The New Chilean Transmission Charge Scheme as Compared With Current Allocation Methods

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***Abstract*—We describe the new method used in Chile to allocate transmission charges among generating companies and customers, as defined in Law 19 940 of March 2004 (also known as *Ley Corta* or Short Law). We show that the new Chilean transmission charge scheme is a hybrid based on marginal cost pricing, identification of use through economic benefits and flow identification methods, and last, a postage stamp to redistribute almost all the charges that customers have to pay. We also estimate the direct per kilowatthour charge that customers will pay and discuss its effect on location and expansion signals.**

***Index Terms*—Allocation methods, generalized generation distribution factors (GGDF), generalized load distribution factors (GLDF), Ley Corta, transmission charges, use.**

I. Introduction

Until 2004, transmission charges were distributed in Chile according to use, and their levels were set in private bargaining between generators and transmission companies. The allocation method worked whenever it was clear which party used a given line. Nevertheless, in many instances, the so-called "area of influence method," which was used to identify use, did not give unambiguous answers, a problem that became more acute as the high tension grid became more dense. This made it increasingly difficult to determine who was to pay for the existing lines and, in some cases, allegedly led to the postponement of investments.

To solve this problem, the Chilean congress changed the electricity law after a protracted discussion. Law 19 940, finally approved in March 2004, stated that transmission charges would be determined in four steps. First, existing lines will be valued every four years by independent experts. This assessment will determine the regulatory asset base and the amount of yearly income to which each line will be entitled.

Second, the transmission charge allocated to each line will be split between generating plants and customers according to the use they make of it. However, contrary to what had been the case in Chile, this time, the law states a detailed method to determine who uses a given line. It defines an "area of common influence" and dictates that 80% of it is used by all generators and the remaining 20% by all customers. Outside the area of common influence, use will be determined by the direction of power flows: lines that inject power into the area of common influence will be assumed to be used by the generating plants responsible for the injections, while lines that take power from it will be assumed to be used by customers responsible for the loads.

Third, after deciding who are the users of a given line, each generating plant will be allocated its share with the generalized generation distribution factors (GGDF) method. Similarly, each customer's share will be determined with the generalized load distribution factors (GLDF) method.

Fourth, for the first time, customers will pay directly to the transmission company for using their lines. Until now, generators were responsible for paying for line use on behalf of their customers. Moreover, almost all the direct transmission charges allocated to customers at each bus will be redistributed. In general terms, most customers will pay the same direct transmission charge per kilowatthour, regardless of their buses' location. Thus, the new scheme introduces postage-stamp charges in Chile.

This paper describes the transmission charge allocation method established by the *Ley Corta*, explains its economic rationale, and estimates the direct charge that customers would pay under the new law in the Central Interconnected System (SIC by its Spanish acronym), simulating the system's operation between April 2005 and May 2006.[1] We also explain where this method fits into the wealth of existing transmission charge allocation methods.

The rest of this paper is organized as follows. In Section II, we define some basic concepts. In Section III, we describe the new Chilean method to determine who uses a given line and relate it with existing transmission charge allocation methods. In Section IV, we explain the transmission charge allocation scheme introduced by the *Ley Corta*. Section V contains calculations and results, and Section VI concludes.

II. Some Basic Concepts

How to charge for a transmission line in liberalized electricity markets is still a conceptually unresolved issue. For one, while it is generally accepted that the high voltage transmission grid is a natural monopoly, there is a surprising variety of methods that are used around the world to set and regulate transmission charges and to price the different components of a grid (e.g., main transmission lines, substations, measurement and control equipment, and reactive power compensation devices).

[1]The SIC system is the largest in the country. It runs for 1921 km from the southern city of Puerto Montt to the nothern Diego de Almagro bus. In 2004, 74.2% of Chile's electricity was generated and consumed in the SIC. Nevertheless, 93% of Chile's population is served by this system (see Fig. 1).

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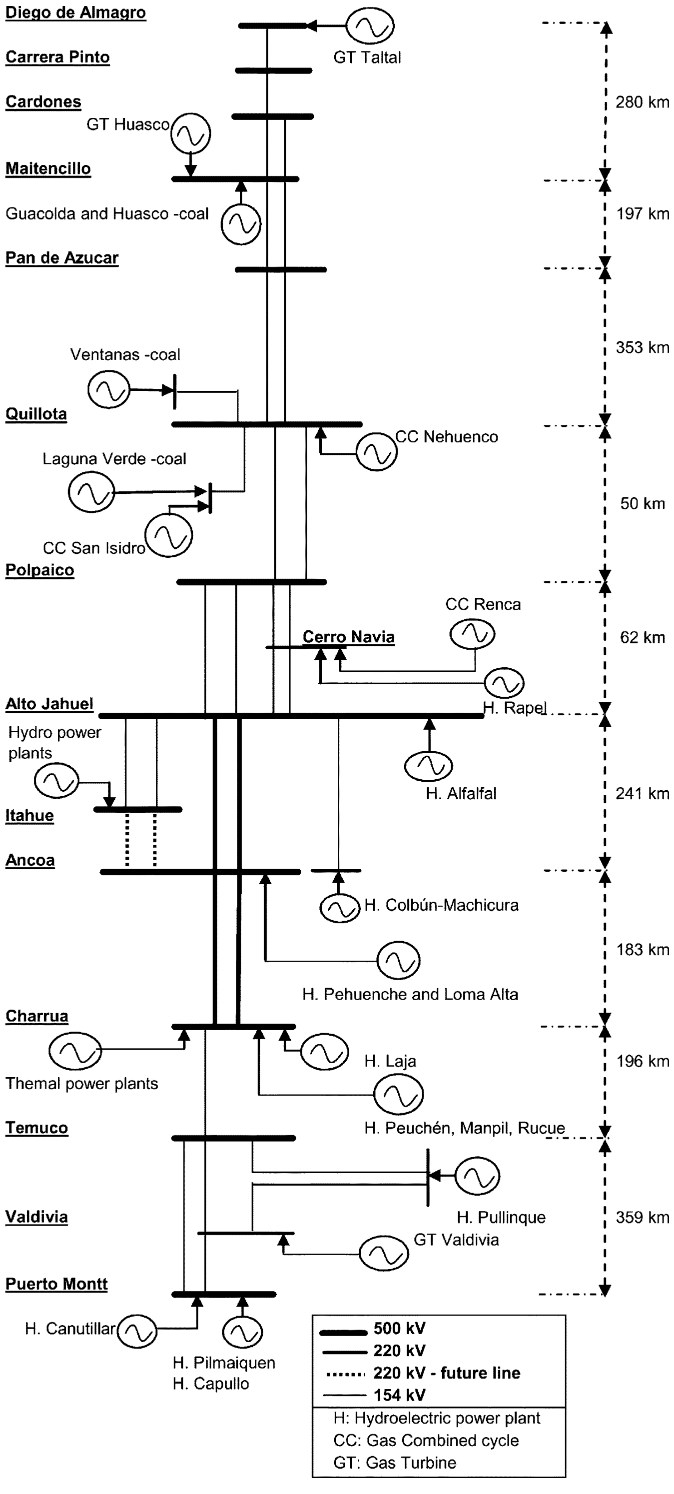

