ASSESSMENT OF THE POWER POTENTIAL EXTRACTION IN THE CHILEAN CHACAO CHANNEL

LUIS VICENTE VILLALÓN SEPÚLVEDA

Thesis submitted to the Office of Research and Graduate Studies in partial fulfillment of the requirements for the Degree of Master of Science in Engineering

Advisor:
DAVID WATTS CASIMIS

Santiago de Chile, August 2014
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To Camila, my parents, grandparents, brothers, and friends who gave me their constant support during this process.
ACKNOWLEDGEMENTS

I would like to express deepest gratitude to my advisor Dr. David Watts for his full support, expert guidance, understanding and encouragement throughout my study and research. Without his incredible patience and timely wisdom and counsel, my thesis work would have been a frustrating and overwhelming pursuit. In addition, I express my appreciation to Dr. Hugh Rudnick, Dr Rodrigo Cienfuegos, and Dr. Hui Ren for having served on my committee. Their thoughtful questions and comments were valued greatly.

I would also like to thank my fellow graduate students at the Pontificia Universidad Católica Electric Department, and also thank my numerous friends, specially Victor and Alexis, who helped me throughout this academic exploration.

Finally, I would like to thank my eternal inspiration and support Camila, my parents, grandparents, brothers, sisters and my whole family for their unconditional love and support during the whole process; I would not have been able to complete this thesis without their continuous love and encouragement.
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RESUMEN

La factibilidad de una planta de corrientes mareales normalmente es evaluada estudiando las velocidades de los flujos, y los impactos hidrodinámicos y perturbaciones que genera en el medio marino. Sin embargo, a medida que las tecnologías mareomotrices se acercan a una etapa comercial, es importante evaluar la factibilidad de inyectar energía a la red de forma costo-efectiva. Una planta de corriente mareal requiere de una infraestructura eléctrica robusta que logre soportar las inyecciones de potencia. Más aún, encontrar capacidad de transmisión disponible y una infraestructura de conexión es ahora una de las principales barrera de entrada para el desarrollo de las energías renovables.

Los objetivos de este artículo son evaluar el potencial energético del canal de Chacao (conocido por ser uno de los canales con mayores potenciales del continente) y modelar el impacto que tendrá la evacuación de energía en la red eléctrica cercana al área de estudio. Finalmente, la meta del estudio es evaluar si las plantas mareomotrices operando en el extremo del sistema de transmisión troncal son técnica y económicamente factibles. Con este propósito, data obtenida a partir de mediciones directas y simulaciones hidrodinámicas es usada para evaluar la potencia eléctrica disponible durante un año completo. La inyección de potencia a la red es simulada usando un solver Newton-Raphson anidado que permite estimar el voltaje y cambios en los flujos de potencia a medida que las corrientes mareales cambian, considerando el estado actual y futuro de la red eléctrica del área. Encontramos que un proyecto piloto de 3 unidades pueden generar 15.6 GWh al año con un factor de planta cercano al 49.5%, interconectado en una línea cercana en 23 kV. La región puede integrar hasta 30 MW sin impactar significativamente las redes de alto voltaje. Pasada esta capacidad, costosos refuerzos al sistema de transmisión chileno deben ser implementados.

Palabras Clave: Corrientes mareales; evaluación del recurso mareomotriz; Chile; Newton-Raphson anidado.
ABSTRACT

The feasibility of a tidal plant is normally assessed by studying the tidal stream velocities, and the hydrodynamic impacts and disturbances in the marine environment. However, as these technologies approaches a commercial stage, it is important to assess the feasibility of injecting energy into the grid in a cost-effective way. A tidal plant needs a robust electric infrastructure to support its power injections. Moreover, finding available transmission capacity and transmission interconnection infrastructure is now one of the main barriers for renewable energy development.

