CRITICAL EVALUATION OF TECHNICAL-ECONOMIC POTENTIAL OF ELECTRIC ENERGY SELF-GENERATION IN BRAZIL

Bruno de Queiroz Lima
IEPUC (PUC-Rio)
brunoqlima@hotmail.com

Alcir de Faro Orlando
PUC-Rio
afo@mec.puc-rio.br

Abstract. *The objective of this work is to evaluate the technical-economic potential of electric energy self-generation in Brazil. A deterministic methodology will be built for market evaluation. It will be based on a developed model for high voltage customers from a local utilility company located in state of Rio de Janeiro, called LIGHT, and extrapolated to establish the national market. The distributed generation is analyzed from the state of the art of reciprocating internal combustion engines, Diesel and Otto cycles. Diesel oil and natural gas are considered as the fuel alternatives for the gensets. Besides the usual diesel oil, used as fuel for diesel engines, it was considered the mix between diesel oil and natural gas. Considering the attractiveness for the enterprise, it is given by a minimum internal rate of return of 15% per year in a horizon of 15 years, it is estimated that the national distributed generation can represent 2.6% of all national electric generation or 7,173 GWh/year, mainly for generation at peak hours. The diesel oil gensets represents 44.6% of that total, the diesel-gas gensets 55.2% and the gas gensets around 0.2%, meaning a daily consumption of 2.2 Mm^3 of natural gas (@ 20^{o}C and 1 atm) and 2,800 m^3 of oil diesel. For the perspective of expansion of the natural gas net distribution in Brazil, a sensibility analysis was accomplished between the natural gas cost and increase of the national distributed generation market. It is concluded that if the natural gas cost less, the national distributed generation market would grow, based mainly in diesel-gas and gas gensets.*

Keywords*: Distributed generation, Self-generation, Brazilian electric energy market, Dual-fuel engine, Diesel and gas gensets.*

1. Introduction

Electrical energy consumption in Brazil increased in the last 10 years in an average of 4.5% (dismissing the data from 2000 and 2001, which Brazil has challenged an electric energy crisis). In the same period, Brazilian economic grew only 2.9% (average) [BEN, 2003]. The fast electric consumption increase requires as a solution, from energy industry, great investments in generation infrastructure and distribution. The electric energy generation demands permanent control and planning for the maintenance of its quality in all productive chain, since the generation until the final consumption. Through the development of self-generation technologies made possible that the consumers of electric energy search supply alternatives, aiming to supply existing gaps or distortions in the traditional electric market.

2. State of the art of reciprocating internal combustion engines

Reciprocating internal combustion engines is widespread and widely known technology. There are two basic types of reciprocating engines: Otto cycle (spark ignition) and Diesel cycle (compression ignition). Otto cycle engines for power generation use natural gas or light fuel (gasoline or digester gas). Diesel cycle operates on diesel fuel or heavy (residual) oil, or they can be set up to run in a dual-fuel configuration that burns primarily natural gas with a small amount of diesel pilot fuel for ignition. These engines are generally low-cost, fast start up and high reliability (Tab. 1).

The diesel engines can be adapted to operate with the combination of two fuels: diesel and natural gas. Installing a dual fuel kit in the engine, that's carburets in the admission air the natural gas. The substitution of the oil diesel depends on the rotation and the load of the generator, but for a stationary generator it is common to get taxes of substitution around 80%. The efficiency of the operation diesel-gas is sufficiently similar to the diesel operation, as it shows the experience of operation of the generator of Pontifícia Universidade Católica (PUC-Rio). We'll consider that the operation of the diesel-gas engines develops the same electrical efficiency of diesel engines. The cost of the diesel-gas kit considered had as reference the price of the kit acquired from GTI/Altronic Controls (Model: Series IV Kit) by PUC-Rio. The total cost of this kit (installed) was of approximately U$$ 30/kW$_e$. Because the importation tax, it is esteem that this kit commercially folds the price (U$$60/kW$_e$). Puc-Rio research equipment is free from importation taxes. The manufacturers guarantee in average an availability of 96% for the reciprocating engines for continuous operation and an average life time of 20 years for engines [NREL, 2003]. In this paper, the natural gas volume is considered in the reference conditions of 20^{o}C and 1 atm.

