of the ideas** being at the moment considered to be part of the policy framework to rule the transaction, have been given. Therefore, it can me mentioned, the path that this future interconnection is taken at a regulatory level was **documented and stated successfully**. Indeed, the **scheme will tend to be similar** to what is being done between **Argentina and Brazil**, in which emergency mode with no economic valuation and transactions with payment or refund will be managed.

Nevertheless, to base and replicate the policy framework is feasible until some extend, as features and **particularities of the case Chile and Argentina need to be analyzed** and taken into account. For instance, **Chile** is in the prompt need of a **supreme decree** to define among other things the cost structure of the transaction, protocols and operation coordination between system operators, regulation to allow international electrical transactions and to create deficit scenarios conditions as well as mechanisms for conflicts resolution.

To make the **interconnection profitable** and commercially operational, it will need to take into account relevant features such as being **interruptible** and not to affect the electricity prices of the local markets which could be achievable with a **surplus transfer scheme**. However, further stages would be to make use of the current commercialization schemes and allow them to be used across the border, in order to permit holding a PPA between a Chilean generator and a consumer or load located in Argentina. This work states that **contractual agreements would be essential** not only to enhance an integrated interconnection but also to boost both electrical markets and further promote generation through NCRE projects.

A good insight and specially the intension, of the players involved, to include regulations in which a wider interconnection and more solid scheme can be created, was documented. Important actors, such as CDEC-SING, CAMMESA, AES GENER and even governmental entities are aware that **contractual options should be included in order to enhance the integration of both electrical markets**. Therefore, SoWiTec should continue its development activities while being optimistic that regulations will come to empower the interconnection which could represent important business opportunities.

6.2.Further work

As further work it is recommended to process information about grid expansions in both SING and SADI in order to contemplate these future reinforcements together with the actual year in which the wind project are being planning to start operation. It would be also desirable, once including the expansion information into the DSPF models, to simulate additional contingencies N-1 in order to support the result of this work.

Studies regarding transient and sub transient stability issues will be definitely necessary to finalize the technical assessment of the interconnection SING-SADI. Some of the dynamic issues which could be taken as starting point are the ones briefly described at the end of Chapter 4. They might represent further limitations and technical constraints to be evaluated and finally determine the total feasible capacity to be transferred. Dynamic models for this task will be necessary to obtain as well as a DSPF license permitting this type of studies.

It will be up to CAMMESA to decide which units to switch off in SADI in order to substitute their generation with power being exported from SING; hence, further understanding in the technical implications at local level of these disconnections will be needed. It would be also required to clarify with CDEC-SING the original setups of the Tocopilla node, have further insight on its operational conditions and perform possible adjustments to the results and solutions presented in this work.

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Appendix A

DSPF Diagrams of SING and SADI

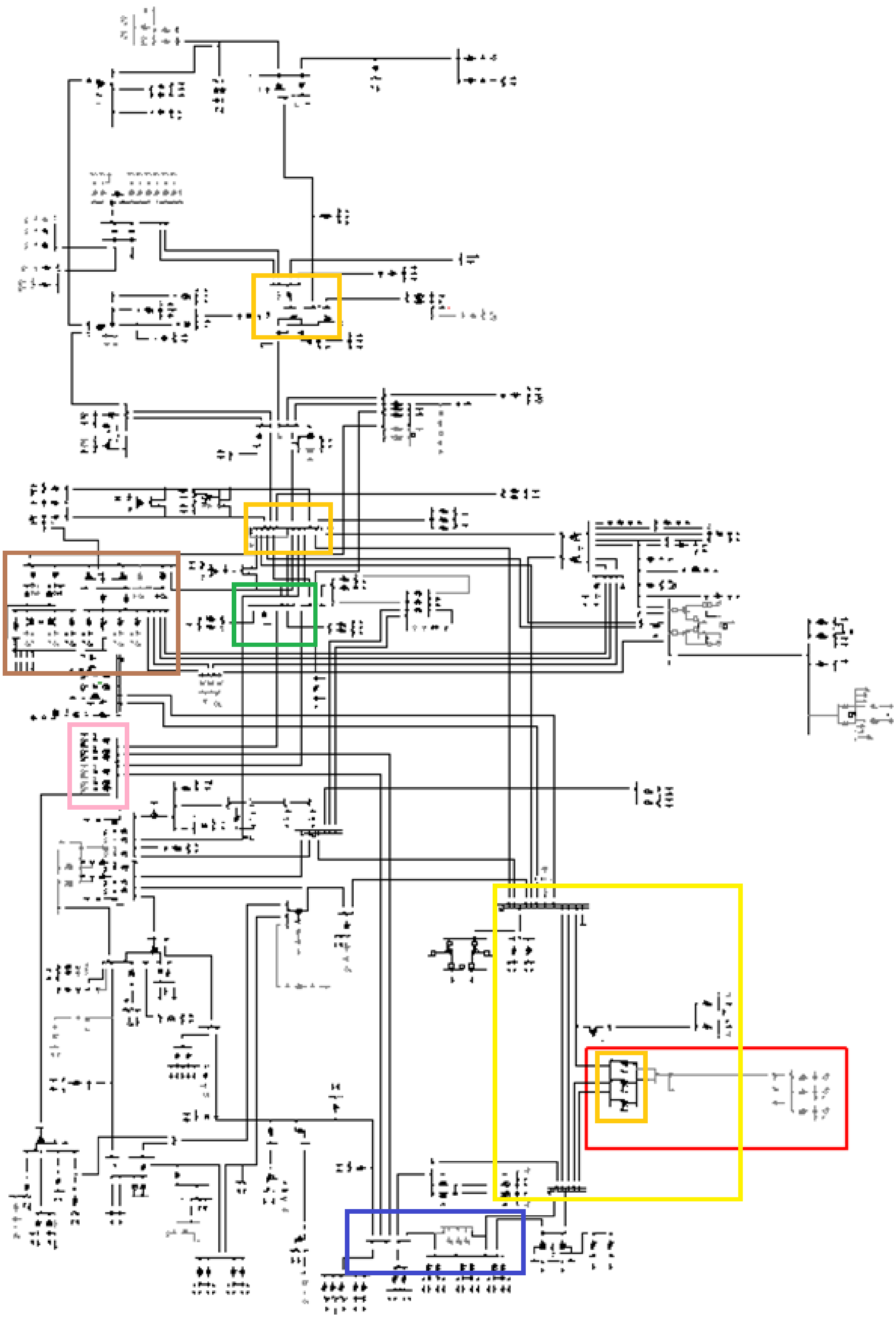

Figure A . 1 – DSPF SING Diagram

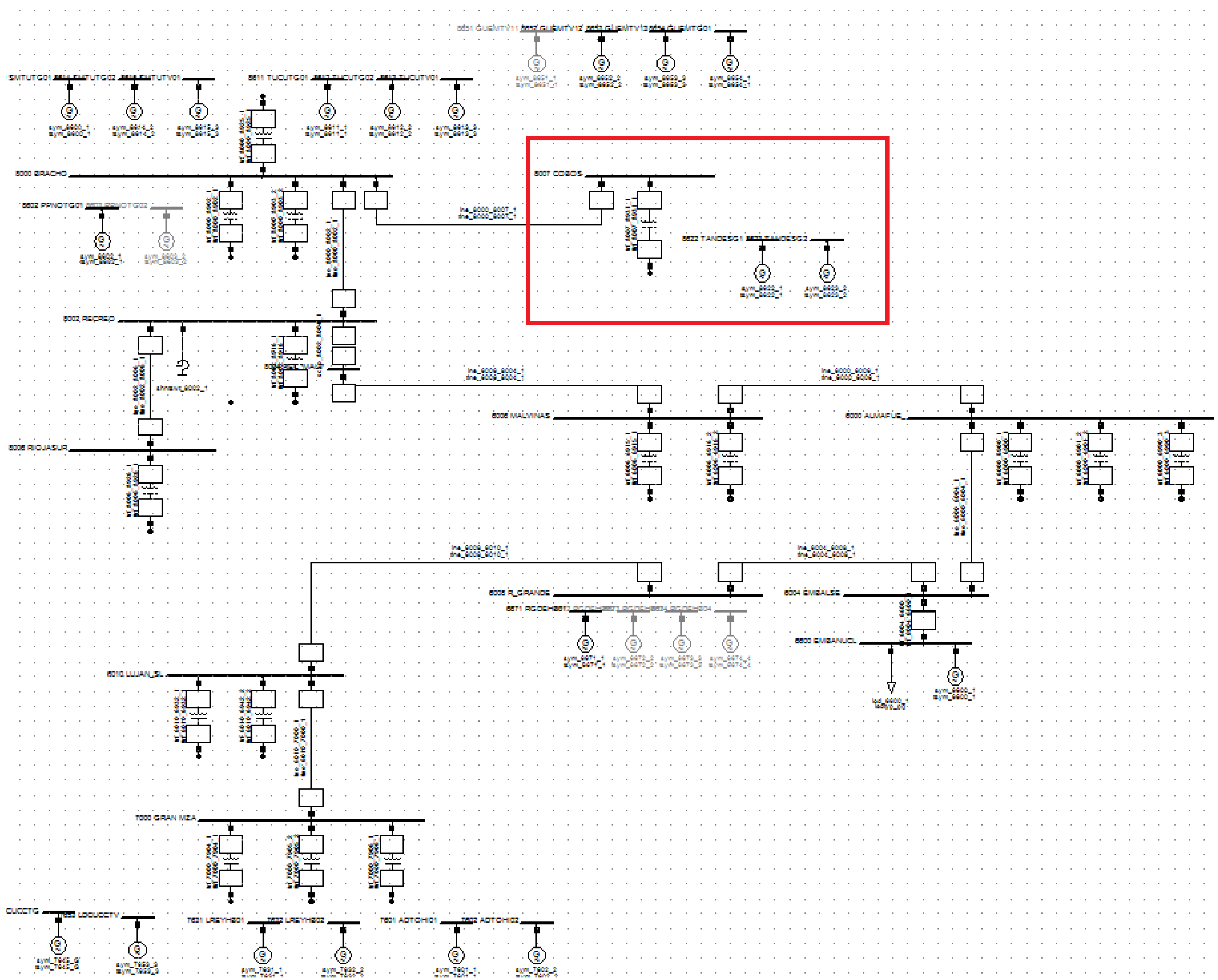

Figure A . 2 - DSPF SADI Diagram (500 kV infrastructure CENTRO, CUYO and NOA)

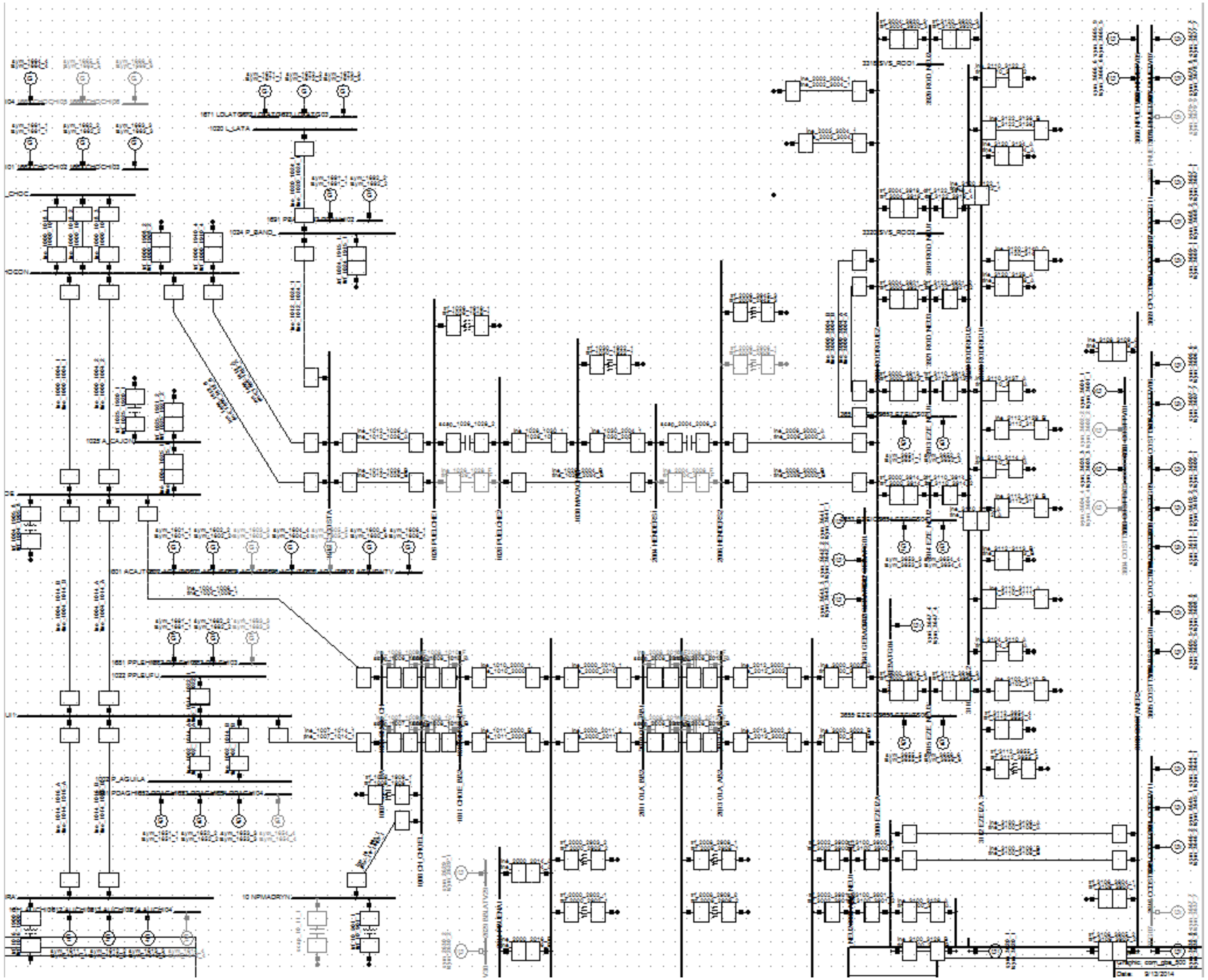

Figure A . 3 - DSPF SADI Diagram (500 kV infrastructure COMAHUE and GRAN BUENOS AIRES)

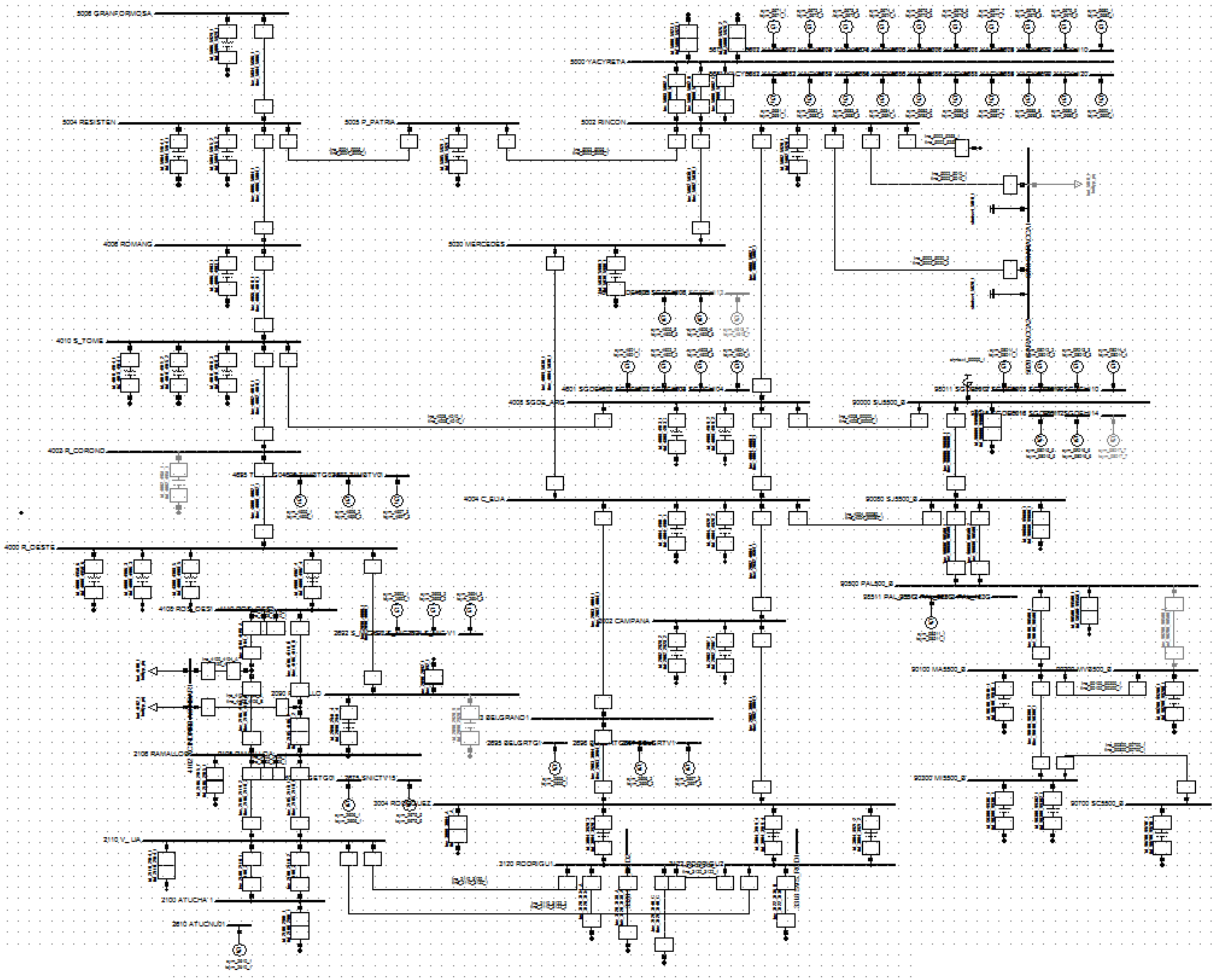

Figure A . 4 - DSPF SADI Diagram (500 kV infrastructure NEA and LITORAL)