The objectives of this paper are to assess the power potential of the Chilean Chacao channel (known to be one of the highest potential of the continent) and to model the power evacuation impacts on the electric grid of the surrounding area. Ultimately, the goal is to assess whether tidal plants in such isolated area are technical and economically feasible. For this purpose, data obtained from direct measurement and hydrodynamic simulations is used to evaluate the electric power available through one year. The injection of power to the grid is simulated using a nested Newton-Raphson power flow solver that allows representing voltage and power flow changes as the tides evolve considering the actual and future characteristics of the grid in the area. We found that a pilot project of 3 units can produce 15.6 GWh per year with a capacity factor of nearly 49.5%, injecting in a neighboring 23 kV line. The region can integrate up to 30 MW without significant impact in the high voltage network. Beyond this capacity, expensive reinforcement along the Chilean trunk transmission system would be needed.

Keywords: Tidal current; tidal resource assessment; Chile; Nested Newton-Raphson
1 INTRODUCTION

The last two decades have been marked by a great interest in tidal current energy investigation. The research programs and the development made by the industry, governments and universities from the United Kingdoms, Ireland, Italy, Sweden, Canada and the United States over the past 20 years have laid the groundwork for the emerging tidal energy industry (Mueller, Jeffrey, Wallace, & Von Jouanne, 2010). This has led to a productive decade of technological developments, pre-commercial testing (MCT, 2013), (OpenHydro, 2014) and research advances in physical models (Garret & Cummins, 2008), (Vennell, 2012), (Masters, Chapman, Orme, & Willis, 2010), (Buckland, Masters, Chapman, & Orme, 2010) and resource assessments (Fairley, Evans, Wooldridge, Willis, & Masters, 2013), (Ramos, Carballo, Álvarez, Sánchez, & Iglesias, 2013), (Goundar & Ahmed, 2014), which finally led the technology to be on the threshold of a commercial stage.

Chile with a lesser degree of technical development, but with extensive shores and high potential, has faced important developments led by the private industry, which have found support in the national shipping and harbor industry, and the navy that has shown great interest in these technologies. The non-conventional renewable energies (NCRE) promoting policies have not been enough to attract pre-commercial pilot plants, but have developed smaller initiatives such as the ones of the Chacao Channel and Magallanes, and some state-private co-financing that have developed resource studies, regulatory studies, and plant designs.

This study presents the research developed in the Chacao Channel. This investigation; made in association with Conicyt, Pontificia Universidad Católica de Chile, DICTUC, and Hydrochile; allowed to assess the energy potential of the channel, and the transmission capacity to evacuate the power generated of the neighboring electric grid.

2 STUDY AREA

The Chacao channel is defined as a southern marine channel of Chile. It is located in the Pacific Ocean within the Chiloé archipelago, in the X region de Los Lagos. The channel
has an east-west direction and its length is of 14 marine miles. Its width varies from less than 1 marine mile in the area of Roca Remolinos, up to 2.5 marine miles in the western entrance. The map and location of the channel is presented in Fig. 1.

Fig. 1. Study area in the Chacao channel. Source: SHOA.
2.1 Data collection and bathymetry ranges

Bathymetry data and flow stream velocities were directly measured with 6 Acoustic Doppler current profilers (ADCPs) and 6 tidal gauges located throughout the channel. The ADCPs took samples approximately every 30 minutes through one month. With the flow velocities and the bathymetry data, a hydrodynamic model was implemented, which is described in section 3.1 Hydrodynamic modelling. With the model, 4050 time series of flow speed were extrapolated to different points in the channel and used to assess the tidal current power potential and electric power injection feasibility.

The data collected form the tidal gauge was used to analyze the bathymetry of the channel and identify the economic and technical accessible sites to deploy tidal current devices. The bathymetry of the nearby area of the channel varies from few meters, near the shores, to up to 250 meters. Nonetheless, in the channel itself, between the continent and the Chiloé Big Island, the maximum depth reaches up to 200 meters. Fig. 2 presents the bathymetry of the channel and the location of the ADCPs and tidal gauges.