Fig. 1. Schematic diagram trunkline SIC.

For another, in systems where there is open access to the grid, there is still no agreement on how to determine who "uses" a given line, let alone how to distribute transmission charges among different users. Last, the fact that allocation methods may differ in who is responsible to make the actual payment to the transmission company may add to the confusion. Thus, it is useful to begin by defining a few basic concepts (allocation rules, payer, use of the transmission line, and direct charge).

TABLE I
EXAMPLE OF AN ALLOCATION RULE

	Payers		Total
	Generators	Customers	
Allocation by injections	(1,1) 21%	(1,2) 31%	52%
Allocation by loads	(2,1) 19%	(2,2) 19%	48%
Total	40%	60%	

A. Allocation Rules

As can be seen in Table I, a transmission charge allocation rule indicates two things: First, it identifies the payer, i.e., the party responsible for issuing the check to the transmission company; second, it identifies the user of each portion of the transmission grid. Broadly speaking, use is attributed either to power plant injections, customer loads, or a combination of the two.

Table I shows an example of a transmission charge allocation rule on a hypothetical line. One way of viewing this is by adding up the rows of the matrix, which determine payment by type of use. In this hypothetical case, 52% of the line's use is charged to power plant injections and the remaining 48% to customer loads.

The allocation rule can also be interpreted by summing the matrix columns, which indicate how much each party has to pay. In this case, the transmission company would receive 40% of the transmission charge from the generating companies and the other 60% directly from customers.

B. What Is Meant by Use?

In the case of infrastructure such as a road, it is easy to determine use, because a vehicle can be tracked as it travels from one point to another. In the case of electric power grids, however, use is much harder to determine, for when a power plant supplies or a consumer uses one additional kilowatt, flows adjust throughout the system according to the Kirchoff laws. It is impossible to physically identify the electrons supplied by an individual power plant or consumed by a specific customer. For this fundamental reason, the methods that exist to determine the use of a transmission line are accounting breakdowns of actual flows (accounting in the sense that they follow certain basic rules of consistency), based on electrical properties.

C. Why Distinguish Between the Payer and the Rule for Defining Use?

The reason is that the incidence of an allocation rule (i.e., who ultimately bears the cost of a line), and hence its economic effect, depend on the criteria for determining the user of a specific line, rather than on the identity of the payers. Provided that transmission charges are not set below cost, in the long run, customers will end up bearing the cost almost irrespective of who actually writes the check. Nonetheless, the rule used to determine use will affect the relative cost of power plant location (and to a lesser degree, customer location) in different parts of the grid. For example, if a criterion where injections are charged the full cost of a given line is replaced by one in which injections pay only 50%, and the other 50% is paid by customers, it immediately becomes cheaper to locate a power plant at the furthermost point of this line, regardless of whether it is the generating companies or customers who pay for the other 50%.

D. What Do We Mean by "Direct Charges"?

By direct charges, we mean all charges that could plausibly be passed directly to the customers' bill, either because customers are payers or because market conditions force them to pay them. We argue that only cells (2,1) and (2,2) in Table I fit in this category.

Consider first cell (2,2), which represents use assigned to customers for which they must directly pay the transmission company. Clearly, the payment assigned to the customers is irrelevant from the standpoint of competition between generators, since the transmission payment is made directly by the customer. For the same reason, even though the payer is the generator in cell (2,1), competition should lead to the transmission charges being irrelevant. Suppose that a group of them compete for a customer whose assigned transmission charge is T. Charge T would form part of the costs of whoever wins the contract and therefore would be passed on to the price to be paid by the customer.

On the other hand, it is reasonable to assume that the payment assigned to injections would not be directly passed on to the prices paid by customers, because this payment varies according to power plant location. However, for given dispatch schedules, energy costs and the power needed to fulfill a contract at a given bus are the same for all generators, irrespective of the transmission charges they pay to their individual power plants. Provided there is competition, the transmission charge will be paid by the power plant.

Although our estimation of the direct charge paid by customers presented in Section V excludes cell (1, 1), this does not render it irrelevant in practice, because whatever the transmission charge allocation rule, the final cost of the energy and power should be adjusted so that generating companies obtain normal returns. Different allocation rules will send signals to power plants regarding locations that are more or less efficient, and the final equilibrium price of electricity will be higher or lower accordingly. This paper does not estimate this total effect, so strictly speaking, it does not address the broader question of how much the customers would finally pay under different transmission charge allocation rules.

III. Chilean Transmission Charge Allocation Scheme

A. Line Use in the Short Law

1) Basic Principle: Chile's main transmission grid (the SIC) is radial. A significant share of generation occurs in the south, while the major share of the load is concentrated in a limited central region. Consequently, most power flows first toward the center, and then the rest flows toward the north of the country (see Figs. 1 and 2). Also, because the central region is a net importer, it follows that the least-cost thermal expansion technology will always be located directly in the center to save on transmission costs. For these reasons, Chilean transmission regulation and the *Ley Corta* have been based on the idea that there exists a central market and most power flows from south to north.