Appendix B

Single Line Diagrams of
Andes and Cobos Substations

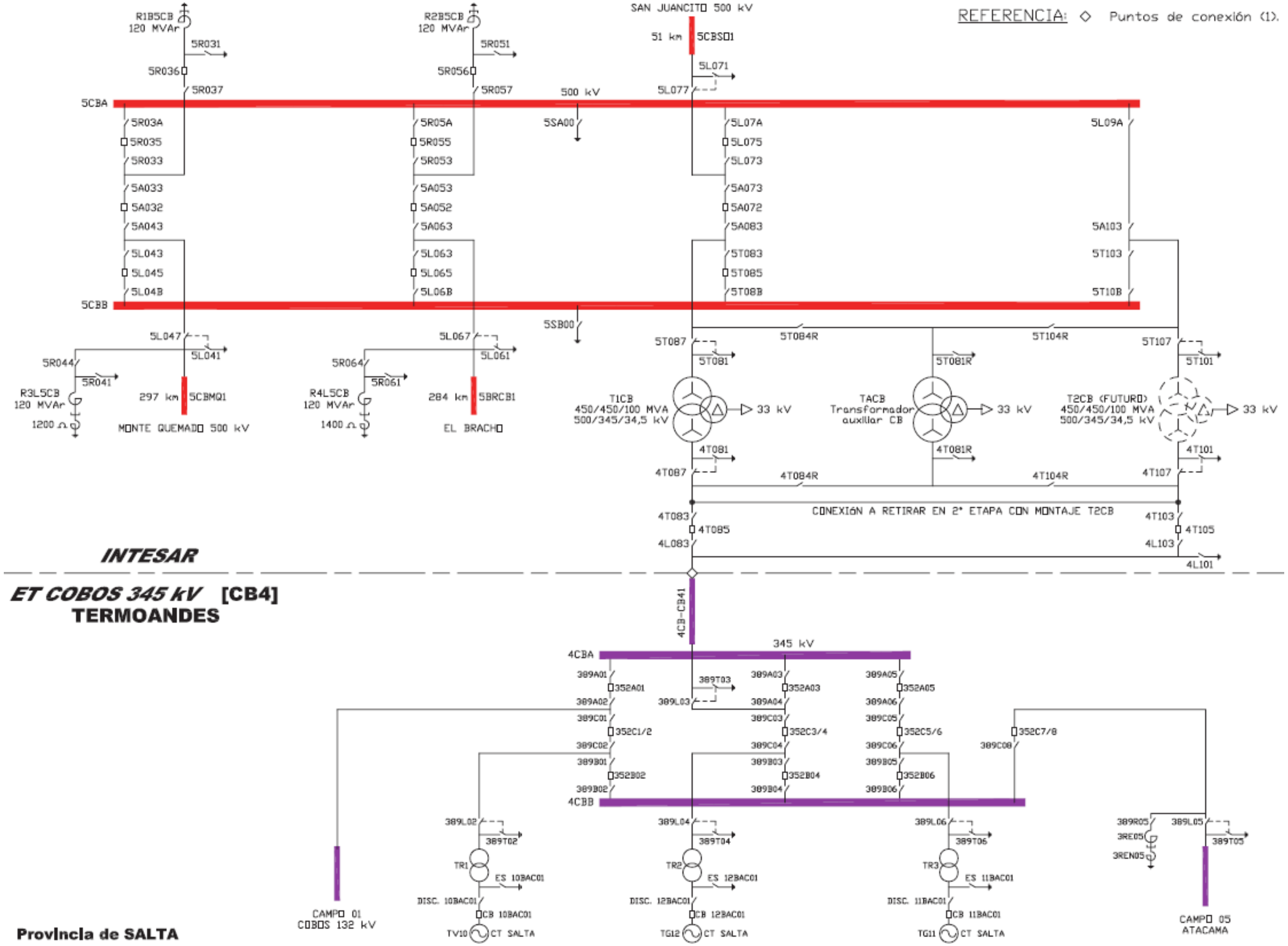

Figure A . 5 – Cobos Substation Single Line Diagram

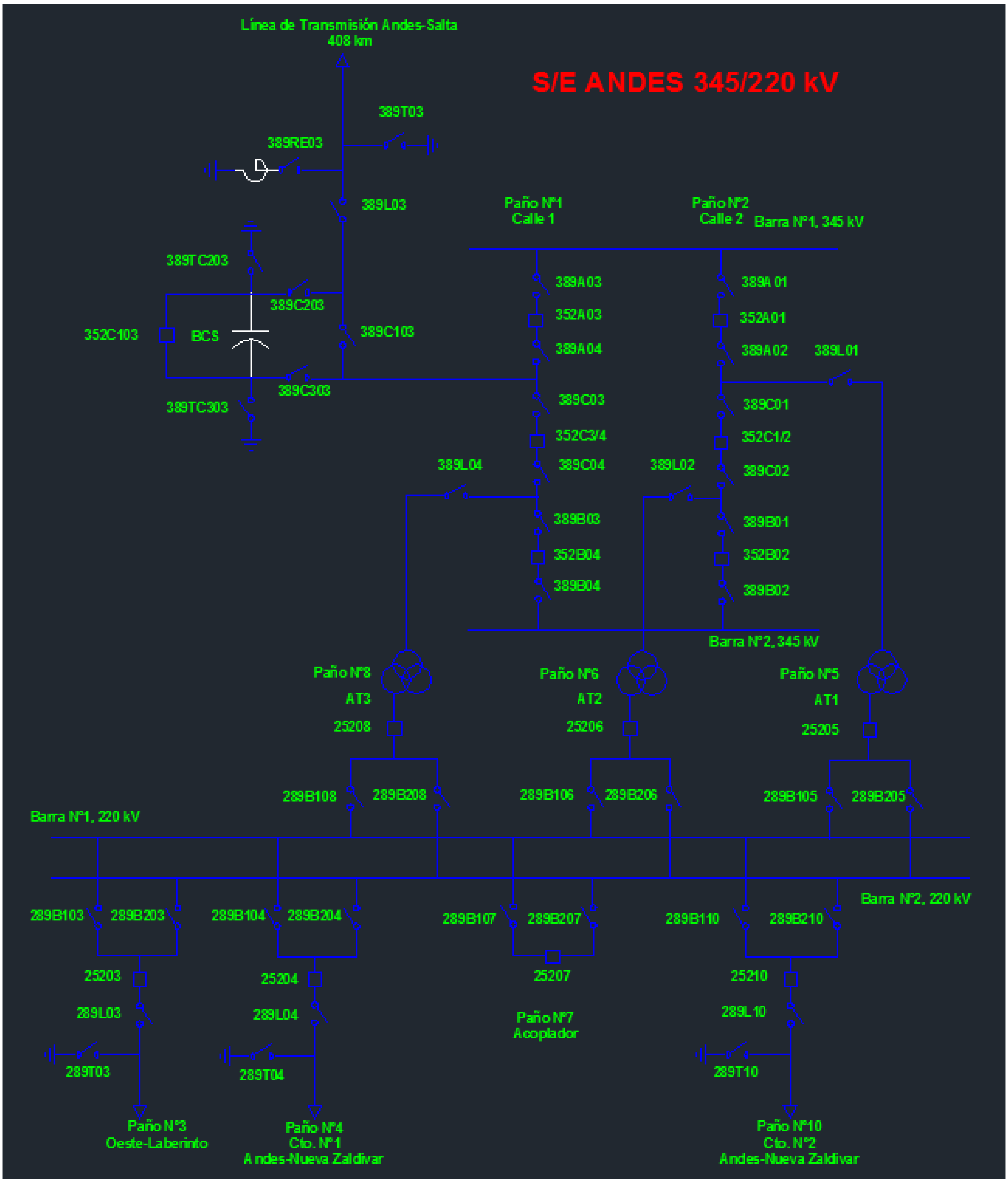

Figure A . 6 – Andes Substation Single Line Diagram

Appendix C

SING – High Demand, Load-Flow simulation results

Generators

Unit Name	Grid	Terminal Busbar	Bus Type	Parallel Machines	Nominal App.Pow. [MVA]	Apparent Power [MVA]	Loading [%]	Active Power [MW]	Reactive Power [Mvar]	Voltage [p.u]	Power Factor
ANG1	SING	ANG 1 18kV	PV	1	330.00	212.68	64.45	209.59	36.09	1.014	0.99
ANG2	SING	ANG2 18kV	SL	1	330.00	212.68	64.45	209.59	36.09	1.014	0.99
CAVA	SING	Iquique Cavancha 4.16	PQ	1	3.65	2.70	73.88	2.69	-0.10	1.007	1.00
CHAP	SING	Arica Chapiquiña 3	PQ	2	6.20	10.03	80.89	9.98	-1.00	1.031	1.00
CTA	SING	Terminal(3)	PV	1	210.00	143.48	68.33	139.73	32.61	1.019	0.97
CTH	SING	Terminal(10)	PV	1	210.00	143.48	68.33	139.73	32.61	1.019	0.97
CTM1	SING	Chacaya CTM1 13.8	PV	1	176.50	152.24	86.26	148.71	32.61	0.988	0.98
CTM2	SING	Chacaya CTM2 13.8	PV	1	197.30	157.12	79.64	153.70	32.61	0.985	0.98
CTTAR	SING	Tarapacá CTTAR 13.8	PV	1	186.00	141.60	76.13	139.73	22.93	0.967	0.99
Chuquicamata UGs N°1 a N°3	SING	Chuquicamata S/E Km-6 UGs 6.6	PQ	10	10.00	23.95	23.95	23.95	0.00	0.989	1.00
NTO1	SING	Norgener NTO1 13.8	PV	1	156.50	136.24	87.05	134.74	20.16	0.985	0.99
NTO2	SING	Norgener NTO2 13.8	PV	1	156.50	136.24	87.05	134.74	20.16	0.985	0.99
PAM	SING	PAM_Noracid 13.8	PQ	1	31.20	20.06	64.30	19.96	2.00	0.999	1.00
Quebrada Blanca Ugs	SING	Collahuasi Quebrada Blanca 13.8	PQ	10	5.86	27.45	46.82	27.45	0.00	0.990	1.00
TG1A	SING	Atacama TG1A 15	PV	1	165.00	111.22	67.40	104.80	37.24	1.011	0.94
TG1B	SING	Atacama TG1B 15	PV	1	165.00	99.81	60.49	99.81	0.00	0.980	1.00
TV1C	SING	Atacama TV1C 15	PV	1	165.00	93.19	56.48	89.82	24.83	1.004	0.96
U12	SING	Tocopilla U12	PV	1	92.00	81.70	88.80	79.84	17.29	0.977	0.98
U13	SING	Tocopilla U13	PV	1	92.00	81.70	88.80	79.84	17.29	0.980	0.98
U14	SING	Tocopilla U14	PV	1	147.00	122.34	83.22	121.76	11.85	0.978	1.00
U16	SING	Tocopilla U16	PV	1	500.00	230.77	46.15	229.55	23.69	0.980	0.99

Table A. 1 – SING, High Demand (Generators)

Transmission Lines

Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	0.000	0.000	0	0	0	0	0	0	0	0	0	0	0
110 kV Tap Off Oeste-Minsal	SING	110	0.960	0.915	-19.63	-20.84	93.26	0.96	27.96	-27.12	23.05	-22.34	0.84	0.20	0.20
220 kV Andes-Nueva Zaldívar.C1	SING	220	0.972	0.975	13.05	13.75	8.31	8.64	-23.55	23.60	-7.14	-1.20	0.05	0.07	0.06
220 kV Andes-Nueva Zaldívar.C2	SING	220	0.972	0.975	13.05	13.75	11.07	8.64	-23.55	23.60	-7.14	-1.20	0.05	0.07	0.06
220 kV Crucero-Laberinto.C1	SING	220	1.013	1.006	16.09	17.70	10.24	18.02	-23.19	23.33	1.87	-19.17	0.14	0.06	0.08
220 kV Crucero-Laberinto.C2	SING	220	1.013	1.006	16.09	17.70	10.13	18.86	-24.03	24.17	1.44	-19.53	0.14	0.06	0.08
220 kV Laberinto-El Cobre	SING	220	1.006	1.006	17.70	17.67	7.38	0.38	19.97	-19.97	-21.33	20.97	0.00	0.08	0.08
220 kV Laberinto-Lomas Bayas	SING	220	1.006	1.005	17.70	17.56	39.40	1.36	29.93	-29.91	2.72	-4.00	0.02	0.08	0.08
220 kV Laberinto-Mantos Blancos	SING	220	1.006	1.002	17.70	18.75	11.40	9.46	-27.96	28.10	8.66	-17.55	0.14	0.08	0.09
220 kV Laberinto-Nueva Zaldívar.C1	SING	220	0.972	1.006	13.05	17.70	36.79	12.33	-102.18	103.96	-23.22	20.00	1.78	0.28	0.28
220 kV Laberinto-Nueva Zaldívar.C2	SING	220	0.972	1.006	13.05	17.70	33.61	12.84	-104.78	106.48	-25.34	21.90	1.70	0.29	0.28
220 kV Nueva Zaldívar-Escondida	SING	220	0.972	0.968	13.05	12.63	23.26	1.74	62.98	-62.87	18.77	-19.97	0.11	0.18	0.18
220 kV Nueva Zaldívar-Sulfuros	SING	220	0.972	0.968	13.05	12.69	22.85	1.61	60.19	-60.07	23.13	-24.25	0.12	0.17	0.18
220 kV Nueva Zaldívar-Zaldívar	SING	220	0.972	0.972	13.05	13.04	41.33	0.03	130.89	-130.89	20.94	-20.93	0.01	0.36	0.36
220 kV Andes-Tap Off Oeste	SING	220	0.975	0.978	13.75	14.69	17.84	4.87	-47.50	47.68	0.28	-4.38	0.19	0.13	0.13
220 kV Tap Off Oeste-Laberinto	SING	220	0.978	1.006	14.69	17.70	29.43	11.25	-75.72	76.82	-22.52	15.82	1.10	0.21	0.20

Table A. 2 – SING, High Demand (Transmission Lines, Selected Nodes)

3-Winding Transformers

Name	Grid	HV-Side Busbar	MV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage MV-Side [p.u.]	Voltage LV-Side [p.u.]	Maximum Loading [%]	Total Losses [MW]
Andes 345/220/23 kV N°1	SING	Andes 345	Andes 220	Andes 23 #1	0.975	0.975	0.975	0.29	0.10
Andes 345/220/23 kV N°2	SING	Andes 345	Andes 220	Andes 23 #2	0.975	0.975	0.975	0.29	0.10
Andes 345/220/23 kV N°3	SING	Andes 345	Andes 220	Andes 23 #3	0.975	0.975	0.975	0.29	0.10
Tap Off Oeste 220/110/12.2 kV	SING	tap off Oeste	Laberinto Oeste 110	Laberinto Oeste 13.2	0.978	0.960	0.885	72.21	0.08

Table A. 3 - SING, High Demand (Transformers, Selected Nodes)

Shunt Compensators

Name	Grid	Terminal BusBar	Voltage [p.u.]	Reactive Power [Mvar]	Active Power [MW]	Nominal Voltage [kV]
R. Andes 345 kV	SING	- tap off reactor Andes	0.000	0.00	0.00	345
R. Laberinto 220 kV	SING	Laberinto 220 kV B2	1.006	20.24	0.00	220
R. Salta 345 kV	NOA	- tap off reactor Salta	0.000	0.00	0.00	345

Table A. 4 - SING, High Demand (Shunt Compensators, Selected Nodes)

Series Compensators

Name	Grid	Terminal i Busbar	Terminal j Busbar	Voltage Terminal i [p.u.]	Voltage Termina l j [p.u.]	Current, Magnitude Terminal i [kA]	Total Reactive Power Terminal i in Mvar	Total Reactive Power Terminal j in Mvar	Loading [%]	Nominal Voltage [kV]
Condensador Serie Andes 1/2	SING	- Andes 345	- Andes Reactor Shunt 345	0	0	0	0	0	0	345

Table A. 5 - SING, High Demand (Series Compensators, Selected Nodes)

Appendix D

SING – Low Demand, Load-Flow simulation results

Generators											
Unit Name	Grid	Terminal Busbar	Bus Type	Parallel Machines	Nominal App.Pow. [MVA]	Apparent Power [MVA]	Loading [%]	Active Power [MW]	Reactive Power [Mvar]	Voltage [p.u]	Power Factor
ANG2	SING	ANG2 18kV	SL	1	330.00	215.19	65.21	210.07	46.69	1.018	0.98
CAVA	SING	Iquique Cavancha 4.16	PQ	1	3.65	2.70	74.05	2.70	-0.10	1.033	1.00
CHAP	SING	Arica Chapiquiña 3	PQ	2	6.20	10.05	81.07	10.00	-1.00	1.034	1.00
CTA	SING	Terminal(3)	PV	1	210.00	142.76	67.98	140.05	27.68	1.016	0.98
CTH	SING	Terminal(10)	PV	1	210.00	142.76	67.98	140.05	27.68	1.016	0.98
CTM1	SING	Chacaya CTM1 13.8	PV	1	176.50	151.60	85.89	149.05	27.68	0.983	0.98
CTM2	SING	Chacaya CTM2 13.8	PV	1	197.30	156.52	79.33	154.05	27.68	0.980	0.98
CTTAR	SING	Tarapacá CTTAR 13.8	PV	1	186.00	141.13	75.88	140.05	-17.47	0.941	0.99
Chuquicamata UGs N°1 a N°3	SING	Chuquicamata S/E Km-6 UGs 6.6	PQ	10	10.00	24.01	24.01	24.01	0.00	1.009	1.00
NTO1	SING	Norgener NTO1 13.8	PV	1	156.50	135.67	86.69	135.04	12.97	0.977	1.00
NTO2	SING	Norgener NTO2 13.8	PV	1	156.50	135.67	86.69	135.04	12.97	0.977	1.00
PAM	SING	PAM_Noracid 13.8	PQ	1	31.20	20.11	64.44	20.01	2.00	1.000	1.00
Quebrada Blanca Ugs	SING	Collahuasi Quebrada Blanca 13.8	PQ	10	5.86	27.51	46.92	27.51	0.00	1.001	1.00
TG1A	SING	Atacama TG1A 15	PV	1	165.00	105.93	64.20	105.03	13.75	0.991	0.99
TG1B	SING	Atacama TG1B 15	PV	1	165.00	100.03	60.63	100.03	0.00	0.980	1.00
TV1C	SING	Atacama TV1C 15	PV	1	165.00	90.49	54.85	90.03	9.16	0.991	0.99
U12	SING	Tocopilla U12	PV	1	92.00	80.95	87.99	80.03	12.19	0.970	0.99
U13	SING	Tocopilla U13	PV	1	92.00	80.95	87.99	80.03	12.19	0.973	0.99
U14	SING	Tocopilla U14	PV	1	147.00	122.24	83.16	122.04	7.03	0.973	1.00
U16	SING	Tocopilla U16	PV	1	500.00	220.52	44.10	220.07	14.07	0.977	1.00

Table A. 6 - SING, Low Demand (Generators)

Transmission Lines																
Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
110 kV Tap Off Oeste-Minsal	SING	110	0.975	0.934	-13.75	-14.88	85.85	0.99	26.39	-25.68	21.13	-20.71	0.71	0.18	0.19
220 kV Andes-Nueva Zaldívar.C1	SING	220	0.979	0.983	19.11	19.59	6.41	8.77	-16.82	16.84	-9.09	0.48	0.03	0.05	0.04
220 kV Andes-Nueva Zaldívar.C2	SING	220	0.979	0.983	19.11	19.59	8.54	8.77	-16.82	16.84	-9.09	0.48	0.03	0.05	0.04
220 kV Crucero-Laberinto.C1	SING	220	1.017	1.010	23.95	22.58	8.30	18.17	22.30	-22.19	-7.11	-10.51	0.11	0.06	0.06
220 kV Crucero-Laberinto.C2	SING	220	1.017	1.010	23.95	22.58	8.27	19.02	22.92	-22.82	-7.15	-11.28	0.11	0.06	0.07
220 kV Laberinto-El Cobre	SING	220	1.010	1.010	22.58	22.59	4.62	0.38	-13.76	13.76	-12.18	11.80	0.00	0.05	0.05
220 kV Laberinto-Lomas Bayas	SING	220	1.010	1.009	22.58	22.43	40.26	1.37	30.71	-30.69	2.84	-4.13	0.02	0.08	0.08
220 kV Laberinto-Mantos Blancos	SING	220	1.010	1.005	22.58	24.18	16.81	9.53	-42.92	43.24	14.80	-23.03	0.31	0.12	0.13
220 kV Laberinto-Nueva Zaldívar.C1	SING	220	0.979	1.010	19.11	22.58	28.92	12.47	-78.62	79.70	-26.45	19.49	1.08	0.22	0.21
220 kV Laberinto-Nueva Zaldívar.C2	SING	220	0.979	1.010	19.11	22.58	26.43	12.98	-80.52	81.55	-28.34	21.04	1.03	0.23	0.22
220 kV Nueva Zaldívar-Escondida	SING	220	0.979	0.975	19.11	18.80	18.20	1.77	47.14	-47.08	20.67	-22.11	0.06	0.14	0.14
220 kV Nueva Zaldívar-Sulfuros	SING	220	0.979	0.974	19.11	18.90	17.49	1.63	38.48	-38.41	30.54	-31.89	0.07	0.13	0.13
220 kV Nueva Zaldívar-Zaldívar	SING	220	0.979	0.979	19.11	19.10	33.85	0.03	107.16	-107.16	21.75	-21.75	0.00	0.29	0.29
220 kV Andes-Tap Off Oeste	SING	220	0.983	0.986	19.59	20.24	12.66	4.94	-33.99	34.09	-3.12	-1.44	0.09	0.09	0.09
220 kV Tap Off Oeste-Laberinto	SING	220	0.986	1.010	20.24	22.58	23.94	11.38	-60.54	61.26	-22.96	14.53	0.71	0.17	0.16