![Bathymetry and ADCPs location in the study area.](image)
2.2 Electric grid of the area

The area of study is located in the southern extreme of the Chilean trunk transmission system, 60 kilometers away from the main electric lines. In the nearby area, the electric grid consists in a subtransmission system and additional lines of 23 kV, 110 kV and a few of 220 kV.

The closest lines of the area of study are 23 kV feeders, such as the ones in Pihuio, Ahínco and Carelmapu. Some lines of 110 and 220 kV can be used to evacuate the power of large scale projects. The electric grid near the study is presented in Fig. 3.

![Electric grid of the study area](image-url)
3 METHODOLOGY

3.1 Hydrodynamic modelling

The hydrodynamic modelling of the Chacao Canel was made using the FVCOM model (Chen, Liu, & Beardsley, An unstructured, finite-volume, three-dimensional, primitive equation ocean model: application to coastal ocean and estuaries., 2003), (Chen, y otros, 2013). The domain consisted on a regional area that included the area of the Chilean Ocean that surrounds the Chiloé Island, including the Chacao channel and a part of the continental platform. The limits of the model are presented in blue and orange in Fig. 4; Error! No se encuentra el origen de la referencia.

![Fig. 4. Geographical limits of the FVCOM model.](image)

The FVCOM model solves the equations discretizing the domain of study in triangular elements in the horizontal axis and utilizing a sigma coordinate in the vertical axis. This vertical coordinate divides the water column in 10 layers. The triangular grid element and the sigma coordinate in the vertical axis used in the model are shown in Fig. 5.
The discretization of the hydrodynamic variables utilizes a staggered grid. The depth, free-surface variation and the turbulent kinetic energy are defined in each node, while the horizontal velocities u and v are defined in the centroid of each triangular element. The u velocity is the east horizontal velocity, and the v velocity is the north horizontal velocity.

For a more detailed modeling of the channel, the density of the grid used in the channel is higher. The biggest elements used in the grid, which are located at the west of the domain, have a side length of 6,000 m and an area of 15.5 km². The smaller elements, located in the area of interest, have a side length of 50 m and an area of 1,250 m². The grid has 49,977 triangular elements and 26,546 nodes. The staggered grid used in the model is presented in Fig. 6.
3.2 Temporal data extrapolation

Specialized techniques have been formulated to take advantage of the deterministic nature of tidal processes (Pawlowicz, Beardsley, & Lentz, 2002). In this study, the classical tidal harmonic analysis is used to model and extrapolate the tidal currents. The classical tidal harmonic analysis models the tidal forcing as a set of spectral lines, i.e., the sum of a finite set of sinusoids at specific frequencies (Pawlowicz, Beardsley, & Lentz, 2002):

\[ x(t) = a_0 + \sum_{k=1}^{N} a_k \cos(\sigma_k t) + b_k \sin(\sigma_k t) \] (1)

The case study uses 36 harmonic constituents, whose frequencies were obtained from (Pawlowicz, Beardsley, & Lentz, 2002). With the frequencies or period of each harmonic constituent \( \sigma_k \) known, the unknown parameters are the amplitudes...
components \(a_0\), \(a_k\), & \(b_k\). A variety of methods are defined to estimate the value of the parameters [18]. In this case study the method used is minimizing the quadratic error:

\[
E = \sum_{i=1}^{M} \left[ y(t_i) - \left( a_0 + \sum_{k=1}^{N} a_k \cos(\sigma_k t_i) + b_k \sin(\sigma_k t_i) \right) \right]^2
\] (2)

Once the coefficients \(a_0\), \(a_k\), & \(b_k\) are estimated, the amplitude \(\alpha\) of constituent \(k\) is found as \(\alpha_k = \sqrt{a_k^2 + b_k^2}\), and the phase angle \(\beta\) is found as \(\beta_k = \text{Imag}(\log(a_k + j b_k))\) (Leffler & Jay, 2009). The tidal current is then defined as a cosine function with amplitude \(\alpha\) and phase angle \(\beta\):

\[
x(t) = a_0 + \sum_{k=1}^{n} \alpha_k \cos(\sigma_k t + \beta_k)
\] (3)

### 3.3 Calculation of electric power output

A simplified model is used to evaluate performance for an individual device. The device may operate in three stages that will be defined by the tidal current speed that is passing through the device and its characteristics.

