The Influence of Market Regulations in the Development of Distributed Generation

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***Abstract*—In this work the influence of market regulations in the development of Distributed Generation is analysed. A general review of the additional value that Distributed Generation may provide to the network is also presented, giving simple illustrations of the issues assesed. In addition, the environmental externalities costs associated to generation are considered regarding to the additional competitiveness of Distributed Renewable Generation. As cases of study, the electricity markets of Argentina and Chile are studied considering the degree of penetration of Distributed Generation in relation with their market rules. For these cases, the present amount of Distributed Generation is estimated and a forecast of the future development is done.**

***Index Terms*— Distributed Generation, Market Regulations, Environmental Externalities Costs.**

I. INTRODUCTION

CIGRE defines Embedded Generation [1] as the generation which has the following characteristics:

- It is not centrally planned
- It is not centrally dispatched at present
- It is usually connected to the distribution network
- It is smaller than 50-100 MW

In this paper we are going to consider Embedded or Dispersed or Distributed Generation (DG) all that generation which is directly connected into the distribution network instead of the transmission network. This is the same definition that is used in [2].

Examples of DG are CHP (Combined Heat and Power) plants (also known as co-generation plants), wind energy converters, hydro power stations, Photo-voltaic systems (PV), fuel cells and bio-mass plants.
Usual power levels for this plants are from 2 kW to 100 MW.

In the past, before the construction of big transmission networks covering large areas, all generation was embedded in distribution networks.
Then the situation changed, big generation plants were constructed and large transmission networks were built interconnecting generators and consumers. Economies of scale involved in constructing large generation plants influenced this process. In addition, the presence of a transmission system gave more reliability and quality of supply [3].

Today there is an Electricity Supply Industry (ESI) which has large and strong transmission networks. However, in the last decades, the proportion of DG in the networks has been growing up.
Information provided by CIGRE shows that the percentage of DG in Denmark reach 37 % and in Netherlands 40 %. In other countries of Europe, the proportion of DG is clearly less than 15 %. See Fig. 1.

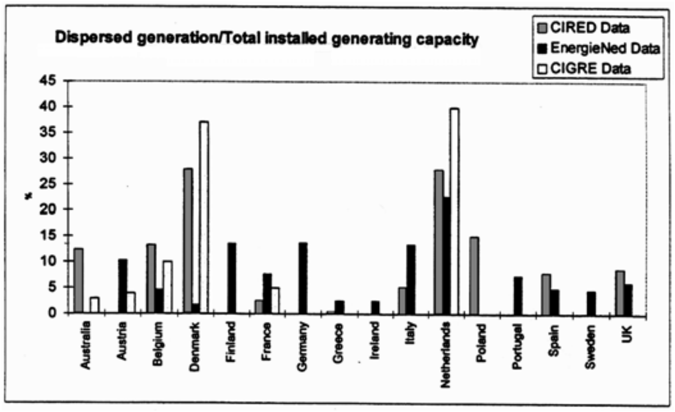


Fig. 1. DG in Europe.

There is an interest of governments to increase the amount of clean energy. This takes the form of government schemes which promote renewable generation. In many cases, the result are distributed renewable generation (DRG) plants.
In addition, interest in obtaining high overall efficiencies, for example through CHP plants, may be observed. The result are co-generation plants embedded in distribution networks.

The Working Group 37.23 of CIGRE [1] has summarised the reasons for an increasing share of DG in different countries. The aspects included in the report are the following:

- DG nowadays have mature technology that is readily available and modular in a capacity range from 100 kW to 150 MW.
- The generation can be sited close to customer load, which may decrease transmission costs.
- Sites for smaller generators are easier to find.
- No large and expensive heat distribution systems are required for local systems fed by small CHP-units.
- Natural gas, which is often used as fuel for DG, is expected to be readily available in most customer load centres and is expected to have stable prices.

- Gas based units are expected to have short lead times and low capital costs compared to large central generation facilities.
- Higher efficiency is achievable in co-generation and combined cycle configurations leading to low operational costs.
- Politically motivated regulations, e.g. subsides and high reimbursement tariffs for environmentally friendly technologies, or public service obligations, e.g. with the aim to reduce CO_2 – emissions, lead to economically favourable conditions.
- In some systems DG competes with the energy price paid by the consumer without contributing to or paying for system services, which leads to an advantage of DG in comparison to large generation facilities.
- Financial institutions are often willing to finance DG-projects since economics are often favourable.
- Unbundled systems with more competition on the generation market provide additional chances for industry and others to start a generation business.
- Customers demand for "green power" is increasing. (It is also interesting to read [4]).

On the other hand, the growth of DG has led to concerns about the impact on the network of high levels of DG penetration. These concerns include aspects related to stability, voltage control, power quality, protection and security of the overall system. In addition, distribution companies are concerned with regard to the nature of their networks, which were designed for customers which consume electricity rather for customers which generate electricity.

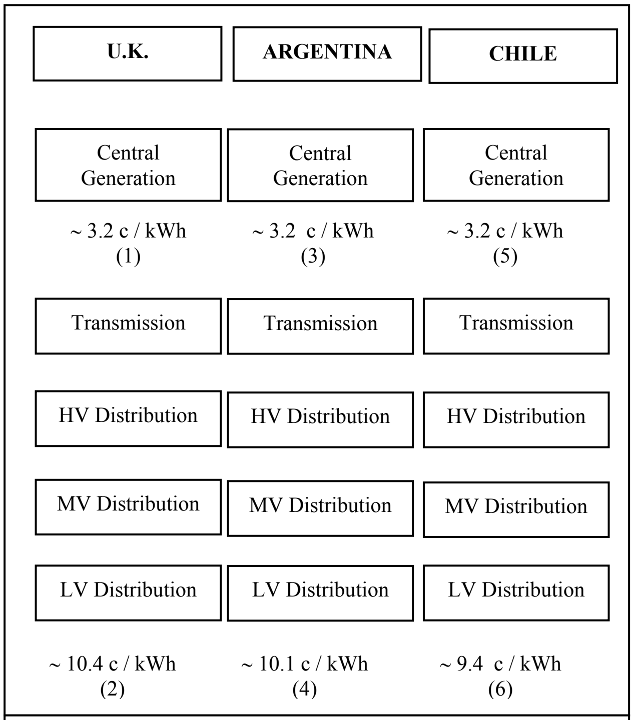
From the commercial point of view, considering the framework of a competitive Electricity Supply Industry (ESI), DG becomes a big question. Is DG competitive? Does the present network practices and electricity tariffs structures consider the real value of DG?

In Fig. 2, tariffs at different levels of the ESI in U.K., Argentina and Chile are shown[1].
The difference between wholesale electricity market prices and retail prices of electricity are, for the different countries considered, the following:

U.K. $\Delta p \cong 7.2$ c / kWh
Argentina $\Delta p \cong 6.9$ c / kWh
Chile $\Delta p \cong 6.2$ c / kWh

The network charges directly measure the relative grade of competitiveness between central and DG.
Transmission and distribution networks, together with the supply business are responsible for the difference of prices (Δp). Electricity produced by central generation requires transmission and distribution networks to reach its consumers, while DG, often located closer to loads, requires less transporting facilities.
Consequently, electricity produced by DG may have a higher value than that produced by central generation.
However, it depends on the tariffs structures how much of that Δp is DG allowed to collect. The issue of competitiveness of DG is a network pricing problem. As a result, it is of major concern to study and know the real value (costs and benefits) of DG and to analyse how good does the tariffs structures of the ESI consider that value.