Table A. 7 - SING, Low Demand (Transmission Lines, Selected Nodes)

3-Winding Transformers									
Name	Grid	HV-Side Busbar	MV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage MV-Side [p.u.]	Voltage LV-Side [p.u.]	Maximum Loading [%]	Total Losses [MW]
Andes 345/220/23 kV N°1	SING	Andes 345	Andes 220	Andes 23 #1	0.982	0.983	0.983	0.29	0.10
Andes 345/220/23 kV N°2	SING	Andes 345	Andes 220	Andes 23 #2	0.982	0.983	0.983	0.29	0.10
Andes 345/220/23 kV N°3	SING	Andes 345	Andes 220	Andes 23 #3	0.982	0.983	0.983	0.29	0.10
Tap Off Oeste 220/110/12.2 kV	SING	tap off Oeste	Laberinto Oeste 110	Laberinto Oeste 13.2	0.986	0.975	0.899	66.37	0.07

Table A. 8 - SING, Low Demand (Transformers, Selected Nodes)

Shunt Compensators						
Name	Grid	Terminal BusBar	Voltage [p.u.]	Reactive Power [Mvar]	Active Power [MW]	Nominal Voltage [kV]
R. Andes 345 kV	SING	- tap off reactor Andes	0.000	0.00	0.00	345
R. Laberinto 220 kV	SING	Laberinto 220 kV B2	1.010	20.40	0.00	220
R. Salta 345 kV	NOA	- tap off reactor Salta	0.000	0.00	0.00	345

Table A. 9 - SING, Low Demand (Shunt Compensators, Selected Nodes)

Series Compensators										
Name	Grid	Terminal i Busbar	Terminal j Busbar	Voltage Terminal i [p.u.]	Voltage Terminal j [p.u.]	Current, Magnitude Terminal i [kA]	Total Reactive Power Terminal i in Mvar	Total Reactive Power Terminal j in Mvar	Loading [%]	Nominal Voltage [kV]
Condensador Serie Andes 1/2	SING	- Andes 345	- Andes Reactor Shunt 345	0.000	0.000	0	0	0	0	345

Table A. 10 - SING, Low Demand (Series Compensators, Selected Nodes)

Appendix E

SADI – High Demand, Load-Flow simulation results

Generators											
Unit Name	Grid	Terminal Busbar	Bus Type	Parallel Machines	Nominal App.Pow. [MVA]	Apparent Power [MVA]	Loading [%]	Active Power [MW]	Reactive Power [Mvar]	Voltage [p.u]	Power Factor
sym_6600_1	Centro	6600 EMBANUCL	SL	1	763.50	609.10	79.78	607.78	40.21	0.99	1.00
sym_8622_1	NOA	8622 TANDESG1	PV	1	270.00	185.75	68.80	179.34	48.36	1.020	0.97
sym_8623_2	NOA	8623 TANDESG2	PV	1	270.00	185.75	68.80	179.34	48.36	1.020	0.97
sym_8624_1	NOA	8624 TANDESTV	PV	1	270.00	207.54	76.87	199.27	58.01	1.020	0.96

Table A. 11 - SADI, High Demand (Generators, Selected Nodes)

Transmission Lines															
Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
lne_8000_8007_1	Transnor	500	1.030	1.007	-0.92	1.81	17.58	340.59	-165.87	166.70	-73.17	-257.32	0.83	0.20	0.35
lne_8007_8008_1	Transnor	500	1.007	1.003	1.81	1.95	13.37	51.82	-44.86	44.89	55.66	-107.05	0.03	0.08	0.13
lne_8007_8009_1	Transnor	500	1.007	1.015	1.81	-2.03	17.89	351.87	228.38	-227.09	-212.49	-123.78	1.30	0.36	0.29
lne_8217_8326_1	NOA	132	1.021	1.056	4.07	7.02	53.06	2.30	-70.34	71.49	-23.58	25.77	1.15	0.32	0.31
lne_8272_8326_1	NOA	132	1.021	1.056	-0.41	7.02	45.23	5.28	-63.23	65.42	1.62	1.45	2.20	0.27	0.27
lne_8243_8326_1	NOA	132	1.035	1.056	0.65	7.02	29.05	7.44	-40.72	41.84	1.12	-4.01	1.12	0.17	0.17
lne_8244_8326_2	NOA	132	1.063	1.056	6.71	7.02	23.97	0.69	-14.41	14.49	31.11	-31.51	0.08	0.14	0.14
lne_8244_8326_1	NOA	132	1.063	1.056	6.71	7.02	23.97	0.69	-14.41	14.49	31.11	-31.51	0.08	0.14	0.14

Table A. 12 - SADI, High Demand (Transmission Lines, Selected Nodes)

2-Winding Transformers							
Transformer Name	Grid	HV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage LV-Side [p.u.]	Loading [%]	Voltage Setpoint [p.u.]
trf_8007_8931_1	Transnor	8007 COBOS	8931 COB_NEU1	1.007	1.051	78.94	1.05
trf_8120_8622_1	NOA	8120 COBOS	8622 TANDESG1	1.047	1.020	63.90	1.01
trf_8120_8623_2	NOA	8120 COBOS	8623 TANDESG2	1.047	1.020	63.90	1.01
trf_8120_8624_1	NOA	8120 COBOS	8624 TANDESTV	1.047	1.020	71.39	1.00
trf_8120_8930_1	NOA	8120 COBOS	8930 COB_NEU1	1.047	1.054	39.27	1.01
trf_8120_8931_1	Transnor	8120 COBOS	8931 COB_NEU1	1.047	1.051	78.94	1.04
trf_8326_8930_1	NOA	8326 COBOS	8930 COB_NEU1	1.056	1.054	39.27	1.01
trf_8530_8930_1	NOA	8530 COB_TER1	8930 COB_NEU1	1.054	1.054	0.00	1.01
trf_8805_8931_1	Transnor	8805 COB_TER1	8931 COB_NEU1	1.051	1.051	0.00	1.04

Table A. 13 - SADI, High Demand (Transformers, Selected Nodes)

Shunt Compensators						
Name	Grid	Terminal BusBar	Voltage [p.u.]	Reactive Power [Mvar]	Active Power [MW]	Nominal Voltage [kV]
shnt_8000_8007_1	Transnor	8000 BRACHO	1.030	127.22	0	500
shnt_8007_8000_1	Transnor	8007 COBOS	1.007	121.62	0	500
shnt_8007_8009_1	Transnor	8007 COBOS	1.007	121.62	0	500
shnt_8008_8007_1	Transnor	8008 JUANCITO	1.003	50.29	0	500
shnt_8009_8007_1	Transnor	8009 MQUEM-CB	1.015	123.52	0	500
shntswt_8007_1	Transnor	8007 COBOS	1.007	121.62	0	500
shntswt_8007_2	Transnor	8007 COBOS	1.007	121.62	0	500

Table A. 14 - SADI, High Demand (Shunt Compensators, Selected Nodes)

Appendix F

SADI – Low Demand, Load-Flow simulation results

Generators											
Unit Name	Grid	Terminal Busbar	Bus Type	Parallel Machines	Nominal App.Pow. [MVA]	Apparent Power [MVA]	Loading [%]	Active Power [MW]	Reactive Power [Mvar]	Voltage [p.u]	Power Factor
sym_6600_1	Centro	6600 EMBANUCL	SL	1	763.5	420.45	55.07	409.09	-97.04	0.990	0.97
sym_8622_1	NOA	8622 TANDESG1	PV	1	270	123.34	45.68	120.72	25.31	1.020	0.98
sym_8623_2	NOA	8623 TANDESG2	PV	1	270	123.34	45.68	120.72	25.31	1.020	0.98
sym_8624_1	NOA	8624 TANDESTV	PV	1	270	137.56	50.95	134.13	30.55	1.020	0.98

Table A. 15 - SADI, Low Demand (Generators, Selected Nodes)

Transmission Lines															
Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
lne_8000_8007_1	Transnor	500	1.048	1.021	-0.63	1.20	16.72	351.65	-111.38	111.90	-71.60	-273.79	0.52	0.15	0.33
lne_8007_8008_1	Transnor	500	1.021	1.018	1.20	1.29	11.76	53.36	-29.03	29.05	46.44	-99.51	0.02	0.06	0.12
lne_8007_8009_1	Transnor	500	1.021	1.023	1.20	-1.30	14.02	359.98	153.05	-152.49	-195.08	-158.21	0.56	0.28	0.25
lne_8217_8326_1	NOA	132	1.047	1.071	2.69	4.62	35.26	2.39	-47.78	48.29	-16.64	16.22	0.51	0.21	0.21
lne_8272_8326_1	NOA	132	1.058	1.071	-0.31	4.62	30.26	5.54	-43.00	43.97	4.23	-6.10	0.97	0.18	0.18
lne_8244_8326_2	NOA	132	1.077	1.071	4.39	4.62	19.66	0.71	-9.55	9.60	26.67	-27.19	0.05	0.12	0.12
lne_8244_8326_1	NOA	132	1.077	1.071	4.39	4.62	19.66	0.71	-9.55	9.60	26.67	-27.19	0.05	0.12	0.12
lne_8243_8326_1	NOA	132	1.068	1.071	0.35	4.62	20.10	7.78	-27.67	28.18	2.97	-8.69	0.51	0.11	0.12

Table A. 16 - SADI, Low Demand (Transmission Lines, Selected Nodes)

2-Winding Transformers							
Transformer Name	Grid	HV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage LV-Side [p.u.]	Loading [%]	Voltage Setpoint [p.u.]
trf_8007_8931_1	Transnor	8007 COBOS	8931 COB_NEU1	1.021	1.062	54.08	1.048
trf_8120_8622_1	NOA	8120 COBOS	8622 TANDESG1	1.058	1.020	42.43	1.005
trf_8120_8623_2	NOA	8120 COBOS	8623 TANDESG2	1.058	1.020	42.43	1.005
trf_8120_8624_1	NOA	8120 COBOS	8624 TANDESTV	1.058	1.020	47.32	1.000
trf_8120_8930_1	NOA	8120 COBOS	8930 COB_NEU1	1.058	1.068	27.35	1.005
trf_8120_8931_1	Transnor	8120 COBOS	8931 COB_NEU1	1.058	1.062	54.08	1.040
trf_8326_8930_1	NOA	8326 COBOS	8930 COB_NEU1	1.071	1.068	27.35	1.005
trf_8530_8930_1	NOA	8530 COB_TER1	8930 COB_NEU1	1.068	1.068	0.00	1.005
trf_8805_8931_1	Transnor	8805 COB_TER1	8931 COB_NEU1	1.062	1.062	0.00	1.040

Table A. 17 - SADI, Low Demand (Transformers, Selected Nodes)

Shunt Compensators						
Name	Grid	Terminal BusBar	Voltage [p.u.]	Reactive Power [Mvar]	Active Power [MW]	Nominal Voltage [kV]
shnt_8000_8007_1	Transnor	8000 BRACHO	1.048	131.74	0	500
shnt_8007_8000_1	Transnor	8007 COBOS	1.021	125.18	0	500
shnt_8007_8009_1	Transnor	8007 COBOS	1.021	125.18	0	500
shnt_8008_8007_1	Transnor	8008 JUANCITO	1.018	51.81	0	500
shnt_8009_8007_1	Transnor	8009 MQUEM-CE	1.023	125.61	0	500
shntswt_8007_1	Transnor	8007 COBOS	1.021	125.18	0	500
shntswt_8007_2	Transnor	8007 COBOS	1.021	125.18	0	500

Table A. 18 - SADI, Low Demand (Shunt Compensators, Selected Nodes)

Appendix G

SING-SADI/High Demand/ Null Transfer, Load-Flow simulation results

Generators											
Unit Name	Grid	Terminal Busbar	Bus Type	Parallel Machines	Nominal App.Pow. [MVA]	Apparent Power [MVA]	Loading [%]	Active Power [MW]	Reactive Power [Mvar]	Voltage [p.u]	Power Factor
sym_6600_1	Centro	6600 EMBANUCL	SL	1	763.5	609.115	79.78	607.87	38.99	0.990	1.00
sym_8622_1	NOA	8622 TANDESG1	PV	1	270	182.402	67.56	179.37	33.12	1.020	0.98
sym_8623_2	NOA	8623 TANDESG2	PV	1	270	182.402	67.56	179.37	33.12	1.020	0.98
sym_8624_1	NOA	8624 TANDESTV	PV	1	270	203.076	75.21	199.30	38.98	1.020	0.98

Table A. 19 – SING-SADI, High Demand – Null Transfer (Generators, Selected Nodes)

Transmission Lines															
Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	1.037	1.057	9.45	9.59	14.74	187.80	-4.02	4.26	-109.49	-75.70	0.25	0.18	0.12
220 kV Laberinto-El Cobre	SING	220	1.018	1.018	13.54	13.52	3.94	0.39	18.32	-18.32	-0.90	0.52	0.00	0.05	0.05
220 kV Laberinto-Lomas Bayas	SING	220	1.018	1.018	13.54	13.40	38.91	1.39	29.93	-29.91	2.63	-3.95	0.02	0.08	0.08
220 kV Laberinto-Mantos Blancos	SING	220	1.018	1.008	13.54	14.65	13.60	9.64	-27.41	27.60	19.77	-28.62	0.19	0.09	0.10
220 kV Laberinto-Nueva Zaldívar.C1	SING	220	0.999	1.018	8.91	13.54	35.02	12.83	-102.40	104.04	-5.84	1.41	1.64	0.27	0.27
220 kV Laberinto-Nueva Zaldívar.C2	SING	220	0.999	1.018	8.91	13.54	31.99	13.36	-105.24	106.81	-7.48	2.79	1.57	0.28	0.28
220 kV Andes-Nueva Zaldívar.C1	SING	220	0.999	1.022	8.91	9.43	16.99	9.31	-24.85	25.03	-45.40	37.25	0.18	0.14	0.12
220 kV Andes-Nueva Zaldívar.C2	SING	220	0.999	1.022	8.91	9.43	22.65	9.31	-24.85	25.03	-45.40	37.25	0.18	0.14	0.12
220 kV Andes-Tap Off Oeste	SING	220	1.022	1.015	9.43	10.40	21.03	5.29	-46.40	46.64	31.13	-35.40	0.25	0.14	0.15
220 kV Tap Off Oeste-Laberinto	SING	220	1.015	1.018	10.40	13.54	27.77	11.81	-74.66	75.64	9.60	-17.34	0.98	0.19	0.20
110 kV Tap Off Oeste-Minsal	SING	110	1.004	0.962	-23.58	-24.71	88.24	1.05	27.94	-27.19	22.36	-21.92	0.75	0.19	0.19
220 kV Crucero-Laberinto.C1	SING	220	1.019	1.018	11.98	13.54	9.35	18.36	-23.89	24.01	-3.50	-14.21	0.13	0.06	0.07
220 kV Crucero-Laberinto.C2	SING	220	1.019	1.018	11.98	13.54	9.24	19.22	-24.67	24.79	-4.09	-14.43	0.13	0.06	0.07
220 kV Nueva Zaldívar-Escondida	SING	220	0.999	0.994	8.91	8.51	24.18	1.84	63.76	-63.64	29.00	-30.26	0.11	0.18	0.19
220 kV Nueva Zaldívar-Sulfuros	SING	220	0.999	0.993	8.91	8.58	26.32	1.70	62.03	-61.87	44.07	-45.12	0.16	0.20	0.20
220 kV Nueva Zaldívar-Zaldívar	SING	220	0.999	0.999	8.91	8.90	40.99	0.03	131.55	-131.55	31.06	-31.06	0.01	0.35	0.35
lne_8000_8007_1	Transr	500	1.031	1.010	-0.99	1.69	17.11	342.28	-163.90	164.67	-82.67	-250.19	0.78	0.21	0.34
lne_8007_8008_1	Transr	500	1.010	1.007	1.69	1.83	13.40	52.21	-44.15	44.19	56.37	-108.16	0.03	0.08	0.13
lne_8007_8009_1	Transr	500	1.010	1.017	1.69	-2.09	17.66	354.09	226.73	-225.47	-210.00	-128.89	1.26	0.35	0.29
lne_8217_8326_1	NOA	132	1.025	1.061	3.89	6.79	53.22	2.32	-70.22	71.38	-25.46	27.66	1.16	0.32	0.32
lne_8243_8326_1	NOA	132	1.039	1.061	0.51	6.79	28.82	7.50	-40.66	41.76	0.44	-3.46	1.11	0.17	0.17
lne_8244_8326_1	NOA	132	1.067	1.061	6.51	6.79	20.02	0.70	-13.96	14.01	25.03	-25.53	0.05	0.12	0.12
lne_8244_8326_2	NOA	132	1.067	1.061	6.51	6.79	20.02	0.70	-13.96	14.01	25.03	-25.53	0.05	0.12	0.12
lne_8272_8326_1	NOA	132	1.024	1.061	-0.54	6.79	45.02	5.32	-63.18	65.36	0.68	2.27	2.18	0.27	0.27

Table A. 20 – SING-SADI, High Demand – Null Transfer (Transmission Lines, Selected Nodes)

2-Winding Transformers							
Transformer Name	Grid	HV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage LV-Side [p.u.]	Loading [%]	Voltage Setpoint [p.u.]
trf_8120_8622_1	NOA	8120 COBOS	8622 TANDESG1	1.057	1.020	62.75	1.005
trf_8120_8623_2	NOA	8120 COBOS	8623 TANDESG2	1.057	1.020	62.75	1.005
trf_8120_8624_1	NOA	8120 COBOS	8624 TANDESTV	1.057	1.020	69.86	1.000
trf_8120_8930_1	NOA	8120 COBOS	8930 COB_NEU1	1.057	1.060	38.42	1.005
trf_8326_8930_1	NOA	8326 COBOS	8930 COB_NEU1	1.061	1.060	38.42	1.005
trf_8530_8930_1	NOA	8530 COB_TER1	8930 COB_NEU1	1.060	1.060	0.00	1.005
trf_8007_8931_1	Transnor	8007 COBOS	8931 COB_NEU1	1.010	1.061	78.69	1.048
trf_8120_8931_1	Transnor	8120 COBOS	8931 COB_NEU1	1.057	1.061	78.69	1.040
trf_8805_8931_1	Transnor	8805 COB_TER1	8931 COB_NEU1	1.061	1.061	0.00	1.040