A device can be defined by the cut-in speed, its efficiency, and the rated velocity (EMEC, 2013). If the current speed is below the cut-in speed of the device, the power output is null, \(P_{out} = 0\). If the current speed is higher than the rated speed, the power output is equal to the rated power \(P_{output} = P_{rated}\). If the current speed is between the cut-in speed and the rated speed, the power output of the device is a portion of the power input available in the stream:

\[
P_{out} = P_{input} \times \eta_r(U)
\] (4)
The power input of the tidal stream is proportional to the area swept by the turbine blades $A$, the water density $\rho$, and the cubic stream speed $U$:

$$P_{\text{input}} = \frac{1}{2} \rho \times A \times U^3$$  \hspace{1cm} (5)

The device used in the assessment is the 1.2 MW SeaGen of Marine Turbine Current. The cut-in speed, rated speed and power, and the rated efficiency were obtained using the information presented in (Douglas, Harrison, & Chick, 2008), (Thiringer, MacEnri, & Reed, 2011) and (Fraenkel, 2010). The power curve used in the assessment is presented in Fig. 7.

![Power curve of the 1.2 MW SeaGen used in the tidal current power plants.](image)

### 3.4 Transmission line power flow modelling using Nested Newton Raphson

The load flow or power flow is the standard method for solving the static operating condition of an electric-power transmission system (Stott, 1974). Nowadays, the power flow is a key tool in power system planning and operation, providing the steady-state solution of the power flowing through the transmission grid. These scenarios are defined mainly by the network topology, loads, and active power generation and the generator voltages (Echavarren, Lobato, & Rouco, 2006). In other words, the power flow solution is determined by the instant operating conditions.
To assess the real impact of the power injection of a tidal current power plant, the analysis should be done considering the impact throughout a whole year, in order to correctly assess the seasonality of the tidal resource. To achieve this, a nested Newton-Raphson is used in this study, which solves the steady state solution of the power scenario conditioned by the instant power injected by the tidal current plant.

The nested Newton-Raphson model first calculates the power output of the tidal current plant, which is injected in the bus of interconnection. The operating condition of the tidal current plant, and the operating condition of the electric-power grid of the area is used as input for the classic Newton-Raphson solver. This solves for both voltages (magnitude and phase) and power flowing through the grid. The nested Newton-Raphson then solves the operating condition of the tidal current plant for the next iteration step and repeats the solving process. In this study each step is a 30 minutes interval of time. The iteration ends when the whole year is analyzed and the voltages for the whole year are obtained. The algorithm of the nested Newton-Raphson used is presented in Fig. 8. For a deep explanation of the Newton-Raphson algorithm refer to (Stott, 1974).
3.5 Interconnection alternatives

This study analyzes plant of different scales, a small pilot (3.6MW), a medium plant (30MW) and a large one (102MW). Different interconnection solutions were design for each of the three different tidal current power plants studied in order to determine if the impact on the grid voltages would stay within the established limits. Two interconnection alternatives were design for the pilot plant in 23kV, two for the medium sized plant in 110kV and two for the large scale plant in 220kV.

One of the alternatives designed for the pilot plant is a section in 11 kV towards the Pihuio feeder in 23 kV. The second alternative is an 11 kV section that injects in Ahínco in 23 kV. Both alternatives need an 11/23 kV power transformer. The first alternative is finally used because the distance to the connection point is shorter.
The two interconnection solutions designed for the medium scale plant includes a line 110 kV, constructed in parallel to the 23 kV feeder that exists in the area (Ahínco and Pihuio). Each generator of the tidal power plant would have its own 11 kV line which finally would reach an 11/110 kV power transformer. Both interconnection would reach a 23/110 kV substation. The first alternative would interconnect in Ancud 110 kV, and the second in Colaco 110 kV. In the analysis, the alternative that goes through Pihuio is used because of its shorter length.