In this paper the additional value that DG can provide to the network will be addressed. In Section II, the impacts of DG in network losses, in system security, in voltage control and in environmental externalities costs are analysed, giving simple examples and a critical assesment of present regulations. In particular, the regulations in Argentina and Chile regarding these issues are submitted. In Section III, the degree of penetration of DG in Argentina and Chile is quantified based on the information provided by [5] and [6]. Finally, in Section IV the conclusions of this work are presented.



Notes:
(1) Source: [7]
(2) Source: [7]
(3) Source: [8]
(4) Source: [CIER]. Buenos Aires, EDESUR, taxes included
(5) Source: [9]
(6) Source: [CIER]. Santiago de Chile, CGE, taxes included.
1 c = 0.01 Euro

Fig. 2. Prices at different levels of the ESI in U.K., Argentina and Chile

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[1] Prices year 2000

II. THE ADDITIONAL VALUE OF DG

The main characteristic of DG is that, by definition, it is connected to the distribution network; and hence, situated close to end consumers.

As a result, each kWh produced by DG displaces a kWh coming from central generation production connected to the transmission system. The use of the transmission system decrease with the degree of penetration of DG and the same occurs with the use of the "upstream" distribution network where the DG is connected. This fact may lead to a reduction in network investment.

From the economic point of view it can be said that DG is a potential substitute of network services. If the network services charges rises, then the demand for DG should increase.

From the former considerations, it comes up that DG is not just generation, but it is also a network service provider.

The tendency in regulatory economics is to regulate that activities that are natural monopolies (i.e. setting tariffs) and let the market forces work in those activities subject to competition. In the ESI, it is clear that generation and supply are activities where competition is possible but transmission and distribution (i.e. network services) are natural monopolies. From the regulatory point of view, the problem of DG is that it is not only generation that can be considered subject to free competition in an energy market, but it is also "network" in the sense that it provides network services. Consequently, if the regulation establishes the same rules for DG as for central generation letting both to compete togheter in a free energy market, the result will be the loss of DG competitiveness.

As for the case of transmission and distribution, tariffs for DG must be regulated. Doing so implies to identify the additional value of DG; this is the aggregate value to the system apart from providing energy.

Some considerations were done with respect to the reduction of the network use when DG was present. In the next items of this section other considerations related to network losses, reliability, voltage regulation and environmental externalities will be presented.

A. Losses in the distribution network

A.1 An example

A simple example [10] can show that the connection of DG can reduce the amount of energy losses in the distribution network.

Fig. 3 shows a simple distribution network consisting of a radial feeder which has two loads (D1 and D2 at point A and B respectively) and a generator (G) embedded at point C. The power demanded by the loads is supposed to be constant and equal to 200 kW. The power delivered by the generator is 400 kW.

The distance between A and B is the same as the distance between B and C. In addition, the distance between T and A is twice the distance between A and B.

Impedances for sections TA, AB and BC are those indicated in the diagram.

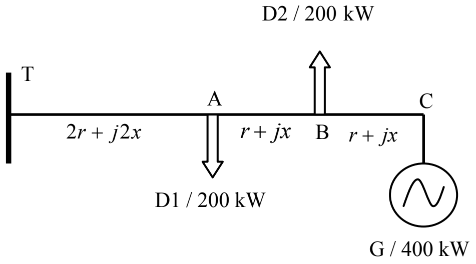


Fig. 3. A simple distribution network.

In order to simplify the calculations, the following hypothesis are made:

- All voltage magnitudes are equal to 1.0 p.u.
- Voltage drops are negligible.
- Losses have no impact on the calculation of power flows.
- $x >> r$

A base value of 100 kW is used and a value of $r = 0.001$ p.u. is chosen.

From the hypothesis made it is easy to demonstrate that the line looses (l) can be calculated multiplying the value of line resistance (r) by the square of the active power flow (p) through the line:

$$l = rp^2$$

For the case shown in Fig. 3 the power flows are the following:

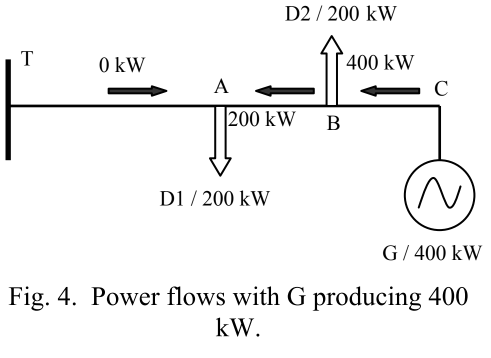


Fig. 4. Power flows with G producing 400 kW.

The looses are then,

$$l = 0.001\left[2^2 + 4^2\right] = 0.02\ p.u.\text{, or 2 kW.}$$

If generator G is not present in the network, then power flows turn out to be those of Fig. 5.

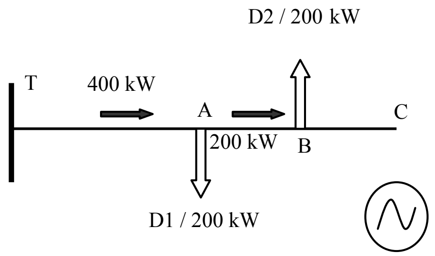


Fig. 5. Power flows without DG

Losses in the network are:

$$l = 4^2 x(2x0.001) + 2^2 x0.001 = 0.036 \ p.u., \text{ or } 3.6 \text{ kW}.$$

As a result, for this particular simple distribution network, the presence of generator G reduces network losses from 3.6 kW to 2 kW (i.e. 44 %). In addition, it is clear that it also reduces the electrical losses in the transmission network as the power flux at point T reduces from 400 kW to 0 kW when generator G is connected.

A.2 Regulatory aspects

As seen before, the presence of DG in the network alter the power flows and consequently the network losses. The method used for the allocation of the cost of losses will necessary have a great impact on the parties involved.
In both Argentina and Chile, the method of allocating the cost of losses in distribution systems consists in averaging them among all customers. These costs are part of the whole tariff that customers pay to the distribution company. No special consideration is given at present for individual customers such as DG, which may reduce the amount of losses in the network. This fact evidently produces a loss of competitiveness of DG in these markets.

An ideal scheme for allocating losses should fulfil the following requirements [10]:

- Economic efficiency. Losses must be allocated so as to reflect the true cost that each user imposes on the network with respect to cost of losses.
- Accuracy, consistency and equity. The loss allocation method must be accurate and equitable, i.e. must avoid or minimise cross subsidies between users and between different times of use. Furthermore, the method must be consistent.
- Must utilise metered data. From a practical standpoint, it is desirable to base allocation of losses on actual metered data.
- Must be simple and easy to implement. In order for any proposed loss allocation method to find favour, it is important that the method is easy to understand and implement.