Table A. 21 – SING-SADI, High Demand – Null Transfer (2- Winding Transformers, Selected Nodes)

3-Winding Transformers									
Name	Grid	HV-Side Busbar	MV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage MV-Side [p.u.]	Voltage LV-Side [p.u.]	Maximum Loading [%]	Total Losses [MW]
Andes 345/220/23 kV N°1	SING	Andes 345	Andes 220	Andes 23 #1	1.037	1.022	1.022	14.10	0.12
Andes 345/220/23 kV N°2	SING	Andes 345	Andes 220	Andes 23 #2	1.037	1.022	1.022	14.10	0.12
Andes 345/220/23 kV N°3	SING	Andes 345	Andes 220	Andes 23 #3	1.037	1.022	1.022	14.10	0.12
Tap Off Oeste 220/110/12.2 kV	SING	tap off Oeste	Laberinto Oeste 110	Laberinto Oeste 13.2	1.015	1.004	0.926	68.22	0.07

Table A. 22 – SING-SADI, High Demand – Null Transfer (3-Winding Transformers, Selected Nodes)

Shunt Compensators						
Name	Grid	Terminal BusBar	Voltage [p.u.]	Reactive Power [Mvar]	Active Power [MW]	Nominal Voltage [kV]
R. Laberinto 220 kV	SING	Laberinto 220 kV B2	1.018	20.74	0	220
R. Andes 345 kV	SING	- tap off reactor Andes	0.000	0.00	0	345
R. Salta 345 kV	NOA	- 8120 COBOS	0.000	0.00	0	345
shnt_8000_8007_1	Transnor	8000 BRACHO	1.031	127.54	0	500
shnt_8007_8000_1	Transnor	8007 COBOS	1.010	122.53	0	500
shnt_8007_8009_1	Transnor	8007 COBOS	1.010	122.53	0	500
shnt_8008_8007_1	Transnor	8008 JUANCITO	1.007	50.67	0	500
shnt_8009_8007_1	Transnor	8009 MQUEM-CB	1.017	124.16	0	500
shntswt_8007_1	Transnor	8007 COBOS	1.010	122.53	0	500
shntswt_8007_2	Transnor	8007 COBOS	1.010	122.53	0	500

Table A. 23 – SING-SADI, High Demand – Null Transfer (Shunt Compensators, Selected Nodes)

Series Compensators										
Name	Grid	Terminal i Busbar	Terminal j Busbar	Voltage Terminal i [p.u.]	Voltage Terminal j [p.u.]	Current, Magnitude Terminal i [kA]	Total Reactive Power Terminal i in Mvar	Total Reactive Power Terminal j in Mvar	Loading [%]	Nominal Voltage [kV]
Condensador Serie Andes 1/2	SING	- Andes 345	- Andes Reactor Shunt 345	0.000	0.000	0	0	0	0	345
scap_8002_8004_1	Transnor	8002 RECREO	8004 REC_MALV	1.039	1.009	0.17	-114.91	108.65	17.38	500

Table A. 24 - SING-SADI, High Demand – Null Transfer (Series Compensators, Selected Nodes)

Appendix H

SING-SADI/Maximum transfer, Load-Flow simulation results

Generators												
Unit Name	Grid	Terminal Busbar	Bus Type	Parallel Machines	Nominal App.Pow. [MVA]	Apparent Power [MVA]	Loading [%]	Active Power [MW]	Reactive Power [Mvar]	Voltage [p.u]	Power Factor
sym_6600_1	Centro	6600 EMBANUCL	SL	1	763.5	618.68	81.03	610.70	99.04	0.990	0.99
sym_8622_1	NOA	8622 TANDESG1	PV	1	270	230.24	85.27	180.21	143.30	1.020	0.78
sym_8623_2	NOA	8623 TANDESG2	PV	1	270	230.24	85.27	180.21	143.30	1.020	0.78
sym_8624_1	NOA	8624 TANDESTV	PV	1	270	266.93	98.86	200.23	176.53	1.020	0.75

Table A. 25 - SING-SADI, Maximum Transfer (Generators, Selected Nodes)

Transmission Lines																
Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	0.913	0.991	78.19	28.20	100.45	141.25	650.01	-594.83	99.82	338.09	55.18	1.21	1.16
110 kV Tap Off Oeste-Minsal	SING	110	0.916	0.868	44.37	43.05	99.20	0.87	28.01	-27.06	23.91	-22.89	0.95	0.21	0.21
220 kV Andes-Nueva Zaldívar.C1	SING	220	0.945	0.929	77.27	78.20	15.39	8.00	-22.68	22.84	30.06	-37.11	0.15	0.10	0.12
220 kV Andes-Nueva Zaldívar.C2	SING	220	0.945	0.929	77.27	78.20	20.52	8.00	-22.68	22.84	30.06	-37.11	0.15	0.10	0.12
220 kV Crucero-Laberinto.C1	SING	220	1.016	0.995	80.17	81.92	13.24	17.89	-22.74	22.97	14.32	-31.04	0.23	0.07	0.10
220 kV Crucero-Laberinto.C2	SING	220	1.016	0.995	80.17	81.92	13.12	18.72	-23.75	23.97	14.26	-31.76	0.22	0.07	0.10
220 kV Laberinto-El Cobre	SING	220	0.995	0.996	81.92	81.88	9.62	0.37	21.23	-21.22	-38.28	37.95	0.01	0.12	0.11
220 kV Laberinto-Lomas Bayas	SING	220	0.995	0.994	81.92	81.77	39.83	1.33	29.93	-29.91	2.79	-4.04	0.02	0.08	0.08
220 kV Laberinto-Mantos Blancos	SING	220	0.995	0.997	81.92	82.93	10.30	9.31	-28.50	28.62	-0.57	-8.25	0.12	0.08	0.08
220 kV Laberinto-Nueva Zaldívar.C1	SING	220	0.945	0.995	77.27	81.92	39.72	11.87	-101.97	104.01	-41.21	39.80	2.04	0.31	0.29
220 kV Laberinto-Nueva Zaldívar.C2	SING	220	0.945	0.995	77.27	81.92	36.28	12.36	-104.31	106.26	-43.82	42.25	1.95	0.31	0.30
220 kV Nueva Zaldívar-Escondida	SING	220	0.945	0.942	77.27	76.81	22.89	1.65	62.41	-62.31	9.37	-10.49	0.10	0.18	0.18
220 kV Nueva Zaldívar-Sulfuros	SING	220	0.945	0.943	77.27	76.86	21.32	1.53	58.80	-58.70	3.85	-4.95	0.10	0.16	0.16
220 kV Nueva Zaldívar-Zaldívar	SING	220	0.945	0.945	77.27	77.26	42.00	0.03	130.43	-130.43	11.69	-11.68	0.01	0.36	0.36
220 kV Andes-Tap Off Oeste	SING	220	0.929	0.942	78.20	79.07	22.03	4.46	-47.97	48.24	-29.18	25.85	0.27	0.16	0.15
220 kV Tap Off Oeste-Laberinto	SING	220	0.942	0.995	79.07	81.92	36.20	10.73	-76.34	77.96	-54.14	50.10	1.62	0.26	0.24
lne_8000_8007_1	Transn	500	1.015	0.994	4.09	10.72	27.43	331.47	-399.64	403.66	-37.55	-245.16	4.02	0.46	0.55
lne_8007_8008_1	Transn	500	0.994	0.988	10.72	10.91	19.47	50.39	-57.68	57.76	106.85	-156.20	0.08	0.14	0.19
lne_8007_8009_1	Transn	500	0.994	1.004	10.72	4.64	24.06	343.85	354.28	-351.12	-214.69	-91.08	3.16	0.48	0.42
lne_8217_8326_1	NOA	132	0.968	1.016	15.58	21.32	90.60	2.10	-118.81	122.19	-18.10	29.21	3.39	0.54	0.54
lne_8243_8326_1	NOA	132	0.991	1.016	11.22	21.32	43.75	6.85	-58.15	60.70	8.03	-4.54	2.55	0.26	0.26
lne_8244_8326_1	NOA	132	1.029	1.016	19.63	21.32	85.35	0.64	-92.03	93.01	76.89	-73.81	0.98	0.51	0.51
lne_8244_8326_2	NOA	132	1.029	1.016	19.63	21.32	85.35	0.64	-92.03	93.01	76.89	-73.81	0.98	0.51	0.51
lne_8272_8326_1	NOA	132	0.980	1.016	10.55	21.32	62.03	4.87	-82.17	86.30	11.21	-0.42	4.12	0.37	0.37

Table A. 26 - SING-SADI, Maximum Transfer (Transmission Lines, Selected Nodes)

2-Winding Transformers							
Transformer Name	Grid	HV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage LV-Side [p.u.]	Loading [%]	Voltage Setpoint [p.u.]
trf_8120_8622_1	NOA	8120 COBOS	8622 TANDESG1	0.991	1.020	79.20	1.01
trf_8120_8623_2	NOA	8120 COBOS	8623 TANDESG2	0.991	1.020	79.20	1.01
trf_8120_8624_1	NOA	8120 COBOS	8624 TANDESTV	0.991	1.020	91.82	1.00
trf_8120_8930_1	NOA	8120 COBOS	8930 COB_NEU1	0.991	1.008	91.06	1.01
trf_8326_8930_1	NOA	8326 COBOS	8930 COB_NEU1	1.016	1.008	91.06	1.01
trf_8530_8930_1	NOA	8530 COB_TER1	8930 COB_NEU1	1.008	1.008	0.00	1.01
trf_8007_8931_1	Transnor	8007 COBOS	8931 COB_NEU1	0.994	0.994	158.68	1.05
trf_8120_8931_1	Transnor	8120 COBOS	8931 COB_NEU1	0.991	0.994	158.68	1.04
trf_8805_8931_1	Transnor	8805 COB_TER1	8931 COB_NEU1	0.994	0.994	0.00	1.04

Table A. 27 - SING-SADI, Maximum Transfer (2- Winding Transformers, Selected Nodes)

3-Winding Transformers									
Name	Grid	HV-Side Busbar	MV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage MV-Side [p.u.]	Voltage LV-Side [p.u.]	Maximum Loading [%]	Total Losses [MW]
Andes 345/220/23 kV N°1	SING	Andes 345	Andes 220	Andes 23 #1	0.913	0.929	0.929	14.85	0.10
Andes 345/220/23 kV N°2	SING	Andes 345	Andes 220	Andes 23 #2	0.913	0.929	0.929	14.85	0.10
Andes 345/220/23 kV N°3	SING	Andes 345	Andes 220	Andes 23 #3	0.913	0.929	0.929	14.85	0.10
Tap Off Oeste 220/110/12.2 kV	SING	tap off Oeste	Laberinto Oeste 110	Laberinto Oeste 13.2	0.942	0.916	0.844	76.93	0.09

Table A. 28 - SING-SADI, Maximum Transfer (3-Winding Transformers, Selected Nodes)

Shunt Compensators						
Name	Grid	Terminal BusBar	Voltage [p.u.]	Reactive Power [Mvar]	Active Power [MW]	Nominal Voltage [kV]
R. Andes 345 kV	SING	- tap off reactor Andes	0.000	0.00	0.00	345
R. Laberinto 220 kV	SING	Laberinto 220 kV B2	0.995	19.81	0.00	220
R. Salta 345 kV	NOA	- 8120 COBOS	0.000	0.00	0.00	345
shnt_8000_8007_1	Transnor	8000 BRACHO	1.015	123.61	0.00	500
shnt_8007_8000_1	Transnor	8007 COBOS	0.994	118.56	0.00	500
shnt_8007_8009_1	Transnor	8007 COBOS	0.994	118.56	0.00	500
shnt_8008_8007_1	Transnor	8008 JUANCITO	0.988	48.78	0.00	500
shnt_8009_8007_1	Transnor	8009 MQUEM-CB	1.004	120.99	0.00	500
shntswt_8007_1	Transnor	8007 COBOS	0.994	0.00	0.00	500
shntswt_8007_2	Transnor	8007 COBOS	0.994	0.00	0.00	500

Table A. 29 - SING-SADI, Maximum Transfer (Shunt Compensators, Selected Nodes)

Series Compensators										
Name	Grid	Terminal i Busbar	Terminal j Busbar	Voltage Terminal i [p.u.]	Voltage Terminal j [p.u.]	Current, Magnitude Terminal i [kA]	Total Reactive Power Terminal i in Mvar	Total Reactive Power Terminal j in Mvar	Loading [%]	Nominal Voltage [kV]
Condensador Serie Andes 1/2	SING	- Andes 345	- Andes Reactor Shunt 345	0	0	0	0	0	0	345
scap_8002_8004_1	Transnor	8002 RECREO	8004 REC_MALV	1.021	0.960	0.40	-234.40	202.06	39.53	500

Table A. 30 - SING-SADI, Maximum Transfer (Series Compensators, Selected Nodes)

Appendix I

SING-SADI/Maximum transfer/Reactive Compensation, Load-Flow simulation results

Generators											
Unit Name	Grid	Terminal Busbar	Bus Type	Parallel Machines	Nominal App.Pow. [MVA]	Apparent Power [MVA]	Loading [%]	Active Power [MW]	Reactive Power [Mvar]	Voltage [p.u]	Power Factor
sym_6600_1	Centro	6600 EMBANUCL	SL	1.00	763.50	618.33	80.99	610.16	100.18	0.99	0.99
sym_8622_1	NOA	8622 TANDESG1	PV	1.00	270.00	227.39	84.22	180.05	138.89	1.02	0.79
sym_8623_2	NOA	8623 TANDESG2	PV	1.00	270.00	227.39	84.22	180.05	138.89	1.02	0.79
sym_8624_1	NOA	8624 TANDESTV	PV	1.00	270.00	263.19	97.48	200.05	171.03	1.02	0.76

Table A. 31 - SING-SADI, Maximum Transfer with Reactive Compensation (Generators, Selected Nodes)

Transmission Lines																
Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	0.954	0.993	78.05	28.98	100.24	148.18	674.16	-618.70	125.17	308.72	55.46	1.20	1.17
110 kV Tap Off Oeste-Minsal	SING	110	0.907	0.858	44.11	42.77	100.54	0.85	28.02	-27.05	24.11	-23.02	0.97	0.21	0.22
220 kV Andes-Nueva Zaldívar.C1	SING	220	0.940	0.920	77.05	78.05	17.81	7.87	-23.61	23.81	37.29	-43.87	0.21	0.12	0.14
220 kV Andes-Nueva Zaldívar.C2	SING	220	0.940	0.920	77.05	78.05	23.74	7.87	-23.61	23.81	37.29	-43.87	0.21	0.12	0.14
220 kV Crucero-Laberinto.C1	SING	220	1.016	0.993	79.88	81.67	13.80	17.85	-23.03	23.28	16.15	-32.72	0.25	0.07	0.11
220 kV Crucero-Laberinto.C2	SING	220	1.016	0.993	79.88	81.67	13.67	18.67	-24.07	24.31	16.15	-33.48	0.24	0.07	0.11
220 kV Laberinto-El Cobre	SING	220	0.993	0.994	81.67	81.63	10.42	0.37	21.90	-21.89	-41.92	41.60	0.01	0.13	0.12
220 kV Laberinto-Lomas Bayas	SING	220	0.993	0.992	81.67	81.52	39.92	1.32	29.93	-29.91	2.81	-4.05	0.02	0.08	0.08
220 kV Laberinto-Mantos Blancos	SING	220	0.993	0.996	81.67	82.67	10.11	9.28	-28.41	28.52	-2.56	-6.23	0.12	0.08	0.08
220 kV Laberinto-Nueva Zaldívar.C1	SING	220	0.940	0.993	77.05	81.67	40.24	11.77	-101.41	103.50	-44.60	43.54	2.09	0.31	0.30
220 kV Laberinto-Nueva Zaldívar.C2	SING	220	0.940	0.993	77.05	81.67	36.76	12.26	-103.68	105.68	-47.30	46.08	2.00	0.32	0.30
220 kV Nueva Zaldívar-Escondida	SING	220	0.940	0.937	77.05	76.58	22.97	1.63	62.58	-62.48	7.49	-8.59	0.10	0.18	0.18
220 kV Nueva Zaldívar-Sulfuros	SING	220	0.940	0.938	77.05	76.63	21.47	1.51	59.09	-58.99	-0.01	-1.06	0.11	0.17	0.17
220 kV Nueva Zaldívar-Zaldívar	SING	220	0.940	0.940	77.05	77.03	42.25	0.03	130.63	-130.62	9.85	-9.84	0.01	0.37	0.37
220 kV Andes-Tap Off Oeste	SING	220	0.920	0.935	78.05	78.90	23.19	4.38	-47.09	47.39	-34.72	31.59	0.30	0.17	0.16
220 kV Tap Off Oeste-Laberinto	SING	220	0.935	0.993	78.90	81.67	37.64	10.62	-75.50	77.24	-60.20	56.80	1.74	0.27	0.25
lne_8000_8007_1	Transnor	500	1.015	0.994	4.35	11.14	27.90	331.21	-409.17	413.38	-35.79	-244.38	4.21	0.47	0.56
lne_8007_8008_1	Transnor	500	0.994	0.987	11.14	11.35	19.65	50.35	-61.64	61.72	106.95	-156.25	0.08	0.14	0.20
lne_8007_8009_1	Transnor	500	0.994	1.003	11.14	4.89	24.52	343.49	364.26	-360.92	-213.13	-90.15	3.34	0.49	0.43
lne_8217_8326_1	NOA	132	0.969	1.017	16.25	22.01	91.17	2.11	-119.62	123.05	-18.41	29.68	3.43	0.55	0.54
lne_8243_8326_1	NOA	132	0.991	1.017	11.78	22.01	44.38	6.86	-59.05	61.68	7.98	-4.18	2.63	0.26	0.27
lne_8244_8326_1	NOA	132	1.030	1.017	20.30	22.01	85.92	0.65	-94.39	95.38	75.43	-72.30	0.99	0.51	0.51
lne_8244_8326_2	NOA	132	1.030	1.017	20.30	22.01	85.92	0.65	-94.39	95.38	75.43	-72.30	0.99	0.51	0.51
lne_8272_8326_1	NOA	132	0.980	1.017	11.14	22.01	62.71	4.88	-83.15	87.36	11.13	0.00	4.21	0.37	0.38

Table A. 32 - SING-SADI, Maximum Transfer with Reactive Compensation (Transmission Lines, Selected Nodes)