The two interconnection solutions designed for the large scale plant includes the construction of a 220 kV line. One line reaches the bus Punta Barranco 220 kV and the other one Punta San Gallán 220 kV. Each generator of the plant would have a line of 11 kV which would reach an 11/110 kV power transformer. The alternative that reaches Punta San Gallán is finally used because of its shorter distance to the interconnection point.

The one line diagram of the selected interconnection alternatives and their main characteristics are presented in Table 1.

Table 1. Selected interconnection solutions for the three tidal current plants and their main characteristics.
Fig. 9. Interconnection solution for the pilot Plant.

**Pilot plant interconnection**

The interconnection is designed with three 11 kV lines connected in Pihuio 23 kV feeder through an 11/23 kV transformer.

- There are three 11 kV lines for each SeaGen. Each line is 2.5 km long.
- The interconnection is made in an 11 kV bus.
- The impact point is the Pihuio 23 kV bus.

Fig. 10. Interconnection solution for the medium size plant.

**Medium scale plant interconnection**

The interconnection involves 11 kV lines that reach a new substation that raises the voltage to 110 kV. From there a 110 kV line goes to the bus Ancud 110 kV.

- The 11 kV section are 25 submarine lines of 2.5 km long.
- The new substation Chacao 11/110 kV is located in the shore.
- The interconnection is made in the bus Chacao 11 kV, 16 km from Ancud substation.
- The impact point is the bus Ancud 110 kV.
Large Scale plant interconnection

The interconnection chosen for the large scale plant is an 11 kV line that reaches an 11/220 kV substation. From there a line of 220 kV connects to the bus Punta San Gallán 220 kV.

- The 11 kV section consists of 85 submarine lines of 2.5 km long.
- The 11 kV lines reaches a new substation, Chacao 11/220 kV, located in the shore.
- From the substation a 13 km 220 kV line goes towards the bus Punta San Gallán 220 kV, which is the impact point.
- The interconnection bus is the Chacao 11 kV.
4 RESULTS AND DISCUSSIONS

4.1 Resource assessment and site selection
The classical tidal harmonic analysis, considering 36 constituents, was used to model each velocity series of all streams present at site. The average correlation between the measured stream flows and modeled stream flow was $r=0.9872$, the maximum $r=0.9882$ and the minimum $r=0.9842$. The stream modeled for the turbine that generates the highest amount of energy annually correlated 0.9882. The comparison of the measured and modeled stream speed and their correlation are shown in Fig. 12.

The main constituents found of the stream with highest power potential were M4, MSF, MN4, MN, and MS4. Their amplitude and phases are shown in Table 2.

Table 2. Amplitude and Phase of the modeled flow speed.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Amplitude (m)</th>
<th>Phase (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M4</td>
<td>0.99</td>
<td>-0.06</td>
</tr>
<tr>
<td>MSF</td>
<td>0.61</td>
<td>0.72</td>
</tr>
<tr>
<td>MN4</td>
<td>0.43</td>
<td>-1.28</td>
</tr>
<tr>
<td>MM</td>
<td>0.32</td>
<td>0.50</td>
</tr>
<tr>
<td>MS4</td>
<td>0.14</td>
<td>3.00</td>
</tr>
</tbody>
</table>

The simple model of power extraction was applied to the three scaled tidal current power plants. The position of each tidal current turbine was selected using the indications described by EMEC (EMEC, 2013). The site was segmented in 100 possible site location
for the turbines. The depths of the turbine hub was selected respecting a 15 meter upper limit and 60 meter maximum depth, and maximizing the energy generation. The location of the turbine hub was selected maximizing the total annual energy output.