In [10], a method which satisfies the former conditions is presented. The method, called Marginal Loss Coefficient method (MLC method), is based on Short-Run Marginal Cost (SRMC) pricing.
MLCs measure, by definition, the change in total active power losses due to a marginal change in consumption or generation of active power P_i and reactive power Q_i at each node i in the network. Losses can be expressed as the summation of reconciliated MLCs multiplied by the actual consumption or generation of active power and reactive power at each node. Revenue reconciliation is necessary since the losses calculated from MLCs turn out to be greater than actual losses incurred in the network. The basic equations of this method are presented below:

Eq. A.2.1

$\tilde{\rho}_{P_i} = \dfrac{\partial L}{\partial P_i}$ is the active power related MLC $i = 1,2,...N$

$\tilde{\rho}_{Q_i} = \dfrac{\partial L}{\partial Q_i}$ is the reactive power related MLC $i = 1,2,...N$

N is the total number of nodes in the network

Eq. A.2.2

$$\sum_{i=1}^{N-1} \left[\tilde{\rho}_{P_i} P_i + \tilde{\rho}_{Q_i} Q_i \right] \approx 2L$$

Eq. A.2.3

$$\kappa_0 = \frac{L}{\sum_{i=1}^{N-1} \left[\tilde{\rho}_{P_i} P_i + \tilde{\rho}_{Q_i} Q_i \right]}, \text{ multiplier reconciliation factor}$$

Eq. A.2.4

$$\rho = \kappa_0 \tilde{\rho}, \text{ reconciliated MLCs vector}$$

Eq. A.2.5

$$\sum_{i=1}^{N-1} \left[\rho_{P_i} P_i + \rho_{Q_i} Q_i \right] = L, \text{ network losses}$$

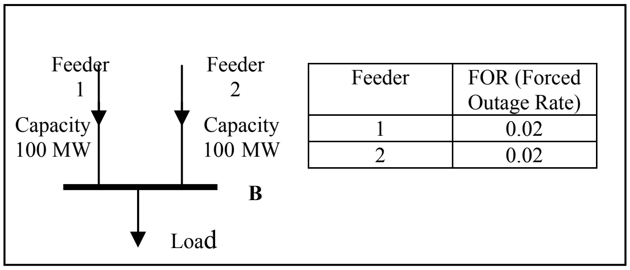
B. Security of supply

Users of electricity expect to have quality and reliability in their supply. The value of not having electricity is, in fact, greater than the cost of electricity [11].
In addition, providing security of supply has its costs. The greater the security the higher the costs of achieving it.

The level of security present in the network is proportional to the resources that have been assigned to the provision of that security. These resources can be either network facilities or generation resources.

B.1 An example

It seems quite clear that the presence of DG tends to increase the level of system security. To confirm this idea, the following example is considered:



Feeder	FOR (Forced Outage Rate)
1	0.02
2	0.02

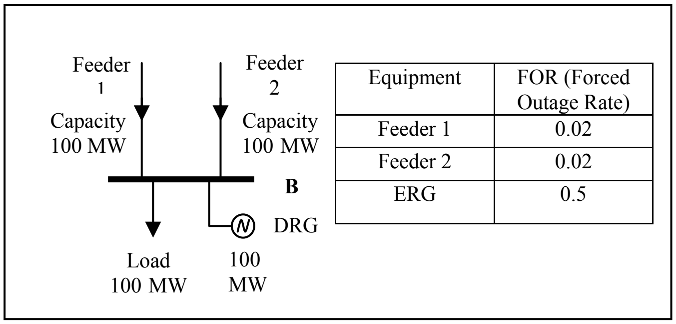
Fig. 6. Security of Supply: Example without DG.

Fig. 6 shows a very simple distribution network. It consists of two radial feeders of 100 MW capacity each, which feed busbar B. A constant load of 100 MW is connected to B. The FOR of the two feeders is given in the table above.
The LOLP (Loss of Load Probability) is calculated for the load. The outage capacity probability table for this case is:

Capacity out (MW)	Capacity in (MW)	State Probability
0	200	0.98x0.98 = 0.9604
100	100	2x0.98x0.02 = 0.0392
200	0	0.02x0.02 = 0.0004

The LOLP is, by definition, the probability of not satisfying the load.
Then, the LOLP is calculated by adding the individual probabilities of those states in which the load experiences troubles:
$LOLP = 0.0004$
The expected number of days in which the load experiences troubles can also be calculated multiplying the LOLP by 365, which results in 0.146 days/year. This number can be expressed in hours/year multiplying by 24, resulting in 3.50 hours/year.

The next step is to evaluate the LOLP when a 100 MW DRG is connected to busbar B. An availability of 50 % for the DRG is assumed. This situation is presented in Fig. 7.



Equipment	FOR (Forced Outage Rate)
Feeder 1	0.02
Feeder 2	0.02
ERG	0.5

Fig. 7. Security of Supply: Example with DG.

The outage capacity probability table for this case is the following:

Capacity out (MW)	Capacity in (MW)	State Probability
0	300	0.98x0.98x0.5 = 0.4802
100	200	2x0.98x0.02x0.5 + 0.98x0.98x0.5 = 0.4998
200	100	2x0.98x0.02x0.5 + 0.02x0.02x0.5 = 0.0198
300	0	0.02x0.02x0.5 = 0.0002

Therefore,
$LOLP = 0.0002$
The expected number of days in which the load experiences troubles in this case is equal to 0.0002x365 = 0.073 days/year. This number, in hours/year is 1.75. This is 50 % of the days in which the load experiences troubles in the first case.

Another approach is to calculate the ELL (expected load lost) for the two cases.
The ELL is defined as:

$$ELL = \sum_{i=1}^{n} x_i p_i$$

where,
i is the capacity state.
n is the number of capacity states.
x_i is the load lost whilst in *i-th* capacity state.
p_i is the probability of the *i-th* capacity state.

Using the ELL for comparing the two cases, results, for the first case, $ELL = 100x0.0004 = 0.04MW$, and for the second case (with ERG), $ELL = 100x0.0002 = 0.02MW$.
Once again, the ELL for the second case is 50% of the ELL for the first case.

From this example it is clear that a generator embedded in the distribution network provides additional system security.

B.2. Regulatory aspects

System security may be provided by both network or generation facilities. DG can potentially replace transmission and distribution network facilities. From this perspective, DG can be seen as a competitor to transmission and distribution in the provision of network services.
On the other hand, a significant proportion of DG does not provide firm capacity (e.g. renewable generation). In this case, generation is not available at all the time. However, it can not be say that this type of generation does not provide system security. From the probabilistic point of view the DRG has a defined level of availability that must be considered in conjunction with the availability of other

equipment. The simple example that was provided before demonstrates this fact.

In both Argentina and Chile, the value of DG in providing additional system security is not properly recognised by present regulation rules. In both countries, all generators distributed or not receive payments for the capacity made available. However, no distinction is made related to the impact in the whole system security which clearly depends, for instance, with generators location.

Security of supply is an extra value or benefit of DG. It is the responsibility of the Regulator to give fair competitiveness to DG regarding to these aspects. It seems important that security standards are included in the regulatory frameworks to define the system level of security. In addition, the probabilistic nature of the DG must be considered.

Reliability of supply has its own value and users of the network may be prepared to pay for security of supply. However, the sensitivity of different users to reliability may be different. Consequently, in an efficient pricing structure, the use of system charges must reflect the value that each user places on network performance. What is more, each user should have a choice regarding the level of security that desires, and should be charged accordingly.

In [12], a method of network pricing that includes the quality of supply driven costs is presented. Allocation of reliability driven capital is based on quantifying the impact of each network user on expected marginal outage cost. This cost corresponds to the expected increase in outage costs imposed on the rest of the customers of the system by an increment in demand.

C. Voltage regulation and reactive power in distribution networks

Under the regulations of the new ESI, distribution utilities must supply electricity to their customers at a voltage within specified limits. What is more, in countries like Argentina hard penalisations are applied if electicity is not provided within those limits.

C.1. An example

In Fig. 4, a simple example is considered. Voltage regulation is achieved by adjusting the taps of transformers T1 and T2.