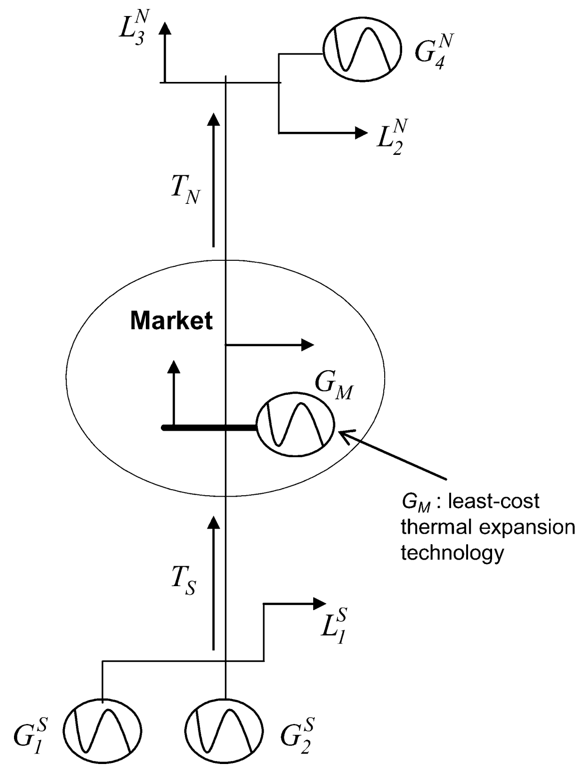

Fig. 2. Schematic representation of the line use concept.

The attribution of use is then clear: power plants located in the south will, in general, use the lines that lead to the central market and should pay for them. Similarly, loads located in the north will import power from the central market most of the time and use the lines that lead to it.

To appreciate this idea, consider Fig. 2. When power flows from the south toward the market located in the center of the country, plants G_1^S and G_2^S use the transmission line T_S to sell their surplus energy there and benefit by obtaining a higher price. So, the Chilean law states that generators G_1^S and G_2^S are responsible for paying the transmission charge on line in proportion to the use that each makes of it.

By contrast, when power flows away from the market, local loads L_2^N and L_3^N use the transmission line T_N. By doing so, they buy energy at lower prices than would prevail if only local generation were available. In this case, therefore, loads use the transmission line and must pay for them in proportion to their use.

2) Expansion and Location Incentives: The role of the main transmission grid in the SIC is to make systematic transfers of energy from the exporting south toward the importing center and north. This follows from the structural characteristics of supply and demand: On the one hand, the Chilean system is heavily dependent on hydro generation located in the south. On the other hand, consumption is concentrated in central Chile around Santiago, the capital city.[2]

A transmission charge scheme should thus provide appropriate location incentives. In particular, a new plant should be installed in the south only if its long-run average cost *plus* the cost of an additional line to reach the market is less than the average cost of the least-cost expansion technology that can be installed directly in the market without adding much new transmission capacity. Thus, fully attributing use of line T_s to power plants G_1^S and G_2^S located in the south and charging them the full cost of the line gives them appropriate location incentives.

Consider now loads located in the north. Their choice is between, on the one hand, buying from capacity installed on site (generator G_4^N) or, on the other hand, buying energy in the market and building a line to transmit it. New capacity should be installed in the north only if its long-run average cost is less than the cost of buying energy in the market *plus* the cost of the line necessary to transmit it. Thus, by making loads responsible for use, one gives local generation a price advantage, which exactly internalizes the fact that energy produced directly in the north saves on transmission lines.

Note that there are three types of agents that would not pay any transmission charges under such use attribution rules: loads located in the south (L_1^S); generation plants located in the market (G_M); and generation plants located in the north (G_4^N).

3) Actual Charges by Use: As said before, in Chile the value of transmission lines is assessed every four years by an independent cost study. This study determines the annuity investment value of each line (call it AIV) and an allowance for operation, maintenance, and administration costs (call it OMAC). The owner of a given line is thus entitled to receive

$$\text{AIV} + \text{OMAC}$$

each year (to ease notation, we consider just one line).

Part of the income to cover these costs comes from nodal differences in energy and power prices, as the transmission company is entitled to keep them. Because Chile adopted a centralized marginal-cost, merit-order dispatch, this equals the value of the differences of marginal costs and marginal transmission losses—call this the transit charge (tc). This tc is calculated as follows. Assume that power flows from bus S to bus N. Then the tc will equal

$$\text{mc}^N \cdot P - \text{mc}^S \cdot (P + \text{pl}) \tag{1}$$

where mc^i is the marginal cost of power in bus i, P is the quantity of power that flows on the line, and pl is the amount of power lost.

Now as is well known, however, there are scale economies in transmission, and thus, the transit charge cannot produce enough income to pay the full cost of a line. Thus

$$T \equiv \text{AIV} + \text{OMAC} - \text{tc} \tag{2}$$

must be distributed among users with a transmission charge.

Now consider generator g that uses the line. The transmission charge that must be paid is given by

$$\text{TChG}_g = \lambda_G \times T \times \frac{\alpha_g \cdot I_g}{\sum_j (\alpha_j \cdot I_j)} \equiv \lambda_G \times T \times A_g$$

where λ_G denotes the fraction of use that is allocated to generators, I_g denotes the power injection of generator g, and $\alpha_g \in [0,1]$ is the use factor of generator g for the given line.

Similarly, the transmission charge allocated to load ℓ that uses the line is

$$\text{TChL}_\ell = \lambda_L \times T \times \frac{\beta_\ell \cdot D_\ell}{\sum_k (\beta_k \cdot D_k)} \equiv \lambda_L \times T \times B_\ell$$

where λ_L denotes the fraction of use that is allocated to all loads, D_ℓ denotes the power demand of load ℓ, and $\beta_\ell \in [0,1]$ is the use factor of load ℓ for the given line.