2-Winding Transformers							
Transformer Name	Grid	HV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage LV-Side [p.u.]	Loading [%]	Voltage Setpoint [p.u.]
trf_8120_8622_1	NOA	8120 COBOS	8622 TANDESG1	0.993	1.020	78.22	1.005
trf_8120_8623_2	NOA	8120 COBOS	8623 TANDESG2	0.993	1.020	78.22	1.005
trf_8120_8624_1	NOA	8120 COBOS	8624 TANDESTV	0.993	1.020	90.54	1.000
trf_8120_8930_1	NOA	8120 COBOS	8930 COB_NEU1	0.993	1.010	92.16	1.005
trf_8326_8930_1	NOA	8326 COBOS	8930 COB_NEU1	1.017	1.010	92.16	1.005
trf_8530_8930_1	NOA	8530 COB_TER1	8930 COB_NEU1	1.010	1.010	0.00	1.005
trf_8007_8931_1	Transnor	8007 COBOS	8931 COB_NEU1	0.994	0.997	162.13	1.048
trf_8120_8931_1	Transnor	8120 COBOS	8931 COB_NEU1	0.993	0.997	162.13	1.040
trf_8805_8931_1	Transnor	8805 COB_TER1	8931 COB_NEU1	0.997	0.997	0.00	1.040

Table A. 33 - SING-SADI, Maximum Transfer with Reactive Compensation (2- Winding Transformers, Selected Nodes)

3-Winding Transformers									
Name	Grid	HV-Side Busbar	MV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage MV-Side [p.u.]	Voltage LV-Side [p.u.]	Maximum Loading [%]	Total Losses [MW]
Andes 345/220/23 kV N°1	SING	Andes 345	Andes 220	Andes 23 #1	0.901	0.920	0.920	17.76	0.10
Andes 345/220/23 kV N°2	SING	Andes 345	Andes 220	Andes 23 #2	0.901	0.920	0.920	17.76	0.10
Andes 345/220/23 kV N°3	SING	Andes 345	Andes 220	Andes 23 #3	0.901	0.920	0.920	17.76	0.10
Tap Off Oeste 220/110/12.2 kV	SING	tap off Oeste	Laberinto Oeste 110	Laberinto Oeste 13.2	0.935	0.907	0.836	77.99	0.09

Table A. 34 - SING-SADI, Maximum Transfer with Reactive Compensation (3-Winding Transformers, Selected Nodes)

Shunt Compensators						
Name	Grid	Terminal BusBar	Voltage [p.u.]	Reactive Power [Mvar]	Active Power [MW]	Nominal Voltage [kV]
R. Andes 345 kV	SING	- tap off reactor Andes	0.000	0.00	0.00	345
R. Laberinto 220 kV	SING	Laberinto 220 kV B2	0.993	19.72	0.00	220
R. Salta 345 kV	NOA	- 8120 COBOS	0.000	0.00	0.00	345
shnt_8000_8007_1	Transnor	8000 BRACHO	1.015	123.51	0.00	500
shnt_8007_8000_1	Transnor	8007 COBOS	0.994	118.48	0.00	500
shnt_8007_8009_1	Transnor	8007 COBOS	0.994	118.48	0.00	500
shnt_8008_8007_1	Transnor	8008 JUANCITO	0.987	48.74	0.00	500
shnt_8009_8007_1	Transnor	8009 MQUEM-CB	1.003	120.82	0.00	500
shntswt_8007_1	Transnor	8007 COBOS	0.994	0.00	0.00	500
shntswt_8007_2	Transnor	8007 COBOS	0.994	0.00	0.00	500

Table A. 35 - SING-SADI, Maximum Transfer with Reactive Compensation (Shunt Compensators, Selected Nodes)

Series Compensators										
Name	Grid	Terminal i Busbar	Terminal j Busbar	Voltage Terminal i [p.u.]	Voltage Terminal j [p.u.]	Current, Magnitude Terminal i [kA]	Total Reactive Power Terminal i in Mvar	Total Reactive Power Terminal j in Mvar	Loading [%]	Nominal Voltage [kV]
Condensador Serie Andes 1/2	SING	Andes 345	Andes Reactor Shunt 345	0.901	0.954	0.22	118.15	-125.14	26.77	345
scap_8002_8004_1	Transnor	8002 RECREO	8004 REC_MALV	1.020	0.959	0.41	-238.33	203.99	40.73	500

Table A. 36 - SING-SADI, Maximum Transfer with Reactive Compensation (Series Compensators, Selected Nodes)

Appendix J

SING-SADI/Wind Scenario 1, Load-Flow simulation results

Generators											
Unit Name	Grid	Terminal Busbar	Bus Type	Parallel Machines	Nominal App.Pow. [MVA]	Apparent Power [MVA]	Loading [%]	Active Power [MW]	Reactive Power [Mvar]	Voltage [p.u]	Power Factor
sym_6600_1	Centro	6600 EMBANUCL	SL	1	763.5	609.93	79.89	608.33	44.22	0.990	1.00
sym_8622_1	NOA	8622 TANDESG1	PV	1	270	187.31	69.37	179.51	53.50	1.020	0.96
sym_8623_2	NOA	8623 TANDESG2	PV	1	270	187.31	69.37	179.51	53.50	1.020	0.96
sym_8624_1	NOA	8624 TANDESTV	PV	1	270	209.60	77.63	199.45	64.42	1.020	0.95

Table A. 37 - SING-SADI, Wind Scenario 1 (Generators, Selected Nodes)

Transmission Lines															
Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	0.987	1.044	14.35	7.54	24.62	176.59	106.84	-105.14	-137.60	-21.07	1.71	0.30	0.17
110 kV Tap Off Oeste-Minsal	SING	110	1.006	0.963	-19.62	-20.74	88.09	1.06	27.94	-27.20	22.34	-21.91	0.75	0.19	0.19
220 kV Andes-Nueva Zaldívar.C1	SING	220	0.999	1.025	13.42	12.76	19.48	9.33	14.78	-14.54	-57.47	49.66	0.24	0.16	0.13
220 kV Andes-Nueva Zaldívar.C2	SING	220	0.999	1.025	13.42	12.76	25.98	9.33	14.78	-14.54	-57.47	49.66	0.24	0.16	0.13
220 kV Crucero-Laberinto.C1	SING	220	1.021	1.019	19.20	18.88	3.98	18.40	5.44	-5.43	-7.80	-10.57	0.01	0.02	0.03
220 kV Crucero-Laberinto.C2	SING	220	1.021	1.019	19.20	18.88	4.00	19.26	5.58	-5.57	-8.10	-11.10	0.01	0.03	0.03
220 kV Laberinto-El Cobre	SING	220	1.019	1.018	18.88	18.87	2.49	0.39	11.58	-11.58	0.55	-0.94	0.00	0.03	0.03
220 kV Laberinto-Lomas Bayas	SING	220	1.019	1.018	18.88	18.74	38.90	1.39	29.93	-29.91	2.63	-3.95	0.02	0.08	0.08
220 kV Laberinto-Mantos Blancos	SING	220	1.019	1.008	18.88	20.11	14.63	9.64	-30.73	30.95	20.79	-29.51	0.22	0.10	0.11
220 kV Laberinto-Nueva Zaldívar.C1	SING	220	0.999	1.019	13.42	18.88	40.99	12.83	-120.01	122.27	-1.25	0.00	2.26	0.32	0.32
220 kV Laberinto-Nueva Zaldívar.C2	SING	220	0.999	1.019	13.42	18.88	37.44	13.36	-123.41	125.57	-3.01	1.59	2.16	0.32	0.32
220 kV Nueva Zaldívar-Escondida	SING	220	0.999	0.994	13.42	13.10	21.60	1.84	53.01	-52.92	32.65	-34.02	0.09	0.16	0.17
220 kV Nueva Zaldívar-Sulfuros	SING	220	0.999	0.992	13.42	13.24	22.92	1.70	40.41	-40.29	51.89	-53.10	0.12	0.17	0.18
220 kV Nueva Zaldívar-Zaldívar	SING	220	0.999	0.999	13.42	13.40	38.02	0.03	120.45	-120.45	34.67	-34.68	0.00	0.33	0.33
220 kV Andes-Tap Off Oeste	SING	220	1.025	1.016	12.76	14.35	32.89	5.31	-78.15	78.76	44.22	-46.98	0.62	0.23	0.24
220 kV Tap Off Oeste-Laberinto	SING	220	1.016	1.019	14.35	18.88	39.92	11.82	-106.78	108.83	21.21	-24.55	2.05	0.28	0.29
lne_8000_8007_1	Transnor	500	1.031	1.016	-0.92	2.42	17.83	344.16	-208.57	209.66	-97.49	-233.47	1.09	0.26	0.36
lne_8007_8008_1	Transnor	500	1.016	1.012	2.42	2.42	12.69	52.78	5.18	-5.15	58.71	-111.14	0.03	0.07	0.13
lne_8007_8009_1	Transnor	500	1.016	1.021	2.42	-1.44	17.70	357.36	234.23	-232.92	-205.40	-136.07	1.32	0.35	0.31
lne_8217_8326_1	NOA	132	1.006	1.052	0.37	4.58	73.06	2.26	-97.09	99.29	-26.82	33.12	2.20	0.44	0.43
lne_8243_8326_1	NOA	132	1.033	1.052	-1.37	4.58	27.07	7.40	-37.82	38.79	0.81	-4.28	0.97	0.16	0.16
lne_8244_8326_1	NOA	132	1.061	1.052	4.36	4.58	23.92	0.69	-6.71	6.79	33.41	-33.81	0.08	0.14	0.14
lne_8244_8326_2	NOA	132	1.061	1.052	4.36	4.58	23.92	0.69	-6.71	6.79	33.41	-33.81	0.08	0.14	0.14
lne_8272_8326_1	NOA	132	1.018	1.052	-2.61	4.58	43.62	5.25	-60.83	62.88	1.41	1.11	2.04	0.26	0.26
Lickan Antai-Encuentro 220 kV	SING	220	1.031	1.021	22.35	19.18	33.61	8.43	114.38	-113.39	-0.16	-1.96	0.98	0.29	0.29

Table A. 38 - SING-SADI, Wind Scenario 1 (Transmission Lines, Selected Nodes)

2-Winding Transformers							
Transformer Name	Grid	HV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage LV-Side [p.u.]	Loading [%]	Voltage Setpoint [p.u.]
trf_8120_8622_1	NOA	8120 COBOS	8622 TANDESG1	1.044	1.020	64.43	1.005
trf_8120_8623_2	NOA	8120 COBOS	8623 TANDESG2	1.044	1.020	64.43	1.005
trf_8120_8624_1	NOA	8120 COBOS	8624 TANDESTV	1.044	1.020	72.10	1.000
trf_8120_8930_1	NOA	8120 COBOS	8930 COB_NEU1	1.044	1.050	40.58	1.005
trf_8326_8930_1	NOA	8326 COBOS	8930 COB_NEU1	1.052	1.050	40.58	1.005
trf_8530_8930_1	NOA	8530 COB_TER1	8930 COB_NEU1	1.050	1.050	0.00	1.005
trf_8007_8931_1	Transnor	8007 COBOS	8931 COB_NEU1	1.016	1.047	50.70	1.048
trf_8120_8931_1	Transnor	8120 COBOS	8931 COB_NEU1	1.044	1.047	50.70	1.040
trf_8805_8931_1	Transnor	8805 COB_TER1	8931 COB_NEU1	1.047	1.047	0.00	1.040
trf_8007_8931_2	Transnor	8007 COBOS	8931 COB_NEU1	1.016	1.047	50.70	1.048
trf_8120_8931_2	Transnor	8120 COBOS	8931 COB_NEU1	1.044	1.047	50.70	1.000

Table A. 39 - SING-SADI, Wind Scenario 1 (2-Winding Transformers, Selected Nodes)

3-Winding Transformers									
Name	Grid	HV-Side Busbar	MV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage MV-Side [p.u.]	Voltage LV-Side [p.u.]	Maximum Loading [%]	Total Losses [MW]
Andes 345/220/23 kV N°1	SING	Andes 345	Andes 220	Andes 23 #1	1.044	1.025	1.025	23.54	0.13
Andes 345/220/23 kV N°2	SING	Andes 345	Andes 220	Andes 23 #2	1.044	1.025	1.025	23.54	0.13
Andes 345/220/23 kV N°3	SING	Andes 345	Andes 220	Andes 23 #3	1.044	1.025	1.025	23.54	0.13
Tap Off Oeste 220/110/12.2 kV	SING	tap off Oeste	Laberinto Oeste 110	Laberinto Oeste 13.2	1.016	1.006	0.927	68.10	0.07

Table A. 40 - SING-SADI, Wind Scenario 1 (3-Winding Transformers, Selected Nodes)

Shunt Compensators						
Name	Grid	Terminal BusBar	Voltage [p.u.]	Reactive Power [Mvar]	Active Power [MW]	Nominal Voltage [kV]
R. Andes 345 kV	SING	- tap off reactor Andes	0.000	0.00	0.00	345
R. Laberinto 220 kV	SING	Laberinto 220 kV B2	1.019	20.75	0.00	220
R. Salta 345 kV	NOA	- 8120 COBOS	0.000	0.00	0.00	345
shnt_8000_8007_1	Transnor	8000 BRACHO	1.031	127.54	0.00	500
shnt_8007_8000_1	Transnor	8007 COBOS	1.016	123.91	0.00	500
shnt_8007_8009_1	Transnor	8007 COBOS	1.016	123.91	0.00	500
shnt_8008_8007_1	Transnor	8008 JUANCITO	1.012	51.21	0.00	500
shnt_8009_8007_1	Transnor	8009 MQUEM-CB	1.021	125.05	0.00	500
shntswt_8007_1	Transnor	8007 COBOS	1.016	123.91	0.00	500
shntswt_8007_2	Transnor	8007 COBOS	1.016	123.91	0.00	500
Cap Lickan N°1	SING	Lickan Antai 23 kV 1	1.013	-7.18	0.00	23
Cap Lickan N°2	SING	Lickan Antai 23 kV 2	1.013	-7.18	0.00	23

Table A. 41 - SING-SADI, Wind Scenario 1 (Shunt Compensators, Selected Nodes)

Series Compensators										
Name	Grid	Terminal i Busbar	Terminal j Busbar	Voltage Terminal i [p.u.]	Voltage Terminal j [p.u.]	Current, Magnitude Terminal i [kA]	Total Reactive Power Terminal i in Mvar	Total Reactive Power Terminal j in Mvar	Loading [%]	Nominal Voltage [kV]
Condensador Serie Andes 1/2	SING	Andes 345	Andes Reactor Shunt 345	1.044	0.987	0.30	-150.29	137.64	36.03	345
scap_8002_8004_1	Transnor	8002 RECREO	8004 REC_MALV	1.036	1.003	0.17	-125.13	119.37	16.69	500

Table A. 42 - SING-SADI, Wind Scenario 1 (Series Compensators, Selected Nodes)

Appendix K

SING-SADI/Wind Scenario 2, Load-Flow simulation results

Generators											
Unit Name	Grid	Terminal Busbar	Bus Type	Parallel Machines	Nominal App.Pow. [MVA]	Apparent Power [MVA]	Loading [%]	Active Power [MW]	Reactive Power [Mvar]	Voltage [p.u]	Power Factor
sym_6600_1	Centro	6600 EMBANUCL	SL	1	763.5	612.78	80.26	608.71	70.49	0.990	0.99
sym_8622_1	NOA	8622 TANDESG1	PV	1	270	193.38	71.62	179.62	71.66	1.020	0.93
sym_8623_2	NOA	8623 TANDESG2	PV	1	270	193.38	71.62	179.62	71.66	1.020	0.93
sym_8624_1	NOA	8624 TANDESTV	PV	1	270	217.75	80.65	199.58	87.09	1.020	0.92

Table A. 43 - SING-SADI, Wind Scenario 2 (Generators, Selected Nodes)

Transmission Lines															
Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	0.977	1.033	31.41	13.07	44.07	171.09	288.20	-279.08	-110.97	35.61	9.12	0.53	0.46
110 kV Tap Off Oeste-Minsal	SING	110	0.993	0.950	-5.17	-6.32	89.48	1.03	27.94	-27.17	22.53	-22.02	0.77	0.19	0.19
220 kV Andes-Nueva Zaldívar.C1	SING	220	0.994	1.011	30.02	26.99	36.47	9.16	98.07	-97.12	-50.94	47.78	0.95	0.29	0.28
220 kV Andes-Nueva Zaldívar.C2	SING	220	0.994	1.011	30.02	26.99	48.63	9.16	98.07	-97.12	-50.94	47.78	0.95	0.29	0.28
220 kV Crucero-Laberinto.C1	SING	220	1.019	1.016	32.90	34.10	7.94	18.31	-18.08	18.16	-2.77	-15.15	0.08	0.05	0.06
220 kV Crucero-Laberinto.C2	SING	220	1.019	1.016	32.90	34.10	7.86	19.16	-18.70	18.78	-3.26	-15.47	0.08	0.05	0.06
220 kV Laberinto-El Cobre	SING	220	1.016	1.016	34.10	34.09	2.14	0.39	9.33	-9.33	-3.39	3.01	0.00	0.03	0.03
220 kV Laberinto-Lomas Bayas	SING	220	1.016	1.015	34.10	33.96	39.00	1.38	29.93	-29.91	2.65	-3.96	0.02	0.08	0.08
220 kV Laberinto-Mantos Blancos	SING	220	1.016	1.007	34.10	35.36	14.53	9.60	-32.16	32.38	18.74	-27.42	0.22	0.10	0.11
220 kV Laberinto-Nueva Zaldívar.C1	SING	220	0.994	1.016	30.02	34.10	31.48	12.73	-90.84	92.15	-12.38	6.37	1.31	0.24	0.24
220 kV Laberinto-Nueva Zaldívar.C2	SING	220	0.994	1.016	30.02	34.10	28.76	13.26	-93.28	94.53	-14.05	7.72	1.25	0.25	0.25
220 kV Nueva Zaldívar-Escondida	SING	220	0.994	0.990	30.02	30.22	15.22	1.82	-21.28	21.32	37.07	-38.67	0.04	0.11	0.12
220 kV Nueva Zaldívar-Sulfuros	SING	220	0.994	0.989	30.02	30.33	22.22	1.68	-34.71	34.82	52.95	-54.18	0.11	0.17	0.17
220 kV Nueva Zaldívar-Zaldívar	SING	220	0.994	0.994	30.02	30.02	17.78	0.03	43.96	-43.96	38.30	-38.32	0.00	0.15	0.15
220 kV Andes-Tap Off Oeste	SING	220	1.011	1.005	26.99	28.90	37.65	5.18	-94.44	95.25	39.58	-41.39	0.82	0.27	0.27
220 kV Tap Off Oeste-Laberinto	SING	220	1.005	1.016	28.90	34.10	45.55	11.66	-123.27	125.96	15.32	-15.82	2.70	0.32	0.33
lne_8000_8007_1	Transnor	500	1.024	1.006	1.24	6.20	22.45	338.48	-305.22	307.54	-68.58	-241.79	2.32	0.35	0.45
lne_8007_8008_1	Transnor	500	1.006	1.002	6.20	6.25	12.40	51.74	-11.95	11.97	55.53	-106.95	0.03	0.07	0.12
lne_8007_8009_1	Transnor	500	1.006	1.011	6.20	1.28	20.52	350.56	293.35	-291.25	-204.42	-120.79	2.10	0.41	0.36
lne_8217_8326_1	NOA	132	0.999	1.045	5.10	9.57	75.98	2.23	-100.84	103.22	-25.31	32.35	2.38	0.46	0.45
lne_8243_8326_1	NOA	132	1.024	1.045	2.65	9.57	31.14	7.29	-43.08	44.37	2.36	-4.43	1.29	0.18	0.19
lne_8244_8326_1	NOA	132	1.055	1.045	9.19	9.57	30.97	0.68	-16.15	16.28	41.05	-41.24	0.13	0.18	0.19
lne_8244_8326_2	NOA	132	1.055	1.045	9.19	9.57	30.97	0.68	-16.15	16.28	41.05	-41.24	0.13	0.18	0.19
lne_8272_8326_1	NOA	132	1.010	1.045	1.56	9.57	48.06	5.17	-66.33	68.81	3.55	0.70	2.48	0.29	0.29
Vientos del Desierto-Escondida 220 kV	SING	220	0.996	0.990	39.68	30.22	46.06	16.46	151.07	-147.25	-13.19	21.30	3.82	0.40	0.39
Wayra-Domeyko 220 kV	SING	220	0.996	0.989	38.50	30.39	44.88	14.47	147.18	-143.99	-12.20	18.27	3.19	0.39	0.39