Table 1- Typical performance parameters and estimated capital cost of reciprocating engines (Diesel and Otto) [Borbely and Krieder, 2001, THERMOFLEX LITE 5.2 ,2002 and NREL, 2003].

	Diesel		Otto
	Diesel	Diesel-gas	Gas
Electrical efficiency (%)	40%	40%	35%
Diesel esp. consumption (L/kWh)	0.25	0.05	-
Natural gas esp. consumption (m^3/kWh)	-	0.20	0.28
O&M costs (US$/kWh)	0.018	0.018	0.013
Installed cost (US$/kW$_e$)	300	360	1000

3. Electric energy tariff and structure

The electric energy tariff that is applied to the final consumers represents the synthesis of all the costs incurred all long of the productive chain of the industry of electric energy: commercial generation, transmission, distribution, commercialization, losses and taxes. The electrical energy tariffs for final consumers are structuralized by: supplied tension level (high and low) and the economic activity. For the high-voltage consumers there are three types of tariffs and five sub-groups. They are summarized in Tab. 2 and Tab. 3.

Table 2 - Electric energy tariff price and structure for high tension level consumers [LIGHT, 2004].

Tariff type		Economic	Sub-group	Contracted demand (R$/kW)		Consumption (R$/MWh)			
						Peak		Out of peak	
				Peak	Out of peak	Dry	Rain	Dry	Rain
Seasonal	Blue	Industrial, commercial and others	A2	17,83	4,03	117,5	108,6	80,66	73,7
			A3a	28,43	9,36	193,8	178,6	94,86	84
			A4	29,69	9,74	200	184,2	97,78	86,6
			AS	32,84	14,52	208,1	191,7	101,7	90
		Residential, rural and public lighting	A3a	27,12	8,93	184,8	170,3	90,47	80,1
			A4	28,31	9,29	190,7	175,7	93,25	82,6
			AS	31,32	13,85	198,5	182,9	96,95	85,8
	Green	Industrial, commercial and others	A3a	9,36		799,6	784,4	94,86	74
			A4	9,74		830	814,3	97,78	86,6
			AS	14,52		873,6	857,3	101,7	90
		Residential, rural and public lighting	A3a	8,93		762,6	748,1	90,47	80,1
			A4	9,29		791,5	776,6	93,25	82,6
			AS	13,85		833,1	817,6	96,95	85,8
Conventional		Industrial, commercial and others	A3a	12,26		157,64			
			A4	12,97		162,84			
			AS	19,17		169,72			
		Residential, rural and public lighting	A3a	11,69		150,34			
			A4	12,36		155,29			
			AS	18,28		161,85			

The peak hours are normally schedule between 5:30 pm and 8:30pm, while the out of peak hours corresponds to the remaining periods of the day (this occurs: Monday to Friday). The "dry period" is composed for 7 months of the year (September/April) and "rain period" the others 5 months of the year (May/August). On the value of the electric energy, stipulated by ANEEL, it must be increased the Tax of Merchandises and Services Circulation - ICMS, (Table 4) [ANEEL, 2004].

Table 3 – ICMS for high tension level consumers assisted by LIGHT [LIGHT, 2004].

	Residential			Commercial, Industrial, Others	Government
	0 to 50 kWh	*51 to 300 kWh*	*> 300 kWh*		
%	0%	19%	30%	30%	0%

4. Methodology

The potential of distributed generation can be analyzed from many points of view, technical, economic or even the possible real market. In this work the technical-economic national potential of the distributed generation is evaluated, focus in the self-generation. An economic vision will be adopted, not being objected of analysis the qualitative benefits (increase of the reliability and the quality of supply of electric energy). A research sponsored by a local utility company located in Rio de Janeiro State, called LIGHT was the reference for this work. This research searched the quantification of self-generation market, using of generators the gas and diesel [Orlando et al., 2004]. In the same way, this work includes in that analyses the dual fuel engines (Diesel-gas) as a possibility of self-generation. The local utility company self-generation potential will be extrapolated for the determination of the national potential. A sensitivity analyses with the natural gas cost was made to determine the impact in national self-generation.