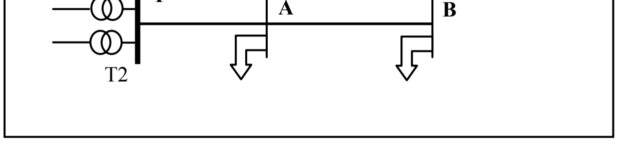


Fig. 7. A simple distribution network without EG.

The taps are adjusted so that the following conditions are satisfied:

- At times of maximum load the most remote customer (B) will receive acceptable voltage (above the minimum allowed).
- At times of minimum load the voltage received by the customers is below the maximum allowed.

If we now consider DG connected to the circuit of Fig. 7, as indicated in Fig. 8, the load flows and hence the voltage profiles will change in the distribution network.

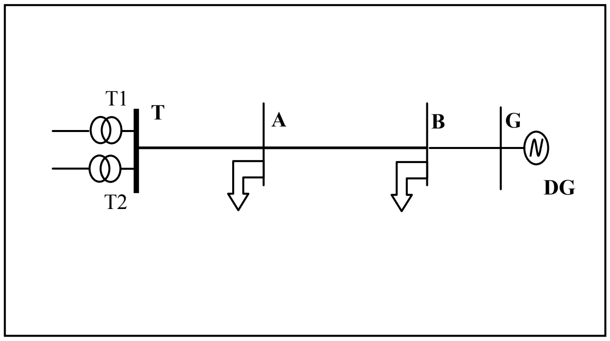


Fig. 8. A simple distribution network with DG.

If the generator is exporting, then this will cause the voltage to rise. The degree of the rise will depend on many factors, such as:

- Level of export relative to the minimum load on the network.
- Siting of the generator (proximity to a busbar where the voltage is regulated by the distribution company).
- Distribution of load on the network.
- Network impedance from busbar to generator.
- Type and size of generator.
- Magnitude and direction of reactive power flow on the network.

The worst case is likely to be when the customer load on the network is at a minimum and the DG is exporting.

On the other hand, if the generator is used on-site it does not adversely affect network voltages (i.e. if a load is connected to busbar **G** consuming most of the power generated by DG).

Supposing that the line between busbar **B** and busbar **G** in Fig. 8, has an impedance, $R + jX$ (in per unit), then the voltage drop $\delta|V|$ (in per unit) can be calculated as follows:

$$\delta|V| \approx \frac{RP + XQ}{E} \qquad \text{(Eq. C.1.1)}$$

where, $\delta|V| = |\overline{E}| - |\overline{V}|$

$|\overline{E}|$ is the modulus of voltage $\overline{E}$ in per unit.

$|\overline{V}|$ is the modulus of voltage $\overline{V}$ in per unit.

$\overline{E}$ and $\overline{V}$, are indicated in the figure below.

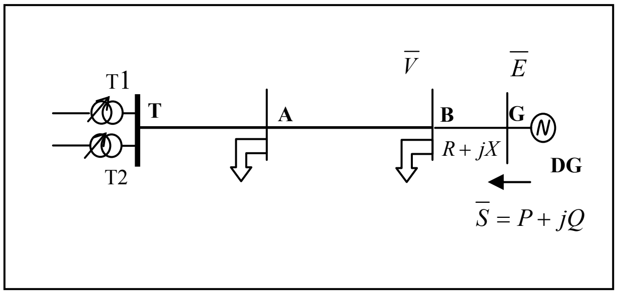


Fig. 9. A simple distribution network with DG.

As a result, the voltage rise may be limited controlling the reactive power Q exported by the generator. In particular, for negative values of Q (i.e. generator importing reactive power), it is possible to achieve $\delta|V| = 0$. This method can be effective for circuits with high X/R ratio, such as higher voltage overhead circuits. However, for LV cable distribution circuits with a low X/R ratio, the method does not work. As a result, only very small DG can generally be connected to LV networks.

C.2. Regulatory aspects

In a scenario with high degree of penetration of DG, distribution networks should be thought as active networks (i.e. such as transmission networks) rather than as passive networks. Voltage control can be achieved using both traditional methods (i.e. tap changing transformers) or reactive power management applied to DG. In Fig. 10, the idea of dynamic voltage control is summarised.

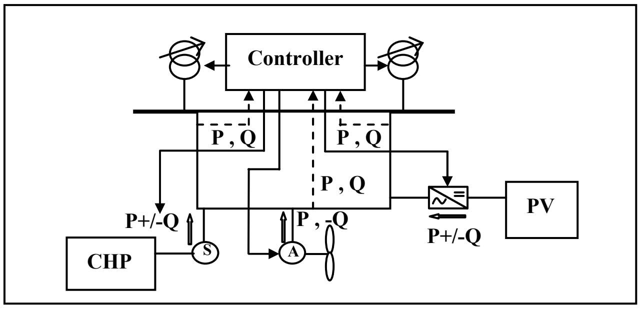


Fig. 10. Integrated DG. New approach to design and operation.

Modelling has to be used to address the effects of the connection of a new DG in a particular distribution network. As a result, the mechanisms to provide voltage regulation can be determined.

In this context, a reactive power market should exist at distribution level to permit DG to participate in voltage regulation. At present, loads in the distribution network are charged for reactive power consumption. On the other hand, DG is not generally paid for providing reactive power. This is the case in the markets of Argentina and Chile where no special consideration is done with regard to DG.

In the case of Argentina, in accordance to [13], all the participants of the Wholesale Electricity Market (WEM) are responsible for voltage regulation and for the control of reactive power flows. MEM generators (i.e. generators which participate in the WEM) must inform the system operator (CAMMESA) about the nominal P-Q capacity curve of the generator. Each MEM generator is obliged to deliver:

- at any time, until 90 % of the reactive power limit of the generator at any operational point in the P-Q capacity curve, for the generator working at maximum refrigeration pressure
- 100 % of the reactive power limit for 20 minutes in intervals of 40 minutes each.

In addition, MEM generators must control the voltage at those busbars that CAMMESA ask the generator to control.

In the case of Self-generators and Co-generators the following rules apply:

- For firm-capacity generation, the generator must follow the established P-Q capacity curve (same case as MEM generators).
- For non firm-capacity generation, the generator cosine-phi must fall between 0.85 inductive and 0.97 capacitive.

It is important to note that, in accordance to [13], generators are not paid for the reactive power delivered[2]. On the other hand, they are penalised if they do not meet their reactive power flow requirements.

In the case of Chile, voltage regulation and reactive power dispatch is co-ordinated by each CDEC (Centre for Economic Load Dispatch). There are no general rules. Each CDEC has an internal agreement about the payments that have to be done to generators for provision of reactive power.

D. Environmental externalities for renewable DG

An externality defines [14] a situation in which the activities of one or more economic agents have consequences on the welfare of other agents without any transaction between them. An externality is defined to be positive if there is an increase of welfare. Conversely, an externality is defined to be negative if there is a decrease of welfare. Pollution produced by electricity generators is an externality of the second group.

D.1. An example

There are studies, such as [15] that intend to make an evaluation of the effects of pollution in monetary terms. Some of the results of [15] are summarised in Fig. 11, 12, 13 and 14.

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[2] There is an exception that corresponds to the case when a generator covers the reactive power that another generator was supposed to supply, but actually did not.