Use factors are calculated with, respectively, GGDF and GLDF factors (see Ng [14] and Rudnick *et al.* [18]). Also, $\lambda_G + \lambda_L = 1$. Moreover, because $\sum_j A_j = \sum_k B_k = 1$, it follows that the transmission company receives exactly AIV+OMAC.

4) In Conclusion: To summarize, transmission charge allocation in the SIC, a radial network, is based on the economic principle that agents who benefit from the line are those who use it. Having determined which agent uses the transmission line, the transmission charge can be distributed among generators or loads, as the case may be, using a mathematical technique. More specifically, among the plants that use a given line, their shares can be calculated using the GGDF method; among the consumers that use a given line of each line, their shares can be determined using the GLDF method.

B. New Chilean Transmission Charge Allocation Scheme as Compared With Other Methods

1) Brief Classification of Transmission Charge Allocation Schemes: [3] Broadly speaking, there are five groups of methods to allocate the cost of lines (see Fig. 3): those based on short- or long-run marginal cost;[4] some adaptation of so-called postage-stamp methods;[5] those that identify flows and attribute use based on an electrical model[6] and graph-theory methods;[7] and according to economic benefits, sometimes using game theory.[8]

The Chilean scheme is, in fact, a hybrid (see Fig. 4). The tc is based on the difference between nodal marginal costs. To cover the difference, there is a second charge, which we have called T [see (2)].

Now T is distributed among users in three steps. First, an economic benefit criteria is used to determine who is and who is not an user of a given line. Only those who benefit from the line

[2]Around 45% of Chile's Gross Domestic Product (GDP) is produced in Santiago.

[3]The literature has been recently surveyed by, among others, Green [6], Jing *et al.* [7], Marangon [12], and Rudnick *et al.* [17].

[4]See Rudnick *et al.* [18].

[5]See Jing *et al.* [7].

[6]See Kirby and Rahman [10], Marangon [12], Pantos and Gubina [15], and Phichaisawat and Song [16].

[7]See Kirschen [11] and Bialek [1], [2].

[8]See, for example, Hobbs and Rijkers [8], Hobbs *et al.*, and Rudnick and Zolezzi [19].

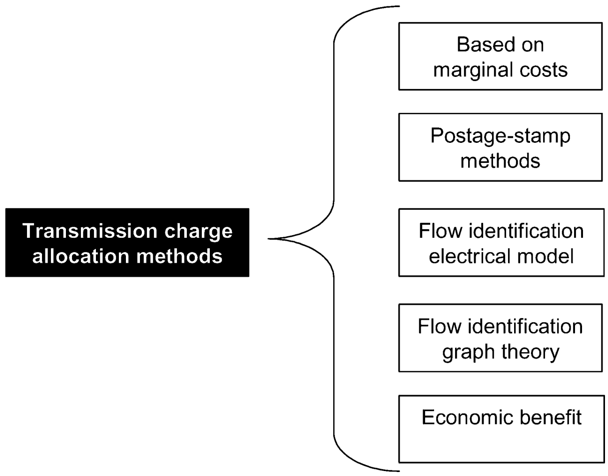

Fig. 3. Transmission charge allocation methods.

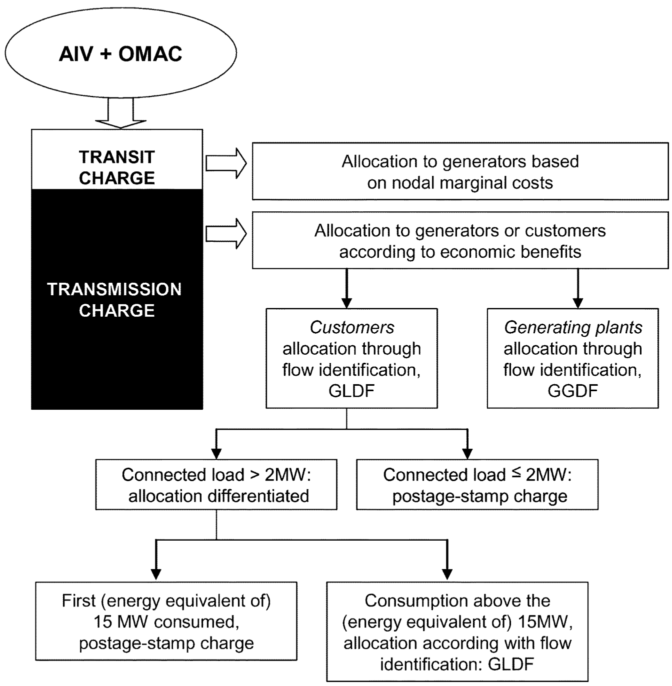

Fig. 4. New Chilean transmission charge allocation scheme.

use it. As we have already seen, to determine use and benefit, a market is defined where the main load and the least-cost expansion technology of the system are located. This economic or benefit criteria should be used to determine λ_G, the fraction of use allocated to generators and λ_L, the fraction of use allocated to customers. It should also determine whether within each of these categories, a given plant or load uses a given line. In this sense, the Chilean transmission pricing scheme can be classified among the so-called economic benefit schemes.

Second, after the generators and loads that use a given line have been identified, then the share of each is determined with, respectively, GGDF and GLDF factors. Because of this, the Chilean pricing scheme also can be classified among those that use flow identification electrical models to allocate transmission charges.

Third, as we will see below, almost all the direct transmission charges allocated to customers at each bus are redistributed. Essentially, each customer pays the same direct transmission charge per kilowatthour, regardless of the buses' location. This introduces a postage-stamp feature to the transmission charge scheme.