4.1 High tension level consumers

In the beginning of 2003, the local utility company had 7,980 high tension level consumers. A selection in that database was made to eliminate all customers with invalid data. The data base was reduced for 4.750 customers, totalizing an electrical energy consumption of 697.868 MWh_e. The passing demand are not contemplated in the data base, and it will be not be evaluated.

4.2. Costs – Electric energy, Fuel and Self-generation

4.2.1. Electric energy tariff

In this work will be used as reference the 2003 electric energy tariff of LIGHT utility company. It will be only considered self-generation in peak period for the customers of Blue and Green Seasonals. These customers pays low electric tariff in the out of peak period, not justifying the self-generation in this period. The customers of Green Seasonal tariff only contract one value of demand for the two periods (peak and out of peak). For these customers the self-generation is projected for the contracted demand, independently of the demand of peak of the customer. The Conventional customers, candidates for the self-generation, have flat electric energy tariff (peak period or dry season). But these tariffs are near from what pays the Blue Seasonal consumers in the peak period. For the Conventional customer will be considered that the self-generation will completely substitute the supply of electric energy of the utility.

The present local utility company data base only contains one month electric energy consumption, disabling the calculation of the total annual electric energy cost. So it was assumed that the consumption is constant along the year. The cost of electric energy Blue Seasonal is also given by the composition of the demand and the consumptions: peak and out of peak. It must be remembered, that electric energy in the period out of peak will remain being acquired through the utility. The calculation of annual average cost of the electric energy Blue Seasonal must lead in consideration the variation of tariff, between the periods (dry/rain), as also, the change of the contracted demand. The calculation of cost of the tariff of Green the Seasonal is similar to the Blue Seasonal tariff. However, Green Seasonal tariff has only one value for the contracted demand and the generation in the peak period does not modify the contracted demand of the customer.

4.2.2. Fuel Costs – Natural gas and Diesel

The natural gas cost will have as reference the contract that the PUC-Rio keeps with the gas utility, CEG (Companhia distribuidora de Gas do Rio de Janeiro) [CEG, 2004]. This contract determines that the final price of the gas is calculated from a cascade. However, instead of the use of the calculation of the final price of the natural gas in cascade, a curve of adjustment was calculated:

$$Cost_{gas} = 2.7068 \cdot \left(consumption_{month}\right)^{-0.1286} \tag{1}$$

Where $Cost_{gas}$ is the gas cost (R\$/m^3) and $consumption_{month}$ is the total gas consumption per month (m^3), considering natural gas in the reference conditions, 20°C and 1 atm. In the case of $con\sup tion_{month}$ are less than 200m^3, the natural gas coast is R$1.5436/m^3. The standard deviation of the curve of trend to the real cost of the natural gas is $R^2 = 0.9635$. The diesel cost for the distributed generation was considered as the average price to the consumer of all brazilians regions, R$ 1.42/L [ANP, 2004].

4.2.3. Costs Investment and O&M.

The investment cost in the generator for the self-generation of electric energy was gotten from the average of market practiced for the diesel and gas (already installed) gensets, being respectively of USS 300/kWe and USS1,000/kWe [Orlando et al., 2004]. Diesel-gas genset price is assumed to be composed of prices of diesel generator and dual fuel kit, evaluated in the market in USS 60/kW$_e$. The specific cost of operation and maintenance is function of the technology. The cost of operation and maintenance for the generators diesel and the diesel-gas is of USS 0.018/kW$_e$ and for the generator the gas is considered the value of USS 0.013/kW$_e$ [NREL, 2003]. The monthly operation cost of the self-generation must also consider the cost of the fuel consumption of the generators (Tab.1). The total cost of monthly operation is given by the addition of the cost of maintenance and operation with the cost of fuels consumed.