EXTERNALITY COSTS FOR COAL-FIRED UNITS

		TYPE OF TECHNOLOGY		
EXTERNALITY	USD/lb	Existing Boiler (1.2 % sulphur coal)	AFBC[1] (1.1 % sulphur coal)	IGCC[2] (0.45 % sulphur coal)
	[A]	[B]	[C]	[D]
[1] SO_2	2.03	1.80	0.55	0.48
[2] NO_x	0.82	0.607	0.3	0.06
[3] Particulates	1.19	0.15	0.01	0.01
[4] CO_2	0.0068	209	209	209
Totals:				
[5] USD/MMBTU Input		5.76	2.80	2.46
[6] Heat Rate (BTU/KWh)		10069	10000	10163
USD/kWh Generated		**0.058**	**0.028**	**0.025**

Notes:
1 AFBC = Atmospheric Fluidised Bed Combustion.
2 IGCC = Integrated Gas Combined Cycle.
[B] [C] [D]: All emissions are expressed as lbs/MMBTU fuel input.
[1]: No SO_2 scrubbers are installed on the first three plants.
[2]: NO_x emissions are uncontrolled in each case.
[3]: Particulates emissions vary widely and are extremely dependent on the ash content and sulfur content and sulfur content of coal.
[5]: Sum of (value of X emissions for each externality) for each plant.
[6]: Assumed heat rates for each plant.
[7]: [5]x[6]/1000000

Fig. 11

EXTERNALITY COSTS FOR OIL-FIRED UNITS

		TYPE OF TECHNOLOGY			
EXTERNALITY	USD/lb	Boiler #6 Oil (0.5 % sulphur oil)	Boiler #6 Oil (1 % sulphur oil)	Boiler #6 Oil (2.2 % sulphur oil)	Combustion Turbine #2 Oil (1.1% sulphur oil)
	[A]	[B]	[C]	[D]	[E]
[1] SO_2	2.03	0.54	1.08	2.38	0.16
[2] NO_x	0.82	0.357	0.287	0.357	0.498
[3] Particulates	1.19	0.055	0.09	0.174	0.036
[4] CO_2	0.0068	169	169	169	161
Totals:					
[5] USD/MMBTU Input		2.60	3.68	6.48	1.87
[6] Heat Rate (BTU/KWh)		10400	10400	10400	13600
USD/kWh Generated		**0.027**	**0.038**	**0.067**	**0.025**

Notes:
[B] [C] [D]: All emissions are expressed as lbs/MMBTU fuel input.
[1]: SO_2 emissions are uncontrolled in each case.
[2]: NO_x emissions are uncontrolled in each case.
[5]: Sum of (value of X emissions for each externality) for each plant.
[6]: Assumed heat rates for each plant.
[7]: [5]x[6]/1000000

Fig. 12

EXTERNALITY COSTS FOR NATURAL GAS-FIRED UNITS

		TYPE OF TECHNOLOGY		
EXTERNALITY	USD/lb	Existing Steam Plant	Combined Cycle	BACT (SCR,SWI)
	[A]	[B]	[C]	[D]
[1] SO_2	2.03	0	0	0
[2] NO_x	0.82	0.248	0.42	0.042
[3] Particulates	1.19	0.003	0.003	0.0002
[4] CO_2	0.0068	110	110	110
Totals:				
[5] USD/MMBTU Input		0.95	1.10	0.78
[6] Heat Rate (BTU/KWh)		10400	9000	9000
USD/kWh Generated		**0.010**	**0.010**	**0.008**

Notes:
[B] [C] [D]: All emissions are expressed as lbs/MMBTU fuel input.
[1]: SO_2 are zero from gas combustion.
[2]: NO_x emissions are uncontrolled in the first two cases. For the BACT case, Selective Catalytic Reduction (SCR) and Steam Water injection (SWI) are assumed.
[5]: Sum of (value of X emissions for each externality) for each plant.
[6]: Assumed heat rates for each plant.
[7]: [5]x[6]/1000000

Fig. 13

SUMMARY OF ENVIRONMENTAL COSTS FOR VARIOUS RENEWABLE ENERGY TECHNOLOGIES

TECHNOLOGY TYPE	USD Cents / kWh
Solar	0 to 0.4
Wind	0 to 0.1
Biomass	0 to 0.7

Fig. 14

The pollutants that are taken into account in [15] are the following:

- Sulphur dioxide, SO_2 (linked with acid rain): a "starting point" value of the negative effects of USD 2.03 / lb has been estimated considering primarily health effects.
- Oxides of nitrogen , NO_x (linked with acid rain and urbane ozone): a "starting point" value of USD 0.82 / lb has been estimated considering also health effects.
- Particulates: a "starting point" value of USD 1.19 / lb has been found based primarily on visibility effects (USD 0.83 / lb), with a strong contribution from health effects (USD 0.36 / lb).
- Carbon dioxide, CO_2 (which is a greenhouse gas): The value of reducing CO_2 emissions was estimated to be

USD Cents 2.5 / lb carbon (or USD Cents 0.068 / lb CO_2) using a mitigation cost estimate for tree planting.

D.2. Regulatory aspects

The new ESI is based on the neo-classic theory which establishes that price is set at the point where the suppliers curve (marginal cost of producing one more unit) meets the demand curve (marginal utility obtained by customers). Maximum social welfare is achieved at this point (Fig. 15).

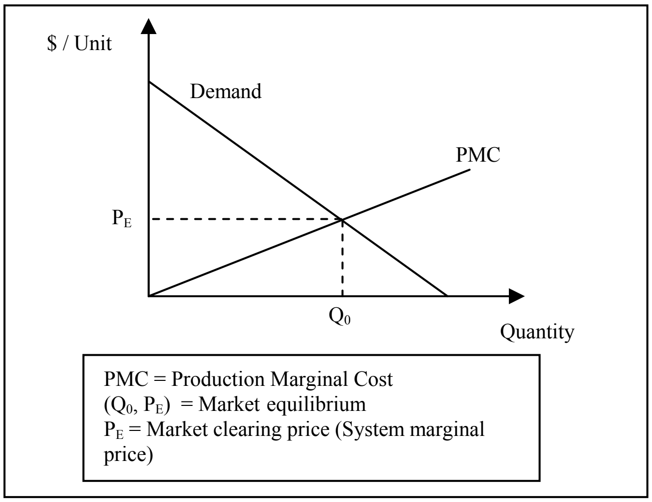

Fig. 15. Market equilibrium.

In Fig. 15 the external costs imposed by environmental externalities are not considered.

If the economic agents do not consider the external costs imposed by their activities, then the price system does not incentive the agents to adjust their activities to the level that maximum social welfare is achieved. As a result, in these conditions, the resources assignment at equilibrium does not maximise the social welfare.

In Fig. 16, the external marginal cost (EMC) is considered. This cost is the externalities cost which increases with the quantity produced.

A social marginal cost (SMC) is defined, which includes the production marginal cost (PMC) and the EMC.

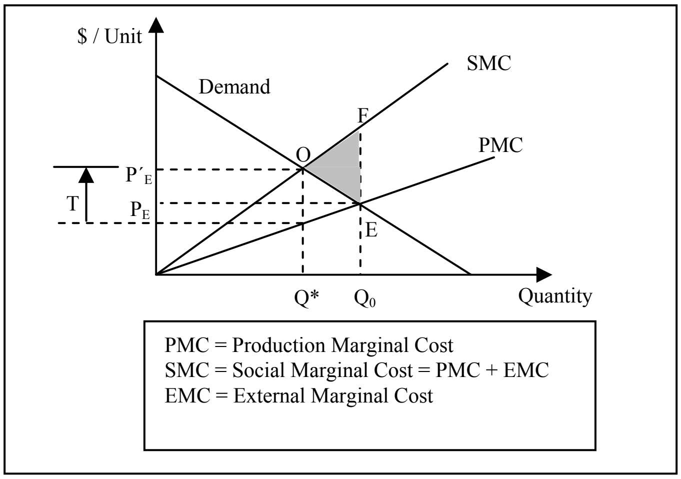

Fig. 16. The effect of considering the external costs in the market equilibrium.