Thus, the Chilean scheme is a hybrid based on marginal cost pricing, identification of use through economic benefits, flow identification, and postage-stamp methods (see Fig. 4). That said, it is particularly important to note the exact role of GGDF and GLDF factors. They are used only to determine the share of each user, *after* these have been identified according to an economic benefit principle—lines are used by generators who inject toward the market or customers who import from the market. This is important, because, as shown by Galetovic and Palma [4], [5], generalized distribution factors by themselves are not enough to define "objective" transmission charge allocation rules. In fact, these methods leave enough degrees of freedom to reach almost *any* arbitrary allocation. This arbitrariness is significantly moderated in the Chilean scheme by the economic benefit principle that determines use.

IV. Transmission Charge Allocation Scheme Defined by the Ley Corta

Under regulations prior to the *Ley Corta*, the payer was always a generator—final customers did not pay transmission companies directly. Thus, cells (1,2) and (2,2) in Table I were empty. Use by generating plants was determined by the so-called "area of influence method," and all other remaining lines were assumed to be used by customers. Generators would then pay on behalf of the users that had contracts with them.[9] In addition, the transit charge reflected nodal price differences due to marginal losses [see (1)].

The current mechanism defined by the *Ley Corta* is somewhat more complicated. It includes direct charges to customers determined by the use of the transmission system due to their loads—cell (2,2) in Table I. In what follows, we describe this transmission charge allocation scheme.

A. Definitions

The *Ley Corta* distinguishes three transmission grids: the trunkline grid, the sub-transmission grid, and the additional transmission grid (arts. 71°-1 to 71°-4).[10] The trunkline grid is defined by law and composes facilities operating at voltages above 220 kV; this is divided between the "area of common influence" and remaining areas. Art. 71°-2 defines which lines are eligible to form part of the trunkline grid.

The area of common influence is defined in art. 71–30 C, as the minimum set of facilities between two buses of the grid, where the following hold: 1) at least 75% of total power injections take place in this area; 2) at least 75% of total demand is in this area; and 3) the density factor must be maximum.

In practice, this rule implies that in the SIC, the area of common influence consists of all buses located between Charrúa-500 kV to the south and Quillota-220 kV to the north (about 536 km). The rest of the trunkline grid consists of two

[9]It should be noted that almost all electricity in Chile has been sold under long-term contracts.

[10]See Ministry of Economics [13].

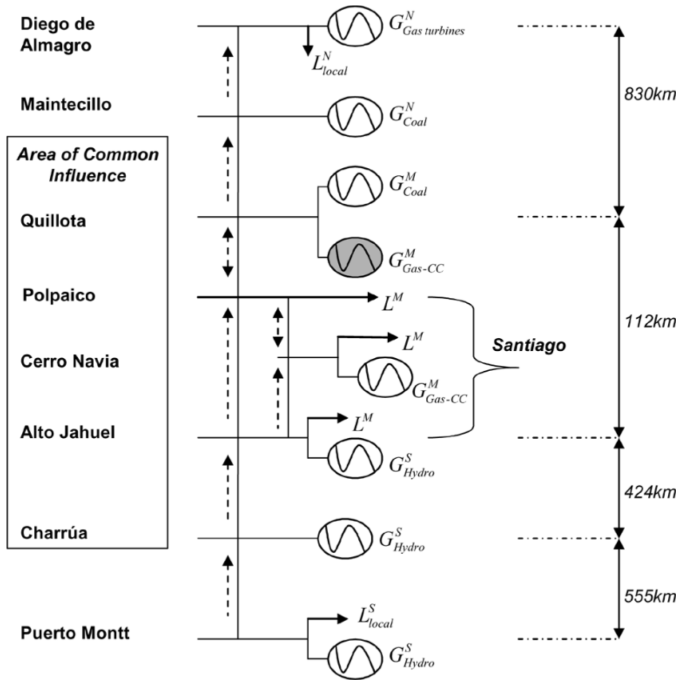

Fig. 5. Schematic diagram of the trunkline grid.

subsystems. To the north, it comprises buses located between Quillota-220 kV and Diego de Almagro-220 kV (about 830 km), and to the south, it comprises buses between Charrúa-500 kV and Puerto Montt-220 kV (about 555 km). A schematic diagram of the trunkline grid is presented in Fig. 5, where we have marked the main buses in the area of common influence.

B. Transmission Charge Determination

Around 70% of the electricity generated in the SIC comes from hydro plants, but water availability is very volatile. Consequently, whether or not a plant runs and how much it injects depends on the hydrology. Moreover, power flows and even their direction may change depending on the hydrology. Thus, it is standard to model the Chilean system in different states of operation, with each determined by a particular hydrology. More important, in practice, transmission charges are calculated by averaging across expected states of operation. Thus, to proceed, we need to define some notation: Let m denote a state of operation, $\mathcal{M}$ be the set of all states of operation, and M be the number of states of operation.[11] We can now describe the determination of transmission charges, and it is useful to do it in three steps.

Step 1: Transit Charge: Recall that according to (2), the transmission charge T of a given line is given by AIV + OMAC − $\overline{\text{tc}}$. The transit charge is then

$$\overline{\text{tc}} = \frac{1}{M}\sum_{m\in\mathcal{M}}\left[\text{mc}_m^N\cdot P_m - \text{mc}_m^S\cdot(P_m+\text{pl}_m)\right]$$

[11]In practice, the system is run assuming 1440 states of operation. This figure is obtained as follows. Each month, there are three periods of demand—peak, medium, and low— and each is represented by a demand block. Each month, in turn, can have 40 levels of rainfall (these are taken from the actual precipitations recorded during the previous 40 years). Last, each month is hydrologically different. Thus, in a given year, we have $3\times 12\times 40 = 1\,440$ possible states of operation.

where now mc_m^i is the marginal cost in bus i in state m, P_m is the quantity of power that flows on the line in state m, and pl_m is the amount of power lost in state m. Note that we are assuming that each state occurs with equal probability. This is how the system is modeled in practice in Chile.