4.3. Economic attractiveness of self-generation

The economic feasibility indicator for the investment in the self-generation, can be evaluated through the payback. The time of investment return is function of the cost of acquisition of the generator and the eventual economy of the customer in generating its proper comparative energy to the current cost supplied by the utility. For this work a minimum internal tax of return of 15 % was adopted, in the horizon of 15 years.

4.4. Local utility company and national self-generation

Applying the economic attractiveness equations in the local utility company data base customers, the economic potential of self-generation could be esteemed for these clients. To maximize the result, for each customers is chosen the best technology alternative, when economic attractiveness feasibility applies. As premise in this work, it was adopted that the natural gas supply would enclose all area of attendance of the local utility company.

The national self-generation will be esteemed from the potential calculated from the local utility company. Knowing the national consumption segmented by tension, the local utility company profile of technical-economic potential of self-generation for the calculation of the national potential will be reproduced linearly. Table 6 presents the consumption for level of national tension of the year of 2000 for the market from Associação Brasileira de Distribuidores de Energia Elétrica - ABRADEE (that encloses 96% of the consumers and 90% of the national consumption through 64 utility companies). As the national consumption presented retraction in 2001, recovering the total consumption of electric energy of 2000 only in 2004, was adopted the premise, that the consumption structure has been maintained.

The consumers of low tension (B), as well the consumers of level A1 tension will be out from the evaluation of the national potential of self-generation. As the local utility company doesn't own A3 customers, the value of potential of self-generation for customers the local utility company A3a will be reproduced to national A3.

Table 4 – National Consumption by tension level, in 2000 [CBIEE, 2003].

Tension Level	B	AS	A4	A3a	A3	A2	A1	Total
Consumption (GWh)	133,649	1,925	71,583	3,513	8,900	47,842	7,896	275,308

5. Simulation and Results

The curves of economic attractiveness for all of customers high-voltage with its respective tariffs form was simulated in software "Mathematica 4.2". Through these curves it is possible to analyze the behavior of the variation of the consumption (kWh) and demand (kW) with time of return of investment of detailed form. This work use equations and models developed and described in Lima (2004).

Calculating it individual economic attractiveness of the customers high-voltage Conventional, comparing the three technologies of generation (diesel, diesel-gas and gas) is possible to analyze the attractiveness of each one of the technologies. It is verified that the self-generation is viable economically for 419 customers. Of this total, the diesel-gas generation corresponds 76.8% (322 customers), the diesel generation 22.7% (95 customers) and the gas generation 0.5% (2 customers).

For the high-voltage Blue Seasonal customers, comparing the three technologies of generation (diesel, diesel-gas and gas), the technology diesel-gas makes possible the self-generation in the peak period in 642 customers. Of this total, the diesel generation corresponds 76.4% (491 customers), the diesel-gas generation 23.6% (151 customers). The gas generation if economically does not show viable for none case.

For the high-voltage Green Seasonal customers, comparing the three technologies of generation (diesel, diesel-gas and gas), it is verified that the self-generation is viable economically for 419. Of this total, the diesel generation corresponds 95.5% (400 customers), the diesel generation 4.5% (19 customers). Again, the generation gas if economically does not show viable for none case.

The result of the potential of self-generation for high-voltage customers of the local utility company is 44.916 MWh per month. This potential is a fraction of an available potential for conversion of 139.028 MWh_e. It must be stand out that the total consumption of the local utility company database is 697.868 MWh_e.

The potential self-generation segmented by economic activity is showed in Tab. 7. The study indicates that the self-generation is intent mainly for commercial and industrial customers using the diesel and diesel gas technologies. The self-generation concentrates in the peak period, representing 75% of the indicated total as being the technical-economic potential (Tab. 8).

Table 5 - Result of the distributed generation segmented by economic activity.