The new equilibrium is achieved at (Q*, P'_E) where the SMC meets the demand curve.

As it can be seen, if the EMC is not considered, the market equilibrium (Q*,P'_E) where maximum social welfare is achieved, is shifted to the point (Q_0, P_E). The difference of social welfare between the two situations is given by area OEF.

As a result, the neo-classic answer to environmental externalities is to impose a tax to the producer that equals the optimum external marginal cost, T (see Fig. 16). These kind of taxes are known as pigouvian taxes (it was Pigou, in 1920, who firstly proposed these taxes).

In this way, the external costs are included in the system prices and therefore the economic agents are given incentives to adjust their activity to the level that maximise their own and social welfare.

The previous statements are based on the hypothesis that producers may change the level of pollution only by changing the level of production. This is not true as producers may reduce pollution in other ways. There is a cost associated to the reduction of pollution, a reduction marginal cost (RMC).

As a result, taxes should be set at the point where RMC equals EMC [14] (Fig. 17).

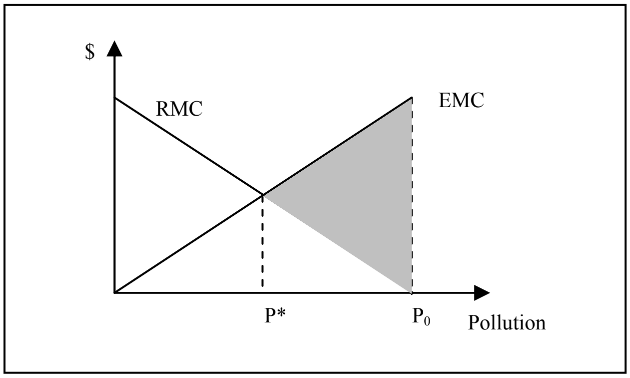

Fig. 17. Optimum pollution level.

The externalities method proposed by the neo-classic theory to account for environmental effects of electricity production is consistent with the philosophy behind the new ESI. However, the value of reducing environmental damage is very difficult to determine, because it depends on the environmental impact of pollutants (which are frequently location specific) and the values attached to those impacts.

A study that quantify the damage costs of existing generating technologies was summarised in *D.1.* From this study it is clear that renewable energy has an extra value, which should be considered by regulators when setting the tariffs structures. An ideal situation seems to be one in which market price signals were given with respect to environmental effects.

The actual situation is that other types of methods are been applied since the beginning of government environmental policies (from late 1960s). For example, limitations in the amount of pollutants that a generator plant can produce have been applied. This policy, although limiting pollution, does not give incentives to keep on reducing it.

In addition, there are policies that promote clean energy. For instance, there is the NFFO (Non Fossil Fuel Obligations) in the U.K. The obligation, within the Energy Act, requires the local distribution companies (RECs) to purchase a proportion of their electricity requirements from clean sources. Moreover, if a renewable generator is not part of the NFFO then a supplier purchasing its electricity would not have to charge the Fossil Fuel Levy on the proportion of its supply backed by that generation.

In the case of Argentina, there is a law which promotes wind and solar energy (Law Nº 25019 together with Decree Nº 1597-99). An additional payment of 0.01 USD / kWh is paid to these type of generators. In addition, a reduction of taxes that this energy pay is applied.

In the case of Chile, there is a programme ("PER"), which promotes the electrification of rural areas mainly by using renewable sources of energy. The type of generation considered under this programme is isolated generation. No other incentives for renewable generation were found in Chile, for instance, regarding to generation connected to the interconnected network.

In sum, it seems to be widely agreement in considering the environmental effects of electricity production. However, the extra benefits of clean energy seems not to be considered in full yet.

A cost reflective tariff with respect to the environmental effects of electricity would have significant impacts in the degree of competitiveness of clean generators in general, and particularly, in the degree of competitiveness of DRG.

III. DG IN ARGENTINA AND CHILE

In this Section, the degree of penetration of DG in Argentina and Chile is quantified based on the information provided by [5] and [6] respectively.

A. DG in Argentina

In accordance to Secretariat of Energy ´s Report 2000 [5] and [13], generation in Argentina can be split up into the following types:

- MEM: It refers to generation that is centrally dispatched by CAMMESA and sold in the Wholesale Electricity Market (WEM). It is generation connected to the transmission network.
- MEMSP: It refers to generation that is centrally dispatched by CAMMESA and sold in the Southern Patagonian Wholesale Electricity Market. It is generation connected to the transmission network.
- INOMEM: It refers to generation that is connected to the SIN (National Interconnected System) but it is not centrally dispatched by CAMMESA. In general, this generation is embedded in distribution networks. It can be part of a provincial electricity company or part of a private distribution company. In the first case, the provincial company is owned by the provincial government and operates as a vertically integrated electricity industry, which buys the energy not locally produced in the wholesale electricity market. In the second case we are talking about generators that were already installed in the distribution network at the moment of concession and therefore were included in that concession.
- ISOLATED: It refers to generation that provides electricity in those areas not connected to the national interconnected system (isolated areas); i.e. small isolated distribution networks with their own generation.
- SELF- PRODUCERS: Refers to industries that produce their own electricity but also buy electricity in the market. Moreover, in the particular case that they also sell electricity, they are called SELF-GENERATORS. In this case, SELF- GENERATORS are centrally dispatched by CAMMESA. SELF-PRODUCERS are installed both in the distribution and transmission system.

The case of CO-GENERATION is included in the first two types (MEM and MEMSP) because co-generation is always centrally dispatched by CAMMESA. Co-generators are industries that produce electricity for their own industrial purposes but also sell some of the electricity produced in the market. They are different from SELF-GENERATORS because they never buy electricity in the market.

In general, CO-GENERATION in Argentina is installed in the transmission system.

Taking into account the definition of DG given in Seccion I, it results that the evaluation of the degree of penetration of DG in the argentine requires to consider:

- The amount of INOMEM generation.
- The amount of SELF-GENERATION in the distribution networks.
- The amount of CO-GENERATION in the distribution networks.

In addition, an evaluation of the amount of isolated generation (IG) is done.

From Secretariat of Energy ´s Report 2000 [5] and for the purpose of this work, the following data was obtained (Figs. 17, 18, 19, 20).

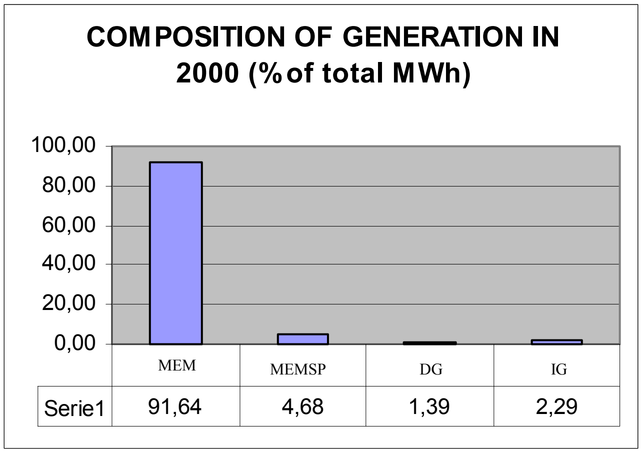

Fig. 17. Argentina: composition of generation in year 2000 (in % of total MWh generated).