The stream velocity has almost 4 full cycles in normal day, and as a consequence the power output has between 4 or 5 peaks in each day. The hours in which the peak power injection occurs varies from day to day, due mainly to the cycles of the moon and in less extent to the relative position of the earth in relation to the sun. This phenomenon of the resource cycles and power peak shift is shown in Fig. 13.

![Stream Velocity and Power Output: May.04](image1)

![Stream Velocity and Power Output: May.06](image2)

Fig. 13. Daily seasonality of the stream resource and power output of the pilot plant.

While production in an hourly basis may change considerably, the monthly average power output of the plants stays within a short range. The monthly average of the pilot plant varies from 2.15 MW in January and February up to 2.65 MW in May. In every month the power plants have lower peaks of 0 MW and higher peaks of their nominal capacity. The monthly seasonality of the pilot plant is presented in Fig. 14, where the central red mark is the median, the edges of the blue box are the 25th and 75th percentiles, and the whiskers extend to the most extreme data points.
The site with higher energy output has an annually energy generation potential of 5.79 GWh with a SEAGEN unit, and the poorest location 4.7 GWh annually. The turbine with higher energy generation would have an estimated (gross) capacity factor of 55% and the turbine with the lowest energy generation would have a capacity factor of 44.8%. Each plant performance is presented in Table 3. This includes the histogram of the resource and the electricity production.

Table 3. Tidal stream velocity histograms and energy generation description.

**Pilot plant generation assessment**

The pilot power plant consists of 3 turbines, which sums a capacity of 3.6 MW.

- The plant would generate 17.3 GWh annually.
- The capacity factor of the plant would be 55%.
- 50% of the time the power plant would be generating more than 1.1 MW.
- 30% of the time the power plant would generate less than 0.25 MW.
Medium scale plant generation assessment

The medium scale plant consists of 25 turbines, giving a nominal 30 MW capacity.

- The medium size plant of 30 MW would generate 141 GWh annually.
- The capacity factor would be of 54%, lower than the pilot plant.
- 50% of the time the plant generation would be higher than 18.3 MW.
- 30% of the time the plant would generate less than 4.6 MW.

Large scale plant generation assessment

The large scale plant consists in 85 turbines adding 102 MW.

- The plant would generate 449 GWh annually.
- The capacity factor would be 50%, the lowest of the three tidal plants assessed.
- 50% of the time the power plant would generate more than 25.7 MW.
- 30% of the time the plant would generate less than 6.97 MW.

It can be noticed that nearly 33% of the time energy is produced from running the generator at nominal power, while only a 16.5% of the time the stream speed is not high enough to allow electricity production, see Fig. 18.
4.2 Electric power injection and impacts on the electric grid

Because of the poor electric system in remote areas, the tidal current projects depend not only on the tidal resource, but also on the electric infrastructure capacity to evacuate its injected power. This capacity is limited by the resource and the transmission capacity that depends in 3 factors:

- Thermal limit or maximum admissible electric current
- Contingencies limitations
- Voltage regulation limit

The thermal limit was considered when designing the lines to be used in the interconnection for each tidal plant. The contingencies limitations were not analyzed in this study, and should be consider in a future assessment. The voltage regulation limit was analyzed thoroughly with the nested Newton-Raphson model with voltage limits established by the Chilean electric security and quality service standard presented in Table 4.
Table 4. Voltages limits of Chilean transmission lines.