Table A. 44 - SING-SADI, Wind Scenario 2 (Transmission Lines, Selected Nodes)

2-Winding Transformers							
Transformer Name	Grid	HV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage LV-Side [p.u.]	Loading [%]	Voltage Setpoint [p.u.]
trf_8120_8622_1	NOA	8120 COBOS	8622 TANDESG1	1.033	1.020	66.52	1.005
trf_8120_8623_2	NOA	8120 COBOS	8623 TANDESG2	1.033	1.020	66.52	1.005
trf_8120_8624_1	NOA	8120 COBOS	8624 TANDESTV	1.033	1.020	74.91	1.000
trf_8120_8930_1	NOA	8120 COBOS	8930 COB_NEU1	1.033	1.042	47.78	1.005
trf_8326_8930_1	NOA	8326 COBOS	8930 COB_NEU1	1.045	1.042	47.78	1.005
trf_8530_8930_1	NOA	8530 COB_TER1	8930 COB_NEU1	1.042	1.042	0.00	1.005
trf_8007_8931_1	Transnor	8007 COBOS	8931 COB_NEU1	1.006	1.036	65.89	1.048
trf_8120_8931_1	Transnor	8120 COBOS	8931 COB_NEU1	1.033	1.036	65.89	1.040
trf_8805_8931_1	Transnor	8805 COB_TER1	8931 COB_NEU1	1.036	1.036	0.00	1.040
trf_8007_8931_2	Transnor	8007 COBOS	8931 COB_NEU1	1.006	1.036	65.89	1.048
trf_8120_8931_2	Transnor	8120 COBOS	8931 COB_NEU1	1.033	1.036	65.89	1.000

Table A. 45 - SING-SADI, Wind Scenario 2 (2-Winding Transformers, Selected Nodes)

3-Winding Transformers									
Name	Grid	HV-Side Busbar	MV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage MV-Side [p.u.]	Voltage LV-Side [p.u.]	Maximum Loading [%]	Total Losses [MW]
Andes 345/220/23 kV N°1	SING	Andes 345	Andes 220	Andes 23 #1	1.030	1.011	1.011	42.14	0.16
Andes 345/220/23 kV N°2	SING	Andes 345	Andes 220	Andes 23 #2	1.030	1.011	1.011	42.14	0.16
Andes 345/220/23 kV N°3	SING	Andes 345	Andes 220	Andes 23 #3	1.030	1.011	1.011	42.14	0.16
Tap Off Oeste 220/110/12.2	SING	tap off Oeste	Laberinto Oeste 110	Laberinto Oeste 13.2	1.005	0.993	0.915	69.20	0.07

Table A. 46 - SING-SADI, Wind Scenario 2 (3-Winding Transformers, Selected Nodes)

Shunt Compensators						
Name	Grid	Terminal BusBar	Voltage [p.u.]	Reactive Power [Mvar]	Active Power [MW]	Nominal Voltage [kV]
R. Andes 345 kV	SING	- tap off reactor Andes	0.000	0.00	0.00	345
R. Laberinto 220 kV	SING	Laberinto 220 kV B2	1.016	20.64	0.00	220
R. Salta 345 kV	NOA	- 8120 COBOS	0.000	0.00	0.00	345
shnt_8000_8007_1	Transnor	8000 BRACHO	1.024	125.84	0.00	500
shnt_8007_8000_1	Transnor	8007 COBOS	1.006	121.46	0.00	500
shnt_8007_8009_1	Transnor	8007 COBOS	1.006	121.46	0.00	500
shnt_8008_8007_1	Transnor	8008 JUANCITO	1.002	50.21	0.00	500
shnt_8009_8007_1	Transnor	8009 MQUEM-CB	1.011	122.77	0.00	500
shntswt_8007_1	Transnor	8007 COBOS	1.006	121.46	0.00	500
shntswt_8007_2	Transnor	8007 COBOS	1.006	121.46	0.00	500
Cap Vientos del Desierto N°1	SING	Los Vientos 23 kV 1	0.974	-6.64	0.00	23
Cap Vientos del Desierto N°2	SING	Los Vientos 23 kV 2	0.974	-6.64	0.00	23
Cap Wayra N°1	SING	Wayra 23 kV 1	0.974	-6.64	0.00	23
Cap Wayra N°2	SING	Wayra 23 kV 2	0.974	-6.64	0.00	23

Table A. 47 - SING-SADI, Wind Scenario 2 (Shunt Compensators, Selected Nodes)

Series Compensators										
Name	Grid	Terminal i Busbar	Terminal j Busbar	Voltage Terminal i [p.u.]	Voltage Terminal j [p.u.]	Current, Magnitude Terminal i [kA]	Total Reactive Power Terminal i in Mvar	Total Reactive Power Terminal j in Mvar	Loading [%]	Nominal Voltage [kV]
Condensador Serie Andes 1/2	SING	Andes 345	Andes Reactor Shunt 345	1.030	0.977	0.53	-151.53	110.98	64.49	345
scap_8002_8004_1	Transnor	8002 RECREO	8004 REC_MALV	1.029	0.983	0.26	-171.91	157.68	26.22	500

Table A. 48 - SING-SADI, Wind Scenario 2 (Series Compensators, Selected Nodes)

Appendix L

SING-SADI/Wind Scenario 3, Load-Flow simulation results

Generators											
Unit Name	Grid	Terminal Busbar	Bus Type	Parallel Machines	Nominal App.Pow. [MVA]	Apparent Power [MVA]	Loading [%]	Active Power [MW]	Reactive Power [Mvar]	Voltage [p.u]	Power Factor
sym_6600_1	Centro	6600 EMBANUCL	SL	1	763.5	613.06	80.30	608.77	72.38	0.99	0.99
sym_8622_1	NOA	8622 TANDESG1	PV	1	270	194.20	71.92	179.64	73.77	1.02	0.93
sym_8623_2	NOA	8623 TANDESG2	PV	1	270	194.20	71.92	179.64	73.77	1.02	0.93
sym_8624_1	NOA	8624 TANDESTV	PV	1	270	218.84	81.05	199.60	89.73	1.02	0.91

Table A. 49 - SING-SADI, Wind Scenario 3 (Generators, Selected Nodes)

Transmission Lines															
Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	0.98	1.03	33.39	13.74	46.45	170.81	309.10	-298.72	-103.75	41.81	10.37	0.56	0.49
110 kV Tap Off Oeste-Minsal	SING	110	0.99	0.95	-4.41	-5.56	89.33	1.03	27.94	-27.18	22.51	-22.01	0.77	0.19	0.19
220 kV Andes-Nueva Zaldívar.C1	SING	220	0.99	1.01	28.13	28.66	14.34	9.15	-23.78	23.91	-36.32	27.97	0.13	0.11	0.10
220 kV Andes-Nueva Zaldívar.C2	SING	220	0.99	1.01	28.13	28.66	19.12	9.15	-23.78	23.91	-36.32	27.97	0.13	0.11	0.10
220 kV Crucero-Encuentro.C1	SING	220	1.02	1.02	31.21	31.17	30.70	0.12	107.26	-107.26	-39.81	39.77	0.01	0.29	0.29
220 kV Crucero-Encuentro.C2	SING	220	1.02	1.02	31.21	31.17	23.17	0.16	80.94	-80.93	-30.07	29.97	0.01	0.22	0.22
220 kV Crucero-Laberinto.C1	SING	220	1.02	1.02	31.21	32.77	9.61	18.31	-23.47	23.60	-1.47	-16.18	0.13	0.06	0.07
220 kV Crucero-Laberinto.C2	SING	220	1.02	1.02	31.21	32.77	9.50	19.16	-24.27	24.39	-2.00	-16.46	0.13	0.06	0.08
220 kV Laberinto-El Cobre	SING	220	1.02	1.02	32.77	32.75	4.12	0.39	18.38	-18.38	-5.32	4.94	0.00	0.05	0.05
220 kV Laberinto-Lomas Bayas	SING	220	1.02	1.01	32.77	32.63	39.01	1.38	29.93	-29.91	2.65	-3.96	0.02	0.08	0.08
220 kV Laberinto-Mantos Blancos	SING	220	1.02	1.01	32.77	33.88	13.11	9.60	-27.68	27.85	17.38	-26.25	0.18	0.08	0.10
220 kV Laberinto-Nueva Zaldívar.C1	SING	220	0.99	1.02	28.13	32.77	35.47	12.72	-102.72	104.40	-10.09	5.95	1.68	0.27	0.27
220 kV Laberinto-Nueva Zaldívar.C2	SING	220	0.99	1.02	28.13	32.77	32.40	13.24	-105.52	107.12	-11.86	7.47	1.60	0.28	0.28
220 kV Nueva Zaldívar-Escondida	SING	220	0.99	0.99	28.13	27.73	23.87	1.82	63.38	-63.27	26.63	-27.88	0.11	0.18	0.18
220 kV Nueva Zaldívar-Sulfuros	SING	220	0.99	0.99	28.13	27.80	25.30	1.68	61.21	-61.07	39.23	-40.31	0.15	0.19	0.19
220 kV Nueva Zaldívar-Zaldívar	SING	220	0.99	0.99	28.13	28.11	40.99	0.03	131.20	-131.20	28.71	-28.71	0.01	0.35	0.35
220 kV Andes-Tap Off Oeste	SING	220	1.01	1.01	28.66	29.64	19.97	5.19	-47.35	47.57	23.65	-27.91	0.22	0.14	0.14
220 kV Tap Off Oeste-Laberinto	SING	220	1.01	1.02	29.64	32.77	27.69	11.68	-75.59	76.58	1.88	-9.44	0.99	0.20	0.20
lne_8000_8007_1	Transn	500	1.02	1.00	1.53	6.67	23.01	337.87	-315.75	318.24	-64.71	-243.03	2.48	0.36	0.46
lne_8007_8008_1	Transn	500	1.00	1.00	6.67	6.72	12.39	51.62	-13.90	13.93	55.19	-106.48	0.03	0.07	0.12
lne_8007_8009_1	Transn	500	1.00	1.01	6.67	1.62	20.87	349.78	300.42	-298.20	-204.30	-118.83	2.21	0.42	0.37
lne_8217_8326_1	NOA	132	1.00	1.04	5.68	10.18	76.31	2.23	-101.27	103.66	-25.14	32.26	2.40	0.46	0.45
lne_8243_8326_1	NOA	132	1.02	1.04	3.15	10.18	31.60	7.27	-43.66	44.99	2.53	-4.43	1.33	0.19	0.19
lne_8244_8326_1	NOA	132	1.05	1.04	9.78	10.18	31.83	0.68	-17.22	17.36	41.94	-42.10	0.14	0.19	0.19
lne_8244_8326_2	NOA	132	1.05	1.04	9.78	10.18	31.83	0.68	-17.22	17.36	41.94	-42.10	0.14	0.19	0.19
lne_8272_8326_1	NOA	132	1.01	1.04	2.07	10.18	48.56	5.16	-66.95	69.48	3.79	0.66	2.53	0.29	0.29
Llasa Amuki - Andes 220 kV	SING	220	1.01	1.01	30.95	28.66	94.16	2.05	311.97	-310.05	-40.92	51.26	1.93	0.82	0.82

Table A. 50 - SING-SADI, Wind Scenario 3 (Transmission Lines, Selected Nodes)

2-Winding Transformers							
Transformer Name	Grid	HV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage LV-Side [p.u.]	Loading [%]	Voltage Setpoint [p.u.]
trf_8120_8622_1	NOA	8120 COBOS	8622 TANDESG1	1.03	1.02	66.80	1.01
trf_8120_8623_2	NOA	8120 COBOS	8623 TANDESG2	1.03	1.02	66.80	1.01
trf_8120_8624_1	NOA	8120 COBOS	8624 TANDESTV	1.03	1.02	75.28	1.00
trf_8120_8930_1	NOA	8120 COBOS	8930 COB_NEU1	1.03	1.04	48.61	1.01
trf_8326_8930_1	NOA	8326 COBOS	8930 COB_NEU1	1.04	1.04	48.61	1.01
trf_8530_8930_1	NOA	8530 COB_TER1	8930 COB_NEU1	1.04	1.04	0.00	1.01
trf_8007_8931_1	Transnor	8007 COBOS	8931 COB_NEU1	1.00	1.03	67.65	1.05
trf_8120_8931_1	Transnor	8120 COBOS	8931 COB_NEU1	1.03	1.03	67.65	1.04
trf_8805_8931_1	Transnor	8805 COB_TER1	8931 COB_NEU1	1.03	1.03	0.00	1.04
trf_8007_8931_2	Transnor	8007 COBOS	8931 COB_NEU1	1.00	1.03	67.65	1.05
trf_8120_8931_2	Transnor	8120 COBOS	8931 COB_NEU1	1.03	1.03	67.65	1.00

Table A. 51 - SING-SADI, Wind Scenario 3 (2-Winding Transformers, Selected Nodes)

3-Winding Transformers									
Name	Grid	HV-Side Busbar	MV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage MV-Side [p.u.]	Voltage LV-Side [p.u.]	Maximum Loading [%]	Total Losses [MW]
Andes 345/220/23 kV N°1	SING	Andes 345	Andes 220	Andes 23 #1	1.03	1.01	1.01	44.41	0.16
Andes 345/220/23 kV N°2	SING	Andes 345	Andes 220	Andes 23 #2	1.03	1.01	1.01	44.41	0.16
Andes 345/220/23 kV N°3	SING	Andes 345	Andes 220	Andes 23 #3	1.03	1.01	1.01	44.41	0.16
Tap Off Oeste 220/110/12.2 kV	SING	tap off Oeste	Laberinto Oeste 110	Laberinto Oeste 13.2	1.01	0.99	0.92	69.09	0.07

Table A. 52 - SING-SADI, Wind Scenario 3 (3-Winding Transformers, Selected Nodes)

Shunt Compensators						
Name	Grid	Terminal BusBar	Voltage [p.u.]	Reactive Power [Mvar]	Active Power [MW]	Nominal Voltage [kV]
R. Andes 345 kV	SING	- tap off reactor Andes	0.00	0.00	0.00	345
R. Laberinto 220 kV	SING	Laberinto 220 kV B2	1.02	20.63	0.00	220
R. Salta 345 kV	NOA	- 8120 COBOS	0.00	0.00	0.00	345
shnt_8000_8007_1	Transnor	8000 BRACHO	1.02	125.68	0.00	500
shnt_8007_8000_1	Transnor	8007 COBOS	1.00	121.18	0.00	500
shnt_8007_8009_1	Transnor	8007 COBOS	1.00	121.18	0.00	500
shnt_8008_8007_1	Transnor	8008 JUANCITO	1.00	50.10	0.00	500
shnt_8009_8007_1	Transnor	8009 MQUEM-CB	1.01	122.51	0.00	500
shntswt_8007_1	Transnor	8007 COBOS	1.00	121.18	0.00	500
shntswt_8007_2	Transnor	8007 COBOS	1.00	121.18	0.00	500
Cap Llasa N°1	SING	Llasa 23 kV 1	0.99	-6.80	0.00	23
Cap Llasa N°2	SING	Llasa 23 kV 2	0.99	-6.80	0.00	23

Table A. 53 - SING-SADI, Wind Scenario 3 (Shunt Compensators, Selected Nodes)

Series Compensators										
Name	Grid	Terminal i Busbar	Terminal j Busbar	Voltage Terminal i [p.u.]	Voltage Terminal j [p.u.]	Current, Magnitude Terminal i [kA]	Total Reactive Power Terminal i in Mvar	Total Reactive Power Terminal j in Mvar	Loading [%]	Nominal Voltage [kV]
Condensador Serie Andes 1/2	SING	Andes 345	Andes Reactor Shunt 345	1.03	0.98	0.56	-148.80	103.76	67.98	345
scap_8002_8004_1	Transnor	8002 RECREO	8004 REC_MALV	1.03	0.98	0.28	-176.28	160.62	27.50	500

Table A. 54 - SING-SADI, Wind Scenario 3 (Series Compensators, Selected Nodes)

Appendix M

SING-SADI/Wind Scenario 1+2+3, Load-Flow simulation results

Generators											
Unit Name	Grid	Terminal Busbar	Bus Type	Parallel Machines	Nominal App.Pow. [MVA]	Apparent Power [MVA]	Loading [%]	Active Power [MW]	Reactive Power [Mvar]	Voltage [p.u]	Power Factor
sym_6600_1	Centro	6600 EMBANUCL	SL	1	763.5	619.63	81.16	610.60	105.44	0.990	0.99
sym_8622_1	NOA	8622 TANDESG1	PV	1	270	220.49	81.66	180.18	127.09	1.020	0.82
sym_8623_2	NOA	8623 TANDESG2	PV	1	270	220.49	81.66	180.18	127.09	1.020	0.82
sym_8624_1	NOA	8624 TANDESTV	PV	1	270	253.98	94.07	200.20	156.30	1.020	0.79
U12	SING	Tocopilla U12	PV	1	92	87.12	94.69	80.08	34.30	1.015	0.92
U13	SING	Tocopilla U13	PV	1	92	87.12	94.69	80.08	34.30	1.019	0.92

Table A. 55 - SING-SADI, Wind Scenario 1+2+3 (Generators, Selected Nodes)