	Self-generation (MWh)			Without Self-generation potential (MWh)	Total electrical consumption (MWh)
	Diesel	Diesel-gas	Gas		
Commercial	11,942	12,213	456	54,956	248,950
Industrial	4,066	8,917	0	16,081	278,648
Government	780	2,916	0	7,958	71,085
Residential	297	1,534	0	3,496	5,789
Rural	0	0	0	151	354
Public Service	93	922	0	10,720	91,370
Others	28	752	0	749	1,672
Total	17,206	27,254	456	94,112	697,868

Table 6 - The potential of self-generation by type of tariff of high-voltage electric energy and generation technology.

	Self-generation Market (KWh)			Total (%)
	Diesel	Diesel-gas	Natural Gas	
Seasonal Blue	10,973,875	15,819,060	-	59.65%
Seasonal Green	5,819,844	1,001,721	-	15.19%
Conventional	412,314	10,433,669	455,664	25.16%
Total	17,206,033	27,254,450	455,664	100%

Knowing the local utility company high-voltage profile consumption (Tab. 7) it is possible to determine the national potential of self-generation considering the premises adopted in this work. Table 9 presents the percentages of self-generation for tension level and technology of the local utility company that will be used for the calculation of the national technician-economic potential of self-generation.

Table 7 – Potential self-generation by tension level and national annual consumption of 2000.

	Self-generation			Without Self-generation potential	National annual consumption (MWh)
	Diesel	Diesel-gas	Gas		
A2	0.11%	2.39%	0.00%	97.50%	47,842,000
A4	3.74%	2.87%	0.00%	93.39%	71,583,000
A3 + A3a	3.04%	3.39%	0.00%	93.57%	12,413,000
AS	4.45%	17.74%	0.84%	76.97%	1,925,000
Total geral	2.47%	3.91%	0.07%	93.56%	133,763,000

The final results of the national potential of self-generation are presented in Tab. 10. The potential is esteem 7,173 GWh/ano, concentrated mainly for generation of peak period. The generators diesel represent 44.6% of this total, the generators diesel-gas 55.2% and the generators the gas only 0.2%. This means in a daily consumption of 2,2 Mm^3 of natural gas and 2,800 m^3 of diesel oil (Tab. 11).

Table 8 – National potential self-generation by tension level and by technology.

		A2	A4	A3 + A3a	AS	Total
National self-generation (MWh)	Diesel	54,023	2,680,569	377,400	85,646	3,197,638
	Diesel-gas	1,144,403	2,052,356	421,252	341,543	3,959,555
	Gas	0	0	0	16,114	16,114

Table 9 – Consumption of diesel oil and natural gas necessary to supply all the self-generation as the technicial-economic.

	Self-generation			Total
	Diesel	Diesel-gas	Gas	
Diesel oil (m^3)	2,219	563	-	2,783
Natural gas (Mm^3/dia)	-	2.174	0.123	2.186

Remaining it methodology of calculation of the potential of self-generation, developed in this work, had been carried through alternative simulations, where if it verifies the variation of the potential of national self-generation with the change of cost of the natural gas (Tab. 12).

Table 10 - Sensitivity analysis of the national potential of self-generation with the variation of the cost of the natural gas.

Fuel final price		Self-generation			Self-generation (MWh)	Fuel consumption	
Diesel oil (R$/L)	Gas (R$/$m^3$)	Diesel (%)	Diesel-gas (%)	Gas (%)		Diesel (m^3/day)	Gas natural (Mm^3/day)
1.42	0.60	8.15%	90.69%	1.16%	11,754,781	2,183	5.958
1.42	0.65	13.99%	85,76%	0.25%	8,693,370	1,906	4.111
1.42	0.70	31.15%	68.85%	0.00%	7,974,196	2,506	3.015
1.42	0.75	39.43%	60.57%	0.00%	7,509,521	2,703	2.498
1.42	0.80	44.23%	55.77%	0.00%	7,212,387	2,787	2.209
1.42	0.85	49.08%	50.92%	0.00%	7,036,606	2,908	1.967
1.42	0.90	60.34%	39.66%	0.00%	6,894,954	3,277	1.502
1.42	0.95	66.91%	33.09%	0.00%	6,821,419	3,490	1.240
1.42	1.00	71.13%	28.87%	0.00%	6,646,182	3,555	1.054