<table>
<thead>
<tr>
<th>Line Voltage</th>
<th>Normal State</th>
<th>Alert State</th>
<th>Emergency State</th>
</tr>
</thead>
<tbody>
<tr>
<td>V &gt;= 500 kV</td>
<td>0.97-1.03</td>
<td>0.97-1.03</td>
<td>0.95-1.05</td>
</tr>
<tr>
<td>200 kV &lt;= V &lt; 500 kV</td>
<td>0.95-1.05</td>
<td>0.95-1.05</td>
<td>0.9-1.10</td>
</tr>
<tr>
<td>V &lt; 200 kV</td>
<td>0.93-1.07</td>
<td>0.93-1.07</td>
<td>0.9-1.10</td>
</tr>
</tbody>
</table>

**Pilot Plant:** The voltage range of the pilot plant stays within the established limits for lines below 200 kV. The voltage in the bus of interconnection starts from 0.9822 [p.u.], when the power generated is 0 MW, and varies up to 1.0503 [p.u.] when the power plant is generating at full capacity. The impact point, i.e. Pihuio 23 kV bus, voltages varies from 0.9822 to 1.0503, staying within the limits. The variation of voltages in the interconnection bus and in the impact point are presented in Fig. 19.

**Midsize Plant:** The medium size plant impacts stays within the established limits. When the power plant is not injecting power, the bus voltages of the interconnection bus and impact point remain at 1 [p.u.]. When the power plant is injecting at full capacity, voltages rises up to 1.0545 [p.u.] in the interconnection bus and up to 1.0314 [p.u.] in the impact point, i.e. Ancud 110 kV. The power impact in the voltages of a 30 MW tidal current plant are presented in Fig. 19.

Fig. 19. Power impact on voltages of a Pilot Plant of 3.6 MW and Midsize project of 30 MW.
**Large Scale Plant:** The large scale plant impact exceeds the established limits for lines higher than 200 kV. When the plant is not injecting power, the voltages of the interconnection bus and impact point bus remains at 1.01 [p.u.]. When the injection reaches 102 MW, the voltages in the interconnection bus raises reaching 1.0925 [p.u.] and the impact point bus reaches 1.0664 [p.u.]. With this operating condition, both voltages exceed the limits established in the electric standard. This means that integrating such large marine tidal farm would need additional coordination requirements with the system operator to allow proper voltage regulation and self-scheduling would no longer be an option for this plant. The power impact of a 102 MW tidal plant in the voltages is presented in Fig. 20.

Fig. 20. Power impact in voltages of a large size planta of 102 MW.
5 CONCLUSIONS

A constrained electricity infrastructure may partially limit the validity of the power potential assessment based exclusively on current velocities and hydrodynamic impacts. This work investigates the voltage impact of three scales of tidal plants in Chacao channel by modeling the power extraction using horizontal axis turbines. The power flow through the transmission network is solved using a nested Newton-Raphson power flow solver. The current velocity data used for modeling the power extraction is obtained from direct measurements using ADCPs and hydrodynamic modelling.

The energy extraction potential of each tidal current power plant was assessed using SeaGen units of 1.2 MW. We found that a 3.6 MW pilot plant would generate 15.6 GWh annually. Similarly, a 30 MW and 102 MW plants would produce 127 GWh and 404 GWh per year respectively.

For each scale of tidal plants, connection alternatives were designed and evaluated. The design considered the thermal limits of the wires and the voltage impact in the whole grid of the nearby area. The impact of a 3.6 MW pilot tidal plant (3 turbines) and a 30 MW plant are within the limits established in the Chilean electric norm. Voltage levels remain within the ±7% range established for lines below 200 kV in normal operation. However, a 102 MW plant would significantly impact the grid, exceeding the ±5% limit established for 220 kV lines.

The Chacao channel power potential extraction is limited by the poor electric infrastructure of the area located in the extreme south of Chile and the continent, where population and industrial activities are scarce. The lack of a transmission system limits the power extraction up to 30 MW. In order to develop a 102 MW tidal plant the electric infrastructure needs to be strengthened.

While transmission is often considered a small part of the project cost, at an early development stage the transmission reinforcement cost can be substantial. Chilean transmission regulatory framework is based on the principles of cost-causation, leaving tidal plants with a heavy interconnection barrier, financing the reinforcement of large
area of the network. More research is needed to assess the real benefit of the country in developing these technologies (jobs, tech development, effects on energy prices) in order to determine if the country should provide further support to Non-Conventional Renewable Energies of national interest.
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