Transmission Lines															
Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	0.956	1.000	63.07	21.25	87.23	153.31	595.56	-554.10	51.28	230.54	41.46	1.05	1.00
110 kV Tap Off Oeste-Minsal	SING	110	0.940	0.894	21.32	20.06	95.85	0.92	27.98	-27.09	23.42	-22.57	0.88	0.20	0.21
220 kV Andes-Nueva Zaldívar.C1	SING	220	0.962	0.957	57.53	53.15	47.47	8.39	138.87	-137.20	-10.57	12.69	1.67	0.38	0.38
220 kV Andes-Nueva Zaldívar.C2	SING	220	0.962	0.957	57.53	53.15	63.29	8.39	138.87	-137.20	-10.57	12.69	1.67	0.38	0.38
220 kV Crucero-Encuentro.C1	SING	220	1.015	1.015	63.15	63.13	19.89	0.12	55.91	-55.91	-48.27	48.18	0.00	0.19	0.19
220 kV Crucero-Encuentro.C2	SING	220	1.015	1.015	63.15	63.13	15.02	0.16	42.19	-42.18	-36.45	36.32	0.00	0.14	0.14
220 kV Crucero-Laberinto.C1	SING	220	1.015	1.001	63.15	62.50	7.52	17.99	12.21	-12.15	0.71	-18.42	0.05	0.03	0.06
220 kV Crucero-Laberinto.C2	SING	220	1.015	1.001	63.15	62.50	7.50	18.82	12.42	-12.37	0.76	-19.28	0.05	0.03	0.06
220 kV Laberinto-El Cobre	SING	220	1.001	1.002	62.50	62.49	5.62	0.37	4.07	-4.07	-25.40	25.04	0.00	0.07	0.07
220 kV Laberinto-Lomas Bayas	SING	220	1.001	1.001	62.50	62.35	39.57	1.35	29.93	-29.91	2.75	-4.02	0.02	0.08	0.08
220 kV Laberinto-Mantos Blancos	SING	220	1.001	1.000	62.50	63.83	13.70	9.40	-36.33	36.54	7.02	-15.55	0.21	0.10	0.10
220 kV Laberinto-Nueva Zaldívar.C1	SING	220	0.962	1.001	57.53	62.50	39.55	12.16	-108.21	110.26	-27.05	25.41	2.05	0.30	0.30
220 kV Laberinto-Nueva Zaldívar.C2	SING	220	0.962	1.001	57.53	62.50	36.12	12.66	-110.92	112.88	-29.36	27.54	1.96	0.31	0.30
220 kV Nueva Zaldívar-Escondida	SING	220	0.962	0.960	57.53	57.81	14.55	1.71	-32.68	32.72	23.10	-24.60	0.04	0.11	0.11
220 kV Nueva Zaldívar-Sulfuros	SING	220	0.962	0.961	57.53	57.98	23.56	1.58	-58.36	58.48	30.21	-31.27	0.13	0.18	0.18
220 kV Nueva Zaldívar-Zaldívar	SING	220	0.962	0.962	57.53	57.53	12.75	0.03	32.41	-32.41	24.25	-24.27	0.00	0.11	0.11
220 kV Andes-Tap Off Oeste	SING	220	0.957	0.962	53.15	55.80	49.22	4.69	-127.44	128.86	17.48	-16.31	1.42	0.35	0.35
220 kV Tap Off Oeste-Laberinto	SING	220	0.962	1.001	55.80	62.50	59.62	11.00	-156.92	161.56	-11.18	19.41	4.64	0.43	0.43
lne_8000_8007_1	Transnor	500	1.010	0.979	4.22	11.46	29.97	324.82	-424.70	429.53	4.97	-271.33	4.82	0.49	0.60
lne_8007_8008_1	Transnor	500	0.979	0.975	11.46	11.48	12.03	48.98	-0.69	0.71	52.92	-101.60	0.02	0.06	0.12
lne_8007_8009_1	Transnor	500	0.979	0.990	11.46	5.11	24.57	333.71	359.64	-356.28	-210.14	-83.12	3.36	0.49	0.43
lne_8217_8326_1	NOA	132	0.977	1.023	11.36	16.41	81.85	2.14	-107.58	110.34	-20.91	29.54	2.76	0.49	0.49
lne_8243_8326_1	NOA	132	1.003	1.023	8.06	16.41	36.64	6.98	-49.32	51.10	5.40	-5.16	1.78	0.22	0.22
lne_8244_8326_1	NOA	132	1.037	1.023	15.51	16.41	54.84	0.65	-43.96	44.36	63.64	-62.77	0.40	0.33	0.33
lne_8244_8326_2	NOA	132	1.037	1.023	15.51	16.41	54.84	0.65	-43.96	44.36	63.64	-62.77	0.40	0.33	0.33
lne_8272_8326_1	NOA	132	0.990	1.023	7.11	16.41	54.23	4.96	-72.85	76.00	7.93	-0.93	3.15	0.32	0.32
Lickan Antai-Encuentro 220 kV	SING	220	1.024	1.015	66.34	63.13	33.80	8.33	114.36	-113.36	-0.50	-1.43	0.99	0.29	0.29
Llasa Amuki - Andes 220 kV	SING	220	0.960	0.957	54.71	53.15	61.60	1.84	195.42	-194.59	-3.88	7.35	0.83	0.53	0.53
Vientos del Desierto-Escondida 220 kV	SING	220	0.979	0.960	67.61	57.81	46.67	15.70	151.01	-147.05	-1.09	10.83	3.96	0.40	0.40
Wayra-Domeyko 220 kV	SING	220	0.979	0.961	66.44	58.05	45.48	13.82	147.12	-143.82	-0.06	7.51	3.31	0.39	0.39

Table A. 56 - SING-SADI, Wind Scenario 1+2+3 (Transmission Lines, Selected Nodes)

2-Winding Transformers							
Transformer Name	Grid	HV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage LV-Side [p.u.]	Loading [%]	Voltage Setpoint [p.u.]
trf_8120_8622_1	NOA	8120 COBOS	8622 TANDESG1	1.000	1.020	75.85	1.005
trf_8120_8623_2	NOA	8120 COBOS	8623 TANDESG2	1.000	1.020	75.85	1.005
trf_8120_8624_1	NOA	8120 COBOS	8624 TANDESTV	1.000	1.020	87.37	1.000
trf_8120_8930_1	NOA	8120 COBOS	8930 COB_NEU1	1.000	1.017	65.50	1.005
trf_8326_8930_1	NOA	8326 COBOS	8930 COB_NEU1	1.023	1.017	65.50	1.005
trf_8530_8930_1	NOA	8530 COB_TER1	8930 COB_NEU1	1.017	1.017	0.00	1.005
trf_8007_8931_1	Transnor	8007 COBOS	8931 COB_NEU1	0.979	1.003	89.57	1.048
trf_8120_8931_1	Transnor	8120 COBOS	8931 COB_NEU1	1.000	1.003	89.57	1.040
trf_8805_8931_1	Transnor	8805 COB_TER1	8931 COB_NEU1	1.003	1.003	0.00	1.040
trf_8007_8931_2	Transnor	8007 COBOS	8931 COB_NEU1	0.979	1.003	89.57	1.048
trf_8120_8931_2	Transnor	8120 COBOS	8931 COB_NEU1	1.000	1.003	89.57	1.000

Table A. 57 - SING-SADI, Wind Scenario 1+2+3 (2-Winding Transformers, Selected Nodes)

3-Winding Transformers									
Name	Grid	HV-Side Busbar	MV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage MV-Side [p.u.]	Voltage LV-Side [p.u.]	Maximum Loading [%]	Total Losses [MW]
Andes 345/220/23 kV N°1	SING	Andes 345	Andes 220	Andes 23 #1	0.968	0.957	0.957	83.40	0.29
Andes 345/220/23 kV N°2	SING	Andes 345	Andes 220	Andes 23 #2	0.968	0.957	0.957	83.40	0.29
Andes 345/220/23 kV N°3	SING	Andes 345	Andes 220	Andes 23 #3	0.968	0.957	0.957	83.40	0.29
Tap Off Oeste 220/110/12.2 kV	SING	tap off Oeste	Laberinto Oeste 110	Laberinto Oeste 13.2	0.962	0.940	0.867	74.27	0.08

Table A. 58 - SING-SADI, Wind Scenario 1+2+3 (3-Winding Transformers, Selected Nodes)

Shunt Compensators						
Name	Grid	Terminal BusBar	Voltage [p.u.]	Reactive Power [Mvar]	Active Power [MW]	Nominal Voltage [kV]
R. Andes 345 kV	SING	- tap off reactor Andes	0.000	0.00	0.00	345
R. Laberinto 220 kV	SING	Laberinto 220 kV B2	1.001	20.06	0.00	220
R. Salta 345 kV	NOA	- 8120 COBOS	0.000	0.00	0.00	345
shnt_8000_8007_1	Transnor	8000 BRACHO	1.010	122.34	0.00	500
shnt_8007_8000_1	Transnor	8007 COBOS	0.979	114.99	0.00	500
shnt_8007_8009_1	Transnor	8007 COBOS	0.979	114.99	0.00	500
shnt_8008_8007_1	Transnor	8008 JUANCITO	0.975	47.53	0.00	500
shnt_8009_8007_1	Transnor	8009 MQUEM-CB	0.990	117.51	0.00	500
shntswt_8007_1	Transnor	8007 COBOS	0.979	114.99	0.00	500
shntswt_8007_2	Transnor	8007 COBOS	0.979	114.99	0.00	500
Cap Lickan N°1	SING	Lickan Antai 23 kV 1	1.006	-7.09	0.00	23
Cap Lickan N°2	SING	Lickan Antai 23 kV 2	1.006	-7.09	0.00	23
Cap Llasa N°1	SING	Llasa 23 kV 1	0.946	-18.79	0.00	23
Cap Llasa N°2	SING	Llasa 23 kV 2	0.946	-18.79	0.00	23
Cap Vientos del Desierto N°1	SING	Los Vientos 23 kV 1	0.964	-13.00	0.00	23
Cap Vientos del Desierto N°2	SING	Los Vientos 23 kV 2	0.964	-13.00	0.00	23
Cap Wayra N°1	SING	Wayra 23 kV 1	0.964	-13.00	0.00	23
Cap Wayra N°2	SING	Wayra 23 kV 2	0.964	-13.00	0.00	23

Table A. 59 - SING-SADI, Wind Scenario 1+2+3 (Shunt Compensators, Selected Nodes)

Series Compensators										
Name	Grid	Terminal i Busbar	Terminal j Busbar	Voltage Terminal i [p.u.]	Voltage Terminal j [p.u.]	Current, Magnitude Terminal i [kA]	Total Reactive Power Terminal i in Mvar	Total Reactive Power Terminal j in Mvar	Loading [%]	Nominal Voltage [kV]
Condensador Serie Andes 1/2	SING	Andes 345	Andes Reactor Shunt 345	0.968	0.956	1.05	-107.50	-51.35	127.65	345
scap_8002_8004_1	Transnor	8002 RECREO	8004 REC_MALV	1.018	0.954	0.41	-246.54	212.40	40.61	500

Table A. 60 - SING-SADI, Wind Scenario 1+2+3 (Series Compensators, Selected Nodes)

Appendix N

SING-SADI/Wind-Solar-Gas, Load-Flow simulation results

Generators											
Unit Name	Grid	Terminal Busbar	Bus Type	Parallel Machines	Nominal App.Pow. [MVA]	Apparent Power [MVA]	Loading [%]	Active Power [MW]	Reactive Power [Mvar]	Voltage [p.u]	Power Factor
sym_6600_1	Centro	6600 EMBANUCL	SL	1	763.5	617.14	80.83	610.05	93.29	0.990	0.99
sym_8622_1	NOA	8622 TANDESG1	PV	1	270	204.72	75.82	180.01	97.49	1.020	0.88
sym_8623_2	NOA	8623 TANDESG2	PV	1	270	204.72	75.82	180.01	97.49	1.020	0.88
sym_8624_1	NOA	8624 TANDESTV	PV	1	270	232.91	86.26	200.02	119.34	1.020	0.86
U12	SING	Tocopilla U12	PV	1	92	85.72	93.18	80.01	30.78	1.011	0.93
U13	SING	Tocopilla U13	PV	1	92	85.72	93.18	80.01	30.78	1.015	0.93
TG2A	SING	Atacama TG2A 15	PV	1	165	104.92	63.59	100.01	31.73	1.000	0.95

Table A. 61 - SING-SADI, Wind-Solar-Gas Scenario (Generators, Selected Nodes)

Transmission Lines															
Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	1.022	1.018	53.06	20.11	72.13	171.05	528.39	-499.92	19.68	108.02	28.47	0.87	0.84
110 kV Tap Off Oeste-Minsal	SING	110	0.999	0.975	15.09	13.47	70.21	1.06	27.71	-27.23	7.10	-7.21	0.48	0.15	0.15
220 kV Andes-Nueva Zaldívar.C1	SING	220	0.974	0.966	51.20	45.94	57.58	8.57	170.68	-168.22	-9.05	15.95	2.46	0.46	0.46
220 kV Andes-Nueva Zaldívar.C2	SING	220	0.974	0.966	51.20	45.94	76.77	8.57	170.68	-168.22	-9.05	15.95	2.46	0.46	0.46
220 kV Crucero-Encuentro.C1	SING	220	1.017	1.017	61.19	61.17	16.91	0.12	51.92	-51.92	-35.49	35.39	0.00	0.16	0.16
220 kV Crucero-Encuentro.C2	SING	220	1.017	1.017	61.19	61.17	12.77	0.16	39.17	-39.17	-26.81	26.67	0.00	0.12	0.12
220 kV Crucero-Laberinto.C1	SING	220	1.017	1.005	61.19	57.65	19.06	18.07	56.29	-55.61	-7.44	-7.17	0.67	0.15	0.15
220 kV Crucero-Laberinto.C2	SING	220	1.017	1.005	61.19	57.65	18.90	18.90	57.91	-57.26	-6.99	-8.33	0.65	0.15	0.15
220 kV Laberinto-El Cobre	SING	220	1.005	1.005	57.65	57.65	4.24	0.38	-4.26	4.26	-19.02	18.65	0.00	0.05	0.05
220 kV Laberinto-Lomas Bayas	SING	220	1.005	1.004	57.65	57.51	39.45	1.35	29.93	-29.91	2.73	-4.01	0.02	0.08	0.08
220 kV Laberinto-Mantos Blancos	SING	220	1.005	1.001	57.65	59.14	15.39	9.44	-40.12	40.38	10.77	-19.12	0.26	0.11	0.12
220 kV Laberinto-Nueva Zaldívar.C1	SING	220	0.974	1.005	51.20	57.65	48.33	12.33	-137.61	140.74	-8.78	12.45	3.12	0.37	0.37
220 kV Laberinto-Nueva Zaldívar.C2	SING	220	0.974	1.005	51.20	57.65	44.13	12.84	-141.39	144.38	-10.99	14.64	2.99	0.38	0.38
220 kV Nueva Zaldívar-Escondida	SING	220	0.974	0.973	51.20	51.41	10.09	1.76	-27.24	27.26	7.59	-9.24	0.02	0.08	0.08
220 kV Nueva Zaldívar-Sulfuros	SING	220	0.974	0.973	51.20	51.73	27.01	1.62	-73.33	73.50	22.08	-23.02	0.17	0.21	0.21
220 kV Nueva Zaldívar-Zaldívar	SING	220	0.974	0.974	51.20	51.20	12.16	0.03	38.21	-38.21	8.19	-8.21	0.00	0.11	0.11
220 kV Andes-Tap Off Oeste	SING	220	0.966	0.972	45.94	49.28	62.40	4.79	-162.78	165.06	25.42	-20.78	2.28	0.45	0.45
220 kV Tap Off Oeste-Laberinto	SING	220	0.972	1.005	49.28	57.65	72.50	11.13	-192.81	199.73	11.46	6.03	6.91	0.52	0.52
lne_8000_8007_1	Transnor	500	1.016	0.991	4.16	10.99	28.35	330.92	-409.91	414.21	-23.21	-255.64	4.30	0.47	0.57
lne_8007_8008_1	Transnor	500	0.991	0.988	10.99	11.05	11.98	50.26	-16.61	16.63	51.14	-101.10	0.02	0.06	0.12
lne_8007_8009_1	Transnor	500	0.991	0.998	10.99	4.78	24.07	341.02	359.91	-356.66	-203.10	-98.69	3.26	0.48	0.43
lne_8217_8326_1	NOA	132	0.988	1.035	10.91	15.75	80.11	2.19	-106.00	108.65	-23.08	31.20	2.64	0.48	0.48
lne_8243_8326_1	NOA	132	1.012	1.035	7.69	15.75	35.78	7.13	-48.84	50.54	4.20	-4.42	1.70	0.21	0.21
lne_8244_8326_1	NOA	132	1.046	1.035	15.06	15.75	44.08	0.67	-33.67	33.93	52.80	-52.48	0.26	0.26	0.26
lne_8244_8326_2	NOA	132	1.046	1.035	15.06	15.75	44.08	0.67	-33.67	33.93	52.80	-52.48	0.26	0.26	0.26
lne_8272_8326_1	NOA	132	1.000	1.035	6.75	15.75	53.18	5.06	-72.37	75.40	6.13	0.32	3.03	0.32	0.32
Lickan Antai-Encuentro 220 kV	SING	220	1.027	1.017	63.91	61.17	29.25	8.36	98.76	-98.02	3.26	-6.86	0.74	0.25	0.25
Vientos del Desierto-Escondida 220 kV	SING	220	1.028	0.973	57.06	51.41	32.39	16.72	98.79	-96.98	32.87	-37.97	1.81	0.27	0.28
Wayra-Domeyko 220 kV	SING	220	1.020	0.973	56.83	51.80	32.26	14.60	98.76	-97.17	31.95	-36.33	1.59	0.27	0.28
Valle de los vientos - Calama 110 kV	SING	110	0.950	1.041	55.56	54.92	50.53	0.19	49.54	-49.43	8.53	-8.13	0.11	0.28	0.28

Table A. 62 - SING-SADI, Wind-Solar-Gas Scenario (Transmission Lines, Selected Nodes)

2-Winding Transformers							
Transformer Name	Grid	HV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage LV-Side [p.u.]	Loading [%]	Voltage Setpoint [p.u.]
trf_8120_8622_1	NOA	8120 COBOS	8622 TANDESG1	1.018	1.020	70.42	1.005
trf_8120_8623_2	NOA	8120 COBOS	8623 TANDESG2	1.018	1.020	70.42	1.005
trf_8120_8624_1	NOA	8120 COBOS	8624 TANDESTV	1.018	1.020	80.12	1.000
trf_8120_8930_1	NOA	8120 COBOS	8930 COB_NEU1	1.018	1.030	59.17	1.005
trf_8326_8930_1	NOA	8326 COBOS	8930 COB_NEU1	1.035	1.030	59.17	1.005
trf_8530_8930_1	NOA	8530 COB_TER1	8930 COB_NEU1	1.030	1.030	0.00	1.005
trf_8007_8931_1	Transnor	8007 COBOS	8931 COB_NEU1	0.991	1.021	85.20	1.048
trf_8120_8931_1	Transnor	8120 COBOS	8931 COB_NEU1	1.018	1.021	85.20	1.040
trf_8805_8931_1	Transnor	8805 COB_TER1	8931 COB_NEU1	1.021	1.021	0.00	1.040
trf_8007_8931_2	Transnor	8007 COBOS	8931 COB_NEU1	0.991	1.021	85.20	1.048
trf_8120_8931_2	Transnor	8120 COBOS	8931 COB_NEU1	1.018	1.021	85.20	1.000

Table A. 63 - SING-SADI, Wind-Solar-Gas Scenario (2-Winding Transformers, Selected Nodes)

3-Winding Transformers									
Name	Grid	HV-Side Busbar	MV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage MV-Side [p.u.]	Voltage LV-Side [p.u.]	Maximum Loading [%]	Total Losses [MW]
Andes 345/220/23 kV N°1	SING	Andes 345	Andes 220	Andes 23 #1	1.036	0.966	0.966	73.27	0.25
Andes 345/220/23 kV N°2	SING	Andes 345	Andes 220	Andes 23 #2	1.036	0.966	0.966	73.27	0.25
Andes 345/220/23 kV N°3	SING	Andes 345	Andes 220	Andes 23 #3	1.036	0.966	0.966	73.27	0.25
Tap Off Oeste 220/110/12.2 kV	SING	tap off Oeste	Laberinto Oeste 110	Laberinto Oeste 13.2	0.972	0.999	0.924	54.78	0.05

Table A. 64 - SING-SADI, Wind-Solar-Gas Scenario (3-Winding Transformers, Selected Nodes)

