ANALYSIS OF HYBRID SYSTEMS FOR ENERGY PRODUCTION IN HORIZONTAL RESIDENTIAL CONDOMINIUMS

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Abstract. *The main purpose of this work is to develop a technical and economic study of energy supply alternatives by self-production of electrical energy in horizontal condominiums. The case study will be in a neighborhood of São José dos Campos city, São Paulo state. The proposal method is to analyze the alternatives forms of energy generation, compatible with this kind of enterprise: wind, photovoltaic and generation electrical with a internal combustion engine. Thus, it will be possible to establish the technical basis of those energetic alternatives, as well as the economical aspects. Subsequently, the electrical needs will be lifted in time basis for the common areas of the condominium, where the consumption and the costs are shared between the residents, which is the object of analysis. Related to the configuration of the system, in a first approach it is considered a basic outline of the main alternative sources of energy of the hybrid system photovoltaic (PV), wind (WE) and internal combustion engine (ICE). Variations of this proposal will be subject to a technical and economic analysis considering the simultaneous or alternated use of those different sources of energy. The next step is to structure an evaluation model, on time basis, to establish the best alternatives of self-production of electrical energy and comparing the results of its cost of electricity production with those charged by the local electricity company. Besides those objectives, in some cases, it will be possible to negotiate, to sell, the excessive electricity produced with the local electricity company. To achieve those goals, the software "Linear, Interactive and Discrete Optimizer – LINDO / LINGO", will be taken for simulations and obtaining the optimal technological route. Will be considered the simulation scenarios with different conditions of energy prices and equipment costs in order to obtain the conditions under which renewable technologies are able to be qualified to compose the final configuration of the system of electricity self-generation. The database needed to compose the frame of variables and parameters will be requested to the Board of the Condominium. Those variables and parameters define the dimension and characteristics of energy demand in the horizontal residential condominium which is object of this case study.*

Keywords*: decentralized energy; wind energy; photovoltaic, cogeneration, condominium*

1 INTRODUCTION

1.1 Background

The development of researches that have as objective to determine the degree of energy efficiency of cities and their buildings have been revealed in recent years to be essential to the practice of rational use of energy resulting from gains in the structure of the energy matrix of a country. Data published in the State of São Paulo (2009), referring to the same state, presents the energy consumption in residential level between 1980 and 2007, with consumption projected for the following years until 2020. It is observed the increasing trend until 2001, when the occurrence of an electricity supply problem (blackout). Planned increases in residential area are 150% in 40 years.

In Brazil's case, centralized generation based mainly in hydropower systems are used to provide the electrical needs of residential and public areas, and the vast majority of activities developed in the tertiary sector. The Brazilian energy matrix currently has 113.74 GW, of which 0.82% of wind generation, 28.25% based on thermoelectric power stations and solar is responsible for just 86 kW (ANEEL, 2010).

International experiences - especially in California (Go Solar California, 2011) and Germany (Bundesanzeiger, 2009) – reveal that decentralization of power generation is a possible and interesting way of modifying the countries energetic matrix. Programs for renewable energy use have been extended to small entrepreneurs, through technologies of power generation based on photovoltaic (PV), wind, mini and micro cogeneration with internal combustion engines and even fuel cell.

The present study has as aim to develop a technical and economic study of alternative energy supply for horizontal residential condominiums by self-generation from the development of an optimization model.

2 CONCEPT OF DISTRIBUTED GENERATION

According with INEE (2011), distributed generation or decentralized power generation it is a term used to designate the electric generation produced along or near to consumers, regardless of power, technology and energy source. Distributed generation has for concept the spraying of suppliers, which can be cogenerators, compounders, generators at peak times of the electrical system, emergency generators, homes and condominiums equipped with solar photovoltaic generation, among others. In this context, in Brazil, the principal decrees, resolutions and laws related to the subject, which define and regulate the self-production of energy are: Decree No. 2003 of 10/09/1996, Decree 5163 of 30/07/2004, Law No. ° 9,074, of 07/07/1995, Resolution No. 371 of 29/12/1999 of the National Agency of Electric Energy - ANEEL, Resolution No. 235 of normative 14/11/2006 Aneel; normative Resolution No. 281, 25 / 09/2007, Aneel; normative Resolution No. 304 of 04.03.2008, ANEEL.

The facilities that employ cogeneration contribute to the environment through the rational use of energy. The result is improved energy efficiency, with lower consumption of energy sources, as compared to the individual and independent generation of heat and electricity. This is referenced in the ANEEL Resolution 235 of 14/11/2006.