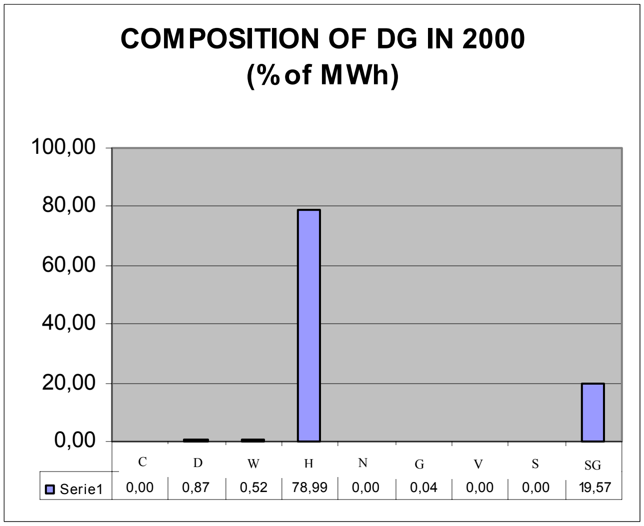

Fig. 18. Argentina: composition of DG in year 2000.

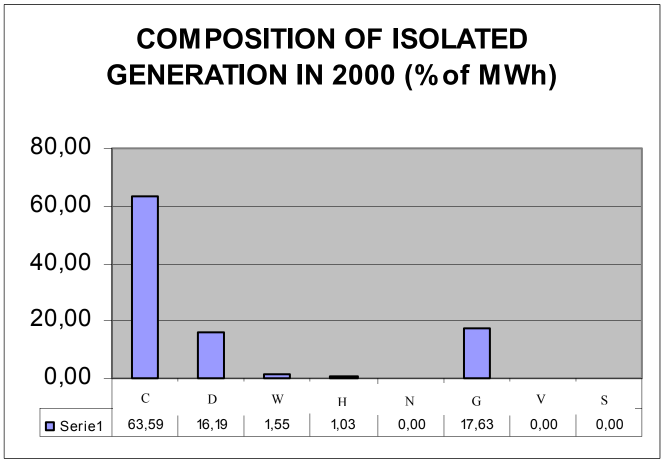

Fig. 19. Argentina: composition of IG in year 2000.

In the previous figures, the following notation applies:

C: Combined Cycle
D: Diesel
W: Wind
H: Hydro
N: Nuclear
G: Gas Turbine
V: Vapour Turbine
S: Solar
SG: Self-generator

It results that, from the total energy production in Argentina (2000), 1.39 % comes from distributed generators. This value was obtained by adding the production of INOMEM generation plus the production of SELF-GENERATORS.

It is important to note that INOMEM generators are owned by local distribution companies or provincial electricity companies. Consequently, the energy produced by INOMEM generators is used, by these companies, to decrease the amount of energy they bought in the wholesale market.

On the other hand, the production of SELF-GENERATORS considered here is that traded in the wholesale market (i.e. generation which is consumed by themselves is not counted).

From Fig. 18 it is clear that DG is composed basically of hydro generation (80 %) and self-generation (19.6 %). There are also small amounts of wind generation (0.52 %) and diesel generation (0.9 %).

The amount of IG in the argentine system is 2.29 % (Fig. 17) which is composed basically of 63.6 % of combined-cycle generation, 17.63 % of gas generation, 16.2 % of diesel generation, 1.6 % of wind generation and 1.0 % of hydro generation (Fig. 19).

An analysis of the installed generation capacity leads to the following results.

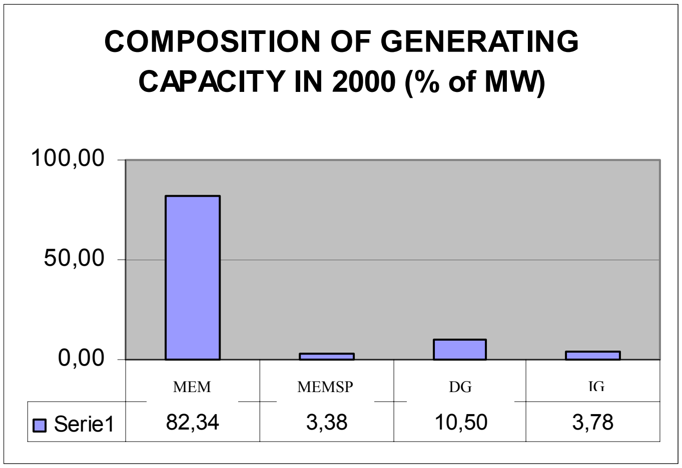

Fig. 20. Argentina: composition of generating capacity in year 2000 (in % of total MW).

From Fig. 20 it can be seen that the proportion of DG capacity installed in Argentina (2000) is 10.5 %. This value seems to be large if we compare it with the proportion of DG energy production (1.39 % in Fig. 17). The reason for obtaining this number is that we are adding to the INOMEM capacity (2.38 %) the total self-producers capacity (8.12 %). The majority of the energy produced by self-producers is consumed by themselves (only 221350 MWh are traded from a total of 7919643 MWh produced by self-producers, which represents 2.8%). On the other hand, the installed capacity of IG is 3.78 %, which is closer to the value of 2.29 % obtained in Fig. 17.

The Electricity Supply Program for Dispersed Rural Population in Argentina ("PAEPRA") promotes the IG in rural areas in Argentina, which are not reached by electricity networks.

The different areas are given in concession to private companies, which are in charge of the electricity supply to the area. The customers pay a fair tariff for the electricity consumed and the national and provincial governments make an extra payment to the company. The concession is made to the company who requires the lower subside.

In Fig. 21 there is a list of some of the projects under this program. It is important to note that these projects involve the use of renewable energy.

PROJECTS	TYPE
Project Nº 1 - Thermal-electric plant using bio-mass waste	Bio-mass
Project Nº 2 - Electrification of Rural Schools in Santa Fe Province	PV
Project Nº 4 - Wind Farm in Cerro Arenales (10 MW)	Wind
Project Nº 6 - Hydro generation for Rural Areas	Hydro
Project Nº 8 - Installation of Micro-turbines at River De los Sauces	Hydro
Project Nº 10 - Installation Program of a Bio-gas plant in Mendoza province	Bio-gas
Project Nº 23 - Electricity Supply using Wind-Solar generation in San Juan province	Wind-Solar

Fig. 21. Some of the projects under the Electricity Supply Program for Dispersed Rural Population in Argentina [16].

B. DG in Chile

The analysis of CDEC-SIC Report [6] gives the following composition of the energy generated in the SIC in 2000 (Fig. 22).