Step 2: Transmission Charges Assigned According to the Use of the Line: The rule for assigning use of a given line is defined in article 71–30. This rule is the first innovation of the new law, for it states that the same line might be used by generators in one state of operation and by customers in another. It implies the following.

a) Lines in the Area of Common Influence: Eighty percent of the transmission charge in this area is assigned to all generating plants in the system (i.e., $\lambda_G = 0,8$) and the remaining 20% to all customers in the system (i.e., $\lambda_L = 0,2$). Thus, for each state m, the transmission charge to be paid by generator g for using a line in the area of common influence will be proportional to the use that its power injection $I_{g,m}$ makes of that line in that state. Formally

$$A_g(m) \equiv \frac{\alpha_{g,m}\cdot I_{g,m}}{\sum_j(\alpha_{j,m}\cdot I_{j,m})}.$$

It is assumed that within the area of common influence, each generator uses the line in all states, regardless of its location in the system (the only exception is when a generator injects against the direction of the flow of power or counterflow). Hence, generator g pays

$$\text{TChG}_g = 0.8\times T\times\frac{1}{M}\sum_{m\in\mathcal{M}}A_g(m)$$

and $A_g(m) = 0$ if the generator injects against the direction of the flow of power.

Similarly, the transmission charge allocated to load ℓ in a given state m will be proportional to the use that its demand $D_{\ell,m}$ makes of the line (the only exception is when a load extracts power in counterflow and relaxes the transmission line). Formally

$$B_\ell(m) \equiv \frac{\beta_{\ell,m}\cdot D_{\ell,m}}{\sum_k(\beta_{k,m}\cdot D_{k,m})}$$

and customer ℓ is allocated the following charge:

$$\text{TChL}_\ell = 0.2\times T\times\frac{1}{M}\sum_{m\in\mathcal{M}}B_\ell(m).$$

Again, $B_\ell(m) = 0$ if the load reduces power transmitted by the line.

The 80/20 split between generating plants and loads may seem arbitrary, and to some extent, it is. These numbers were set because it was found that, on average, power flows northwards 80% of the time on lines in the area of common influence. Nevertheless, this average conceals significant variations. In particular, almost all the time, power flows toward the north on the 424 km-long Charrúa-Alto Jahuel stretch; flow reversals occur only within the much more localized and limited area between the Alto Jahuel and Quillota buses, which form a ring around Santiago, the country's capital. Because of this, it would have been far more natural to define a small area of common influence between the Alto Jahuel and Quillota buses (see Fig. 5), thus excluding the Charrúa-Alto Jahuel stretch. By doing so, location signals to power plants in the south would have been strengthened.

b) Lines Outside the Area of Common Influence: Things are slightly more complicated for a line outside the area of common influence. If the direction of the flow in state m is toward the area of common influence, then use in that state is assigned to generators that inject toward the area of common influence. On the other hand, if the direction of the flow in state m is away from the area of common influence, use in that state is attributed to loads located in buses that receive power from the area of common influence.

Thus, one can partition the set of states $\mathcal{M}$ in two disjoint subsets $\mathcal{G}$ and $\mathcal{L}$ with, respectively, G and L elements. It follows that $\lambda_G = (G/M)$ and $\lambda_L = (L/M)$. The transmission charge allocation then is

$$\mathrm{TChG}_g = \lambda_G \times T \times \frac{1}{G} \sum_{m \in \mathcal{G}} A_g(m)$$

and

$$\mathrm{TChL}_\ell = \lambda_L \times T \times \frac{1}{L} \sum_{m \in \mathcal{L}} B_\ell(m).$$

Step 3: Customers as Payers: A further innovation of the *Ley Corta* is that customers are going to be responsible for directly paying part of transmission charges—they will become payers. Until this change, only generators were payers. As we will see, direct customer charges are a mixture of a location and a postage-stamp charge.

We will need some additional notation. Let b be a bus in the system and $\mathcal{B}$ the set of all buses. The use calculations that we have already described will yield a total of transmission charges allocated to the loads in bus b. With a slight abuse of notation, denote that total transmission charge by TChL_b. We can now describe how TChL_b will be distributed among customers located in bus b according to the *Ley Corta.*

a) Customers With a Connected Load of 2 MW or Less: Legislators decided that each customer in this category would pay the same per kilowatthour charge, regardless of the bus where located.[12] In this sense, the *Ley Corta* introduced a postage-stamp charge. The amount of this per kilowatthour charge is determined as follows.

In each bus b, the share of energy consumed by customers with a connected load of 2 MW or less is determined (call it $\mu_b^{\leq 2}$). Then a fraction $\mu_b^{\leq 2}$ of the transmission charge TChL_b is allocated to customers in this category. Next these charges are over all buses $b \in \mathcal{B}$, which yields $\sum_{b\in\mathcal{B}} \left[\mu_b^{\leq 2} \times \mathrm{TChL}_b\right]$. Last, the per kilowatthour charge paid by each customer is

$$\frac{\sum_{b\in\mathcal{B}} \mu_b^{\leq 2} \times \mathrm{TChL}_b}{\sum_{b\in\mathcal{B}} e_b^{\leq 2}}$$

with $e_b^{\leq 2}$ the total energy consumed by customers with loads of 2 MW or less located in bus b.

b) Customer With a Connected Load Greater Than 2 MW: For customers in this category, legislators devised a cumbersome scheme: a mixture of a location and postage-stamp charge.

Essentially, the energy consumption of each customer with connected load above 2 MW located at bus b is partitioned in two: the first (energy equivalent of) 15 MW[13] and the rest. Now assume that customer i located in bus b consumes X MWh above the (energy equivalent) of 15 MW and, moreover, that these X MWh are equal to a share $\eta_{i,b}$ of the total energy load of bus b.[14] Then customer i must directly pay

$$\eta_{i,b} \times \mathrm{TChL}_b.$$

Now note that

$$\mu_b^{>2} = 1 - \mu_b^{\leq 2} - \sum_i \eta_{i,b}$$

is the total share of energy consumed by customers with a connected load of 2 MW or more, *excluding* consumptions above (the energy equivalent of) 15 MW. These consumptions are used to determine a per kilowatthour postage stamp that is equal to

$$\frac{\sum_{b\in\mathcal{B}} \mu_b^{>2} \times \mathrm{TChL}_b}{\sum_{b\in\mathcal{B}} e_b^{>2}}$$

where $e_b^{>2}$ is the energy consumed by customers in bus b with a connected load of 2 MW or more, excluding consumptions above (the energy equivalent of) 15 MW.