Shunt Compensators						
Name	Grid	Terminal BusBar	Voltage [p.u.]	Reactive Power [Mvar]	Active Power [MW]	Nominal Voltage [kV]
R. Andes 345 kV	SING	- tap off reactor Andes	0.000	0.00	0.00	345
R. Laberinto 220 kV	SING	Laberinto 220 kV B2	1.005	20.18	0.00	220
R. Salta 345 kV	NOA	- 8120 COBOS	0.000	0.00	0.00	345
shnt_8000_8007_1	Transnor	8000 BRACHO	1.016	123.82	0.00	500
shnt_8007_8000_1	Transnor	8007 COBOS	0.991	117.95	0.00	500
shnt_8007_8009_1	Transnor	8007 COBOS	0.991	117.95	0.00	500
shnt_8008_8007_1	Transnor	8008 JUANCITO	0.988	48.78	0.00	500
shntswt_8007_1	Transnor	8007 COBOS	0.991	117.95	0.00	500
shntswt_8007_2	Transnor	8007 COBOS	0.991	117.95	0.00	500
C. Lixiviación N°1 13.8 kV	SING	Lixiviación 13.8 #11	0.990	-9.61	0.00	13.8
C. Lixiviación N°2 13.8 kV	SING	Lixiviación 13.8 #21	0.990	-9.61	0.00	13.8
C. Minsal N°1 23 kV	SING	Laberinto Minsal 23 B1	0.930	-6.48	0.00	23
C. Minsal N°2 23 kV	SING	Laberinto Minsal 23 B2	0.993	-7.39	0.00	23
Cap Lickan N°1	SING	Lickan Antai 23 kV 1	1.010	-7.14	0.00	23
Cap Lickan N°2	SING	Lickan Antai 23 kV 2	1.010	-7.14	0.00	23
Cap VDLV N°1(1)	SING	VDLV 23 kV 1	1.031	-7.44	0.00	23
Cap VDLV N°2(1)	SING	VDLV 23 kV 2	1.031	-7.44	0.00	23
Cap Vientos del Desierto N°1	SING	Los Vientos 23 kV 1	1.025	-22.06	0.00	23
Cap Vientos del Desierto N°2	SING	Los Vientos 23 kV 2	1.025	-22.06	0.00	23
Cap Wayra N°1	SING	Wayra 23 kV 1	1.017	-21.73	0.00	23
Cap Wayra N°2	SING	Wayra 23 kV 2	1.017	-21.73	0.00	23

Table A. 65 - SING-SADI, Wind-Solar-Gas Scenario (Shunt Compensators, Selected Nodes)

Series Compensators										
Name	Grid	Terminal i Busbar	Terminal j Busbar	Voltage Terminal i [p.u.]	Voltage Terminal j [p.u.]	Current, Magnitude Terminal i [kA]	Total Reactive Power Terminal i in Mvar	Total Reactive Power Terminal j in Mvar	Loading [%]	Nominal Voltage [kV]
Condensador Serie Andes 1/2	SING	Andes 345	Andes Reactor Shunt 345	1.036	1.022	0.87	-88.90	-19.71	105.56	345
scap_8002_8004_1	Transnor	8002 RECREO	8004 REC_MALV	1.024	0.968	0.40	-219.29	186.41	39.85	500

Table A. 66 - SING-SADI, Wind-Solar-Gas Scenario (Series Compensators, Selected Nodes)

Appendix O

SING-SADI/Wind-Solar at 50%/Extra Gas, Load-Flow simulation results

Generators											
Unit Name	Grid	Terminal Busbar	Bus Type	Parallel Machines	Nominal App.Pow. [MVA]	Apparent Power [MVA]	Loading [%]	Active Power [MW]	Reactive Power [Mvar]	Voltage [p.u]	Power Factor
sym_6600_1	Centro	6600 EMBANUCL	SL	1	763.5	617.30	80.85	610.28	92.81	0.990	0.99
sym_8622_1	NOA	8622 TANDESG1	PV	1	270	205.02	75.93	180.08	98.00	1.020	0.88
sym_8623_2	NOA	8623 TANDESG2	PV	1	270	205.02	75.93	180.08	98.00	1.020	0.88
sym_8624_1	NOA	8624 TANDESTV	PV	1	270	233.31	86.41	200.09	119.98	1.020	0.86
U12	SING	Tocopilla U12	PV	1	92	85.83	93.29	80.04	30.99	1.011	0.93
U13	SING	Tocopilla U13	PV	1	92	85.83	93.29	80.04	30.99	1.015	0.93
TG1A	SING	Atacama TG1A 15	PV	1	165	109.85	66.57	105.05	-32.11	0.942	0.96
TG1B	SING	Atacama TG1B 15	PV	1	165	105.05	63.67	105.05	0.00	0.970	1.00
TG2A	SING	Atacama TG2A 15	PV	1	165	104.96	63.61	100.05	31.73	1.000	0.95
TG2B	SING	Atacama TG2B 15	PV	1	165	104.96	63.61	100.05	31.73	1.000	0.95
TV1C	SING	Atacama TV1C 15	PV	1	165	114.08	69.14	112.05	-21.40	0.954	0.98
TV2C	SING	Atacama TV2C 15	PV	1	165	104.96	63.61	100.05	31.73	1.000	0.95

Table A. 67 - SING-SADI, Wind-Solar 50%/Extra Gas (Generators, Selected Nodes)

Transmission Lines																
Line Name	Grid	Nominal Voltage [kV]	Voltage Terminal i in p.u.	Voltage Terminal j in p.u.	Voltage Angle Terminal i in deg	Voltage Angle Terminal j in deg	Loading [%]	Capacitive Loading [Mvar]	Active Power Terminal i [MW]	Active Power Terminal j [MW]	Reactive Power Terminal i [Mvar]	Reactive Power Terminal j [Mvar]	Total Losses [MW]	Current Terminal i [kA]	Current Terminal j [kA]
345 kV Central Salta-Andes	SING	345	1.011	1.018	52.54	19.83	71.43	169.16	517.61	-489.89	8.14	113.66	27.72	0.86	0.83
110 kV Tap Off Oeste-Minsal	SING	110	0.990	0.965	14.64	13.00	71.11	1.04	27.70	-27.21	7.51	-7.57	0.49	0.15	0.15
220 kV Andes-Nueva Zaldívar.C1	SING	220	0.966	0.958	50.75	45.41	57.91	8.42	170.37	-167.87	-7.62	14.86	2.49	0.46	0.46
220 kV Andes-Nueva Zaldívar.C2	SING	220	0.966	0.958	50.75	45.41	77.21	8.42	170.37	-167.87	-7.62	14.86	2.49	0.46	0.46
220 kV Atacama-Domeyko.C1	SING	220	1.020	0.965	67.31	51.41	50.93	27.51	159.74	-149.46	1.19	13.95	10.28	0.41	0.41
220 kV Atacama-Domeyko.C2	SING	220	1.020	0.965	67.31	51.41	50.73	27.58	159.13	-148.86	0.99	14.03	10.27	0.41	0.41
220 kV Atacama-Encuentro.C1	SING	220	1.020	1.015	67.31	61.65	21.89	29.29	106.42	-104.77	-21.01	2.12	1.65	0.28	0.27
220 kV Atacama-Encuentro.C2	SING	220	1.020	1.015	67.31	61.65	21.89	29.29	106.42	-104.77	-21.01	2.12	1.65	0.28	0.27
220 kV Atacama-Esmeralda	SING	220	1.020	1.000	67.31	64.72	33.85	9.43	82.57	-81.69	13.55	-18.94	0.88	0.22	0.22
220 kV Crucero-Encuentro.C1	SING	220	1.015	1.015	61.66	61.65	7.34	0.12	5.14	-5.14	-26.77	26.65	0.00	0.07	0.07
220 kV Crucero-Encuentro.C2	SING	220	1.015	1.015	61.66	61.65	5.55	0.16	3.88	-3.88	-20.24	20.08	0.00	0.05	0.05
220 kV Crucero-Laberinto.C1	SING	220	1.015	1.001	61.66	57.55	21.96	17.98	64.95	-64.04	-6.93	-6.43	0.90	0.17	0.17
220 kV Crucero-Laberinto.C2	SING	220	1.015	1.001	61.66	57.55	21.76	18.80	66.82	-65.95	-6.34	-7.69	0.87	0.17	0.17
220 kV Domeyko-Laguna Seca	SING	220	0.965	0.958	51.41	50.62	42.65	1.60	122.61	-122.11	29.96	-29.65	0.49	0.34	0.34
220 kV Domeyko-Planta Óxidos	SING	220	0.965	0.965	51.41	51.39	37.11	0.00	55.06	-55.05	35.52	-35.48	0.01	0.18	0.18
220 kV Domeyko-Sulfuros	SING	220	0.965	0.965	51.33	51.41	44.75	0.13	-155.86	155.90	14.10	-14.00	0.04	0.43	0.43
220 kV Laberinto-El Cobre	SING	220	1.001	1.002	57.55	57.55	5.42	0.37	-5.32	5.32	-24.23	23.87	0.00	0.07	0.06
220 kV Laberinto-Lomas Bayas	SING	220	1.001	1.000	57.55	57.41	39.59	1.34	29.93	-29.91	2.75	-4.02	0.02	0.08	0.08
220 kV Laberinto-Mantos Blancos	SING	220	1.001	1.000	57.55	59.05	15.31	9.39	-41.01	41.28	7.98	-16.28	0.26	0.11	0.12
220 kV Laberinto-Nueva Zaldívar.C1	SING	220	0.966	1.001	50.75	57.55	51.05	12.18	-144.04	147.52	-11.54	17.19	3.48	0.39	0.39
220 kV Laberinto-Nueva Zaldívar.C2	SING	220	0.966	1.001	50.75	57.55	46.62	12.70	-147.95	151.28	-13.92	19.61	3.33	0.40	0.40
220 kV Nueva Zaldívar-Escondida	SING	220	0.966	0.966	50.75	50.89	6.96	1.73	-17.84	17.85	6.62	-8.30	0.01	0.05	0.05
220 kV Nueva Zaldívar-Sulfuros	SING	220	0.966	0.965	50.75	51.33	29.57	1.60	-78.79	78.99	26.65	-27.43	0.20	0.23	0.23
220 kV Nueva Zaldívar-Zaldívar	SING	220	0.966	0.966	50.75	50.74	15.21	0.03	47.89	-47.89	7.44	-7.46	0.00	0.13	0.13
220 kV Reactor Escondida-Escondida	SING	220	0.966	0.966	50.89	50.89	6.96	0.01	-17.85	17.85	8.30	-8.31	0.00	0.05	0.05
220 kV Zaldívar-Escondida	SING	220	0.966	0.966	50.74	50.89	7.47	1.64	-19.46	19.47	6.65	-8.24	0.01	0.06	0.06
220 kV Andes-Tap Off Oeste	SING	220	0.958	0.964	45.41	48.90	64.67	4.71	-167.66	170.11	23.89	-18.47	2.45	0.46	0.47
220 kV Tap Off Oeste-Laberinto	SING	220	0.964	1.001	48.90	57.55	74.85	11.01	-197.86	205.23	8.69	10.81	7.37	0.54	0.54
lne_8000_8007_1	Transr	500	1.016	0.992	4.05	10.81	28.13	331.03	-405.57	409.78	-24.01	-255.99	4.21	0.46	0.56
lne_8007_8008_1	Transr	500	0.992	0.988	10.81	10.87	11.96	50.27	-15.68	15.71	51.17	-101.14	0.02	0.06	0.12
lne_8007_8009_1	Transr	500	0.992	0.999	10.81	4.67	23.87	341.17	355.64	-352.45	-203.77	-99.08	3.18	0.48	0.42
lne_8217_8326_1	NOA	132	0.988	1.035	10.67	15.50	79.95	2.18	-105.78	108.41	-23.05	31.13	2.63	0.48	0.48
lne_8243_8326_1	NOA	132	1.012	1.035	7.49	15.50	35.58	7.13	-48.56	50.24	4.18	-4.48	1.68	0.21	0.21
lne_8244_8326_1	NOA	132	1.046	1.035	14.82	15.50	43.94	0.67	-33.08	33.34	52.94	-52.62	0.26	0.26	0.26
lne_8244_8326_2	NOA	132	1.046	1.035	14.82	15.50	43.94	0.67	-33.08	33.34	52.94	-52.62	0.26	0.26	0.26
lne_8272_8326_1	NOA	132	1.000	1.035	6.54	15.50	52.96	5.06	-72.07	75.08	6.11	0.25	3.01	0.32	0.32
Lickan Antai-Encuentro 220 kV	SING	220	1.026	1.015	62.98	61.65	15.69	8.35	49.60	-49.40	11.06	-18.10	0.20	0.13	0.14
Valle de los Vientos - Calama 110 kV	SING	110	0.947	1.038	53.86	53.56	27.91	0.18	24.84	-24.81	12.08	-12.08	0.03	0.15	0.15
Vientos del Desierto-Escondida 220 kV	SING	220	1.023	0.966	53.49	50.89	22.27	16.52	49.60	-48.83	40.01	-51.60	0.77	0.16	0.19
Wayra-Domeyko 220 kV	SING	220	1.015	0.965	53.74	51.41	21.80	14.40	49.59	-48.93	39.23	-49.40	0.66	0.16	0.19

Table A. 68 - SING-SADI, Wind-Solar 50%/Extra Gas (Transmission Lines, Selected Nodes)

2-Winding Transformers							
Transformer Name	Grid	HV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage LV-Side [p.u.]	Loading [%]	Voltage Setpoint [p.u.]
trf_8120_8622_1	NOA	8120 COBOS	8622 TANDESG1	1.018	1.020	70.53	1.005
trf_8120_8623_2	NOA	8120 COBOS	8623 TANDESG2	1.018	1.020	70.53	1.005
trf_8120_8624_1	NOA	8120 COBOS	8624 TANDESTV	1.018	1.020	80.26	1.000
trf_8120_8930_1	NOA	8120 COBOS	8930 COB_NEU1	1.018	1.030	58.83	1.005
trf_8326_8930_1	NOA	8326 COBOS	8930 COB_NEU1	1.035	1.030	58.83	1.005
trf_8530_8930_1	NOA	8530 COB_TER1	8930 COB_NEU1	1.030	1.030	0.00	1.005
trf_8007_8931_1	Transnor	8007 COBOS	8931 COB_NEU1	0.992	1.021	84.31	1.048
trf_8120_8931_1	Transnor	8120 COBOS	8931 COB_NEU1	1.018	1.021	84.31	1.040
trf_8805_8931_1	Transnor	8805 COB_TER1	8931 COB_NEU1	1.021	1.021	0.00	1.040
trf_8007_8931_2	Transnor	8007 COBOS	8931 COB_NEU1	0.992	1.021	84.31	1.048
trf_8120_8931_2	Transnor	8120 COBOS	8931 COB_NEU1	1.018	1.021	84.31	1.000

Table A. 69 - SING-SADI, Wind-Solar 50%/Extra Gas (2-Winding Transformers, Selected Nodes)

3-Winding Transformers									
Name	Grid	HV-Side Busbar	MV-Side Busbar	LV-Side Busbar	Voltage HV-Side [p.u.]	Voltage MV-Side [p.u.]	Voltage LV-Side [p.u.]	Maximum Loading [%]	Total Losses [MW]
Andes 345/220/23 kV N°1	SING	Andes 345	Andes 220	Andes 23 #1	1.029	0.958	0.958	72.55	0.24
Andes 345/220/23 kV N°2	SING	Andes 345	Andes 220	Andes 23 #2	1.029	0.958	0.958	72.55	0.24
Andes 345/220/23 kV N°3	SING	Andes 345	Andes 220	Andes 23 #3	1.029	0.958	0.958	72.55	0.24
Tap Off Oeste 220/110/12.2 kV	SING	tap off Oeste	Laberinto Oeste 110	Laberinto Oeste 13.2	0.964	0.990	0.915	55.47	0.05

Table A. 70 - SING-SADI, Wind-Solar 50%/Extra Gas (3-Winding Transformers, Selected Nodes)

Shunt Compensators						
Name	Grid	Terminal BusBar	Voltage [p.u.]	Reactive Power [Mvar]	Active Power [MW]	Nominal Voltage [kV]
R. Andes 345 kV	SING	- tap off reactor Andes	0.000	0.00	0.00	345
R. Laberinto 220 kV	SING	Laberinto 220 kV B2	1.001	20.04	0.00	220
R. Salta 345 kV	NOA	- 8120 COBOS	0.000	0.00	0.00	345
shnt_8000_8007_1	Transnor	8000 BRACHO	1.016	123.87	0.00	500
shnt_8007_8000_1	Transnor	8007 COBOS	0.992	117.99	0.00	500
shnt_8007_8009_1	Transnor	8007 COBOS	0.992	117.99	0.00	500
shnt_8008_8007_1	Transnor	8008 JUANCITO	0.988	48.79	0.00	500
shntswt_8007_1	Transnor	8007 COBOS	0.992	117.99	0.00	500
shntswt_8007_2	Transnor	8007 COBOS	0.992	117.99	0.00	500
C. Lixiviación N°1 13.8 kV	SING	Lixiviación 13.8 #11	0.980	-9.42	0.00	13.8
C. Lixiviación N°2 13.8 kV	SING	Lixiviación 13.8 #21	0.980	-9.42	0.00	13.8
C. Minsal N°1 23 kV	SING	Laberinto Minsal 23 B1	0.919	-6.33	0.00	23
C. Minsal N°2 23 kV	SING	Laberinto Minsal 23 B2	0.983	-7.25	0.00	23
Cap Lickan N°1	SING	Lickan Antai 23 kV 1	1.012	-7.17	0.00	23
Cap Lickan N°2	SING	Lickan Antai 23 kV 2	1.012	-7.17	0.00	23
Cap VDLV N°1(1)	SING	VDLV 23 kV 1	1.030	-7.42	0.00	23
Cap VDLV N°2(1)	SING	VDLV 23 kV 2	1.030	-7.42	0.00	23
Cap Vientos del Desierto N°1	SING	Los Vientos 23 kV 1	1.023	-21.97	0.00	23
Cap Vientos del Desierto N°2	SING	Los Vientos 23 kV 2	1.023	-21.97	0.00	23
Cap Wayra N°1	SING	Wayra 23 kV 1	1.014	-21.61	0.00	23
Cap Wayra N°2	SING	Wayra 23 kV 2	1.014	-21.61	0.00	23

Table A. 71 - SING-SADI, Wind-Solar 50%/Extra Gas (Shunt Compensators, Selected Nodes)

Series Compensators										
Name	Grid	Terminal i Busbar	Terminal j Busbar	Voltage Terminal i [p.u.]	Voltage Terminal j [p.u.]	Current, Magnitude Terminal i [kA]	Total Reactive Power Terminal i in Mvar	Total Reactive Power Terminal j in Mvar	Loading [%]	Nominal Voltage [kV]
Condensador Serie Andes 1/2	SING	Andes 345	Andes Reactor Shunt 345	1.029	1.011	0.86	-98.36	-8.17	104.54	345
scap_8002_8004_1	Transnor	8002 RECREO	8004 REC_MALV	1.024	0.968	0.39	-217.64	185.61	39.33	500

Table A. 72 - SING-SADI, Wind-Solar 50%/Extra Gas (Series Compensators, Selected Nodes)