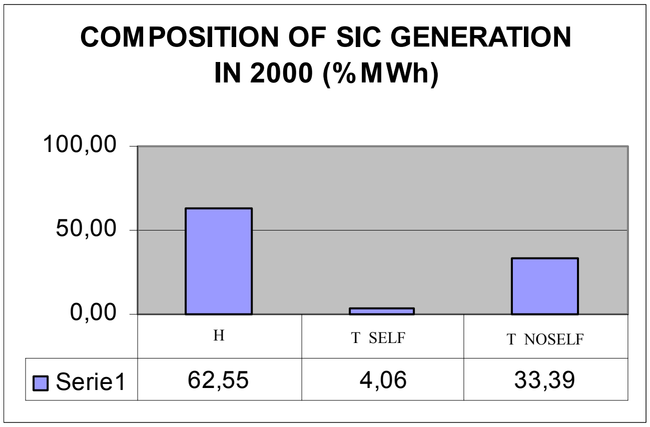

Fig. 22. Composition of the energy generated in the SIC in 2000.

In Fig. 22, the following notation applies:

H: Hydro generation
T_SELF: Thermal generation from Self-producers
T_NOSELF: Thermal generation which is not from Self-producers

It can be observed that the energy generated in the SIC in 2000 is composed by hydro generation (62.6 %) and thermal generation (37.5 %). In addition, from the thermal generation, 4.1 % comes from self-producers. The Energy Act defines a self-producer as an entity which main activity is different from generating or transmitting electricity. CDEC-SIC information is that almost all the self-producers considered in these statistics are connected to the transmission network. Consequently, in accordance to the definition of DG given in Section I, no one of them are DG. The same occurs with hydro generation which is almost connected to the transmission system.

It is important to note that with reference to self-producers, the regulations establish that they may integrate a CDEC (which is condition to sell electricity in Chile) only if the installed generating capacity is greater than 9 MW. Consequently, this gives no place for the installation of DG with capacity less than 9 MW.

No available statistics were found from the SING. However, it is important to note that:

1. The SING has three times less the capacity installed in the SIC.
2. Many of the major mining companies located in the SING have considerable self-generating capacity, which have been developed before the power sector reform. This capacity may be considered DG, although its energy is not traded but consumed internally.

On the other hand, [17] gives evidence of small amounts of isolated generation (IG) spread out in rural areas in Chile and also projects to increase the amount of IG. There is a National Rural Electrification Program ("PER") that promotes IG in areas not reached by the network.

They are mainly, wind-diesel and PV systems. In Fig. 23, the main examples of IG are shown.

INSTALLATIONS AND PROJECTS	TYPE
Applications done by ENTEL	PV
National Television of Chile	PV
Army	PV
PER - 2500 individual domestic installations	PV
CNE - Project - 6000 individual domestic installations	PV
CNE - Project - 3500 individual domestic installations	W-D
CNE - Small rural town - 14.5 kW	W-D

Fig. 23. IG: present installations and projects in Chile.

In addition, feasibility studies for co-generation embedded in the chilean distribution networks may be found. In [18], a study is presented which evaluates a co-generation potential of 300 MW for Santiago de Chile.

IV. CONCLUSIONS

In the last decades, the proportion of DG in the networks of many countries has been growing up. Moreover, it is expected that this situation will continue.

There is an increasing interest of governments to rise the amount of clean energy. This takes the form of government schemes, which promote renewable generation. In many cases, the results are distributed renewable generation (DRG) plants.

In addition, interest in obtaining high overall efficiencies, for example through CHP plants, may be observed. The results are co-generation plants embedded in distribution networks.

The results of the Working Group 37.23 of CIGRE on the reasons for an increasing share of DG in different countries have been summarised in Section I of this paper.

When looking at the difference between wholesale electricity market prices and retail prices of electricity (Δp) in U.K., Argentina and Chile, values in a range from 6.2 c/kWh and 7.2 c/kWh may be obtained.

As a result, the network charges directly measure the relative grade of competitiveness between central and DG. Transmission and distribution networks, together with the supply business are responsible for the difference of prices. Electricity produced by central generation requires transmission and distribution networks to reach its consumers, while DG, often located closer to loads, requires less transporting facilities.

Consequently, electricity produced by DG may have a higher value than that produced by central generation.

However, it depends on the tariff structures how much of that Δp is DG allowed to collect. The issue of competitiveness of DG is a network pricing problem. As a result, it is of major concern to study and understand the real value of DG and to analyse how good does the tariffs structures of the ESI consider that value.

From the analysis made in Section III, A, it resulted that from the total amount of the energy offer in Argentina in 2000, 1.39 % came from DG. From this number, nearly 20 % came from SELF-GENERATORS and the other 80 % from INOMEM generators.

INOMEM generators are, in general, part of the still vertically integrated provincial systems, owned by the provincial governments. Consequently, as mentioned before, the energy produced by INOMEM embedded generators is not traded in the market. This energy is actually used to decrease the amount of energy that provincial companies must bought in the WEM. As a result, the amount of energy produced by DG and traded in the market is that produced by SELF-GENERATORS, and this corresponds to 0.27 % of the total production offered.

For the case of Chile the analysis made in Section III, B, shows that there is practically no penetration of DG in the SIC system, in Chile. However, for the SING, it was found that many of the major mining companies have self-generating capacity, which can be considered DG. For this case, the energy produced is mainly consumed internally, by the companies, and not traded in the WEM.

On the other hand, a study that evaluates the co-generating potential in Santiago de Chile was found, which indicates some interest in DG in Chile.

The assesment of the regulatory issues in both Argentina and Chile, which was presented in Section II (A2, B2, C2 and D2) shows that the present arrangements do not consider the additional value of DG.

The tariff structures consider DG as any other generation in the network not taking into account its situation with respect to the load. No additional value is placed to DG tariffs, thus making DG to compete directly with central generation.

As seen in Section II, A2, distribution use of system charges do not appropriately allocate the cost of losses. Within the present arrangements, the costs of losses are allocated by averaging them among all customers as part of the whole tariff. No special consideration is given at present for individual customers such as DG, which may reduce the total amount of losses in the system.

With reference to the environmental externalities, an additional value is placed for renewable energy in Argentina. As mentioned, under the "Wind Law", wind and solar energy is paid an extra 0.01 USD/kWh. In addition, a reduction in the taxes is applied in the tariffs for this type of energy. However, as seen before (for instance, taking the values of Fig. 11) the environmental costs for an oil-fired unit are, for the best case, 0.025 USD / kWh, while for renewable energy, are, for the worst case, 0.007 USD / kWh. This means that an extra payment of 0.01 USD / kWh is not enough to encounter the environmental effects of energy production.

Under the scope discussed in Section II, D, electricity tariffs should take into account, in accordance to the type of generating plant, the environmental costs of energy.

When looking at security of supply, in both Argentina and Chile, the value of DG in providing additional system security is not properly recognised by present regulation rules. In both countries, all generators distributed or not receive payments for the capacity made available. However, no distinction is made related to the impact in the whole system security which clearly depends, for instance, with generators location.

With reference to voltage regulation and reactive power management, the present arrangements in Argentina usually do not consider additional payments for provision of reactive power, as seen in Section II, C2. Generators must provide the service and are penalised if they do not meet their reactive power flow requirements. This applies to all generators, embedded or not. This situation may not be adequate as it is not cost reflective and may distort the market. However, the situation does not particularly discriminate DG.

In the case of Chile, the present arrangements give freedom to the CDECs to decide their policies. This is quite dangerous for the development of DG as the CDECs are dominated by the biggest generators, which may see EG as a competitor.

In sum, for both the cases of Argentina and Chile, no special considerations have been taken into account, with respect to DG, in the present arrangements.

For DG to grow in both countries a different pricing network policy has to be applied which recognises the additional value of DG.

V. ACKNOWLEDGMENT

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VII. BIOGRAPHY

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