The reader may well ask which is the economic rationale of this scheme. There is none. It was the result of political pressure by firms located at buses in the northern extreme of the system, who would have paid a larger transmission charge because of their location (see the next section). Moreover, because only very few customers consume more than (the energy equivalent of) 15 MW, it is fair to say that in practice, the *Short Law* introduced a postage stamp for customer charges.

V. Estimation of the Direct Transmission Charge to Be Paid by Customers

A. Methodology and Data Sources

The calculations estimate the additional direct charge payable by customers during the hydrological year April 2005 to March 2006. We used a methodology analogous to that described in

[12]Until the *Ley Corta*, all customers in this category paid regulated prices for energy and power. For this reason, they have always been called "regulated" customers. The *Ley Corta* allowed customers with connected loads of 500 kW or more to freely negotiate their rates with generators or distributors.

[13]To be precise, for the first four-year period after the law is approved, from March 2004 to March 2008, the cap-level will be 45 MW; during the following four-year period, the cap-level will be 30 MW; and at the end of this period, the cap-level will be 15 MW.

[14]That is, 15 MW + X is the customer's total consumption.

TABLE II
TRANSMISSION CHARGE ALLOCATION (IN MILLIONS OF AMERICAN DOLLARS)

	(1) Area of common influence	(2) Rest	(3) Total
Injection assignment	41.4 80%	14.0 47%	55.3 68%
Load assignment	10.3 20%	15.7 53%	26.0 32%

TABLE III
DIRECT CHARGES PER BUS (IN AMERICAN DOLLARS PER MEGAWATTHOUR)

	(1) Before *Ley Corta* ($/MWh)	(2) *Ley Corta* ($/MWh)
North		
D. de Almagro	-1.2	4.8
Carrera Pinto	0.3	4.2
Cardones	0.6	3.6
Maitencillo	0.3	2.6
Pan de Azúcar	0.6	1.6
Area of common influence		
Quillota	0.1	0.4
Polpaico	0.2	0.4
Cerro Navia	0.6	0.4
Alto Jahuel	1.0	0.3
Ancoa	0.0	0.1
Charrúa	-1.2	0.1
South		
Temuco	1.7	1
Valdivia	0.7	1.9
Puerto Montt	0.9	2.6
Average charge	**0.3**	**0.7**

Galetovic and Palma [4], [5]; readers who are interested are referred to those articles for further details. Broadly speaking, the procedure consists of the following.

- Economic dispatch was calculated using the Omsic stochastic dynamic programing model, considering 1440 representative states of operation.[15]
- Flows per line were determined for each state of operation using a dc power flow model.
- For each line, GGDF factors for each power plant are calculated, and GLDF factors are calculated for each load, in each case based on a dc power flow model.
- Given the allocation rule with the GGDF and GLDF factors, the transmission charges and unit charges are calculated.

B. Results

Table II separates the payments into injections and loads. Sixty-eight percent of the trunkline grid is ultimately charged to injections and the remaining 32% to loads. These averages come from the 80–20 split in the area of common influence and the 47–53 split in the rest of the trunkline grid. As can be seen, a much larger fraction ends up being assigned to the customers in the rest of the trunkline grid, which increases their share of the payments.

Table III shows the charges per bus in dollars per megawatthour. Column 1, "Before *Ley Corta*," is the charge per megawatthour that customers with loads of less than 2 MW paid under the old regulation. These correspond to the transit charges $\overline{\text{tc}}$ that account for marginal transmission losses.[16] Column 2, "*Ley Corta*," is the per megawatthour charge assigned to the respective bus. It equals the additional direct transmission charge, TChL_b, divided by the total consumption for the bus in megawatthours, estimated for 2005–2006. Last, the bottom line shows the average charge per megawatthour; this corresponds to the estimates per megawatthour postage-stamp charge.

As shown in column 2, the highest charges per megawatthour would occur at the extremes of the grid. In particular, at the northernmost points, Diego de Almagro, Carrera Pinto, and Cardones, charges would rise to over $4/MWh, and at the southern extreme in Puerto Montt, the charge would be $2.6/MWh. In contrast, the charges at buses within the area of common influence would be very low, no higher than $0.4/MWh.

However, as mentioned above, the transmission charges assigned to consumptions below (the energy equivalent of) 15 MW will be redistributed. The estimate of the direct charge per megawatthour is therefore a quotient of total transmission charge payments for the entire trunk system— $26 million—divided by total consumption—estimated at roughly 36 775 GWh between April 2005 and March 2000.[17] This is either a long-term estimate, where contracts will be modified and all transmission charges will be transferred to regulated customers irrespective of the volume and location of their consumption, or an estimate of the average direct charge, as a unitary "postage-stamp" charge, introduced by *Ley Corta* article 71°–30 A.

The result is the figure $0.70/MWh reported at the bottom of the second column in Table III; this represents our estimate of the direct charge that customers will pay per megawatthour. This amount can be compared with the monomic price of energy[18] in the Quillota bus, which was $32.17/MWh in April 2003.[19] In other words, the direct charge is equivalent to 2.2% of the monomic energy price.

It is interesting to note that while the average direct charge customers will pay is a small fraction of the monomic price of energy, the figure conceals significant variations among buses.

[15]Until recently, this was the model used to operate the system. A detailed description of the Omsic model can be found in Galetovic *et al.* [3].

[16]Regulated energy and power prices varied at each bus to reflect marginal losses.

[17]To be precise, two unitary postage-stamps are defined. The first applies to customers with a connected load of 2 MW or less and the second to customers with a connected load greater than 2 MW, considering only their first consumptions below (the energy equivalent of) 15 MW. Our calculations assume that the same postage stamp is applied to both type of customers, which is a reasonable approximation in practice.