5. Conclusion

Self-generation can not only bring benefits as economy and increasing the security of the supply of electric energy for the customer, as also for the national systems of generation, transmission and distribution. The self-generation does not compete with these traditional systems of electric energy, only complements. It´s esteemed that national technical-economic self-generation potential is 7.173 Gwh/year. The diesel generators represent of this total of generation 44.6%, the diesel-gas generators 55.2% and the gas generators about 0.2%. In this work had been esteem a daily potential consumption of natural gas 2.2 Mm^3 (considering the cost of the natural gas of the CEG) and 2,800 m^3 of diesel oil.

In studies of alternative scenes of cost of the natural gas he was refined the great importance and dependence of these costs. The price calculated from the cascade of the CEG for the natural gas inhibits the potential customers of self-generation, which would has a consumption esteemed around 6 Mm^3/day of natural gas if the gas has a fixed cost around 0.60 R$/$m^3$. The incentive for the self generation based in the generators diesel-gas can be created in a new tariff system of the natural gas. The natural gas tariff could follow the electric energy example, that the price is structured for the high tension level by peak hours and out-of-peak. If the natural gas demand peak is not coincidence with the electric energy peak, there is possibility that the natural gas utility company practice lower price for the gas in that period (maximizing he sales in peak electric hours).

Finally, the methodology disclosed to the importance of generators diesel-gas in the participation of the projects of national self-generation. The recent energy crisis lived by Brazil in 2001, showed the high cost of the lack of electric energy, demonstrating that the cost of the investment in the expansion of the electrical system is less harmful than the actual damages of scarcity the electric energy.

6. Acknowledgements

The authors are indebted to LIGHT, Serviços de Eletricidade S.A, for having supplied data for this work.

7. References

ANEEL, website <http://www.aneel.gov.br>.

ANP, website:<http://www.anp.gov.br/petro/levantamento_precos.asp>.

Borbely, A., Kreider, J. Distributed Generation - The new power paradigm for the new millennium. CRC Press, 2001.

Lima, B. Q. Avaliação crítica do potencial técnico-econômico da autogeração de energia elétrica no Brasil. Puc-Rio, 2004.

CBIEE, Setor Elétrico Brasileiro – Cenários de crescimento e requisitos para a retomada de investimentos. Câmara de Investidores em energia elétrica, 2003.

CEG, Contrato de formecimento de gás canalizado para uso exclusivo em geradores a gás (No/04) – Entre Companhia distribuidora de gás do Rio de Janeiro e PUC-Rio. Companhia distribuidora de gás do Rio de Janeiro, 2004.

CEMIG: Atendimento, website <http://www.cemig.com.br/>

LIGHT, Banco de dados de clientes cativos de alta tensão do mês de março de 2003. Companhia LIGHT, 2003

LIGHT: Grandes consumidores, website: <http://www.lightempresas.com.br/>.

MME. Balanço Energético Nacional 2003. Ministério de Minas e Energia, 2003.

NREL. Gas-Fired Distributed Energy Resource Technology. National Renewable Energy Laboratory, 2003.

ORLANDO, A. F., SOUZA, R. C., DO VAL, L. G., MAGALHÃES, F.P., TAVES, S. Desenvolvimento de ferramentas para a avaliação da penetração da geração distribuída no mercado de energia elétrica, Artigo técnico - Projeto LIGHT e PUC-Rio, 2004.

THERMOFLEX LITE 5.2. Reciprocating engine generator sets database, Software – Thermoflow 8, 2002.

8. Responsibility notice

The authors are the only responsible for the printed material included in this paper.