[18]The monomic price is calculated by adding the energy price and the capacity charge—referred to in dollars per megawatthour.

[19]The source of the bus price is the National Energy Commission, Chile's energy regulator.

Table III suggests that, if no postage stamp would have been introduced, transmission would have been an important part of supply cost at the extremes of the grid and could have reached levels approaching 15% of the monomic energy price. Nevertheless, legislators chose to blunt this economic location signal by introducing the postage-stamp charge.

VI. Conclusion

We have shown that the new Chilean transmission charge scheme is a hybrid based on marginal cost pricing; identification of use through economic benefits; allocation of use shares by flow identification methods; and last, a postage- stamp to redistribute charges to customers. Sixty-eight percent of the transmission charges will be paid by generators and the remaining 32% by customers. The direct charge that customers will pay is around \$0.70/MWh, which is equivalent to 2.2% of the monomic price in the Quillota bus located in the center of the system, i.e., \$32.17/MWh.

We have also seen that Chile's main transmission grid is radial. A significant share of generation occurs in the south, while the major share of the load is concentrated in a limited central region. This leads to a natural allocation of the use of lines: Power plants located in the south will, in general, use the lines that lead to the market located in the center, and loads that are located in the north and import from the market use the lines that extract power from it. This allocation rule gives appropriate expansion and location incentives.

The *Ley Corta* transmission charge allocation mechanism provides correct economic location signals for installing new capacity in the system, by charging higher transmission charges to power plants at the extreme south of the high-tension grid, which use the trunkline grid to reach the market in central Chile. Nevertheless, it somewhat weakened those signals by considering somewhat arbitrary use percentages—80% for injections and 20% for loads—within the area of common influence. Also, it defined as the area of common influence a much longer stretch than warranted by power flow reversals, which are confined to a ring around Santiago (the Quillota–Alto Jahuel buses). Last, under the *Ley Corta*, loads do not receive any location signals, because legislators decided to introduce a postage-stamp charge for their direct charges.

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References

[1] J. Bialek, "Topological generation and load distribution factors for supplement charge allocation in transmission open access," *IEEE Trans. Power Syst.*, vol. 12, no. 3, pp. 1185–1192, Aug. 1997.

[2] J. Bialek, "Allocation of transmission supplementary charge to real and reactive loads," *IEEE Trans. Power Syst.*, vol. 13, no. 3, pp. 749–754, Aug. 1998.

[3] A. Galetovic, J. C. Olmedo, and H. Soto, "¿Qué tan probable es una crisis elé ctrica?," *Estudios Públicos*, vol. 87, pp. 175–212, 2002.

[4] A. Galetovic and R. Palma, "Tarificaci ón de la transmisión eléctrica usando factores GGDF y GLDF: una estimación de sus efectos distributivos," *Cuadernos Econ.*, vol. 41, pp. 285–314, 2004.

[5] ——, "Can generalized distribution factors lead to "objective" transmission toll allocations? Some lessons from the recent Chilean experience," *Mimeo*, 2005.

[6] R. Green, "Electricity transmission pricing: An international comparison," *Util. Policy*, vol. 6, pp. 177–184, 1997.

[7] Z. Jing, X. Duan, F. Wen, Y. Ni, and F. Wu, "Review of transmission fixed costs allocation methods power engineering," in *Proc. IEEE Power Engineering Society General Meeting*, 2003, pp. 2585–2592.

[8] B. F. Hobbs and F. A. M. Rijkers, "Strategic generation with conjectured transmission price responses in a mixed transmission pricing system—Part I: Formulation," *IEEE Trans. Power Syst.*, vol. 19, no. 2, pp. 707–717, May 2004.

[9] B. F. Hobbs, F. A. M. Rijkers, and A. F. Wals, "Strategic generation with conjectured transmission price responses in a mixed transmission pricing system—Part II: Application," *IEEE Trans. Power Syst.*, vol. 19, no. 2, pp. 872–879, May 2004.

[10] C. Kirby and M. A. Rahman, "Generator contribution coefficients for pricing transmission services," in *Proc. IEEE Power Engineering Society Winter Meeting*, vol. 2, 2000, pp. 968–974.

[11] D. Kirschen, "Contributions of individual generators to load and flows," *IEEE Transactions in Power Systems*, vol. 12, no. 1, pp. 52–60, Feb. 1997.

[12] J. W. Marangon, "Allocation of transmission fixed charges: An economic interpretation," in *Proc. IEEE/KTH Stockholm Power Tech Conf.*, 1995, pp. 716–721.

[13] Ministry of Economics, Development and Reconstruction, Law 19 940, Mar. 13, 2004. Diario Oficial de la República de Chile.

[14] W. Ng, "Generalized generation distribution factors for power system security evaluations," *IEEE Trans. Power App. Syst.*, no. 3, pp. 1001–1005, Mar. 1981.

[15] M. Pantos and F. Gubina, "Ex-ante transmission-service pricing based on load-flow patterns," *IEEE Trans. Power Syst.*, vol. 19, no. 2, pp. 796–801, May 2004.

[16] S. Phichaisawat and Y. Song, "Transmission pricing using improved sensitivity indices," in *Proc. IEEE Power Engineering Society Winter Meeting*, vol. 3, 2000, pp. 1250–1255.

[17] H. Rudnick, M. Soto, and R. Palma, "Use of system approaches for transmission open access," *Int. J. Elect. Power Energy Syst.*, vol. 21, pp. 125–135, 1999.

[18] H. Rudnick, R. Palma, and J. Fernández, "Marginal pricing and supplement cost allocation in transmission open access," *IEEE Trans. Power Syst.*, vol. 10, no. 2, pp. 1125–1142, May 1995.

[19] H. Rudnick and J. Zolezzi, "Tarificación del sistema de transmisión eléctrica: Aproximación mediante juegos cooperativos," presented at the The VII Symposium of Specialists in Electric Operational and Expansion Planning, VII SEPOPE, Curitiba, Brazil, 2000.

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