3 METHODOLOGY

This paper presents the modeling of optimization of the set of devices established on a superstructure proposed to select electric self-generation technologies in a time basis. Together with the electric grid, solar photovoltaic systems, wind generator systems and internal combustion engine systems were considered as alternative technologies.

For Hongxing Wei and Chengzhi (2009), the maximum output power delivered by the PV module can be calculated according to the equation (1). The parameters α, β, γ, R_s and n take into account all non-linear effect of environmental factors on the performance of the photovoltaic module. α, β, γ, R_s are supplied by the manufacturer of the photovoltaic module.

$$P_{module} = \frac{\dfrac{V_{oc}}{nKT/q} - \ln\left(\dfrac{V_{oc}}{nKT/q} + 0{,}72\right)}{1 + \dfrac{V_{oc}}{nKT/q}} \cdot \left(1 - \frac{R_s}{V_{oc}/I_{sc}}\right) \cdot I_{sco}\left(\frac{G}{G_o}\right)^{\alpha} \cdot \frac{V_{oco}}{1 + \beta \ln \dfrac{G_o}{G}} \cdot \left(\frac{T_o}{T}\right)^{\gamma} \tag{1}$$

in which α = factor responsible for nonlinear effects which the photo current depends on; β = dimensionless coefficient on the specific technology of photovoltaic module; γ = factor that considers the nonlinear effects of voltage and temperature; P_{module} = maximum output power delivered by photovoltaic module (W); V_{oc} = Open circuit voltage (V); n = ideality factor ($1 < n < 2$); K = Boltzmann constant, 1.38×10^{-23} J/K; T = PV module temperature (K); q = magnitude of electron charge (1.6×10^{-19}C); R_S = series resistance (ohm); I_{sc} = short circuit current (A); I_{sco} = short circuit current in standard condition (A); G = solar radiation (W/m^2); G_o = solar radiation in standard condition (W/m^2); V_{oco} = open circuit voltage at standard condition (V); T_o = PV module temperature at standard condition (K).

The wind power achieved through the wind is an important alternative source of energy available in nature and with high sustainability. In the specification of a wind turbine, it is important to analyze the characteristic curve of power of the wind turbine (Cresesb, 2010). The potential for wind energy is practically possible in all regions of Brazil.

According to Reis (2003), in a simplified manner, it is possible to estimate the air velocity for different heights of the air mass in motion. Empirically, it is presented an equation, where the wind speed at the desired height (m/s) is proportional to the wind speed in a known height (m/s) and to the ratio of heights, n exponential (roughness factor of the terrain). The roughness factor of the terrain, n, ranging from 0.10 to 0.32 depending on the conditions of vegetation, presence of trees, forests, buildings and urban areas.

For this case study, the height measurement of wind velocity is equal to the hub height of the wind turbine, equal to 10 m. No need for corrections.

Based on the theoretical efficiency of Betz, developed by Albert Betz in 1920, the aerodynamic efficiency of the rotor was limited to 16/27, or 59.3% of the energy present in the winds. To Terciote (2002), in practice values are found close to 35%. Considering that the electrical power (P_E) of a wind turbine (Reis, 2003) and the maximum mechanical power of the wind turbine rotor, calculated by the Betz limit, Salles (2004) presents the equation (2) to calculate the final power of the wind system.

$$P = \frac{1}{2} \cdot \rho \cdot v^3 \cdot A \cdot \eta \cdot C_P \ \text{(kW)} \tag{2}$$

in which: ρ = air density (kg/m^3); v = wind speed (m/s); A = section of the air mass in motion (m^2); η = wind turbine efficiency (mechanical and electrical); C_P = coefficient of aerodynamic performance. The coefficient of aerodynamic performance C_P depends on wind and control parameters of the wind turbine.

The use of electrical generator with internal combustion engines for electricity production is largely used because of its low cost, ease of operation and maintenance, and flexibility for expansion of equipment.

3.1 Structuring a superstructure for the optimization model

The main alternative of sources of energy hybrid systems considered for generating electricity for a horizontal residential condominium is composed of photovoltaic (PV), wind turbine (EO) and internal combustion engines (M) integrated to electric generators. Figure 1 shows the superstructure of the proposed system. The optimization model will be run for the choice of technology and the amount of equipment to meet the electrical needs of the condominium in a time series basis.

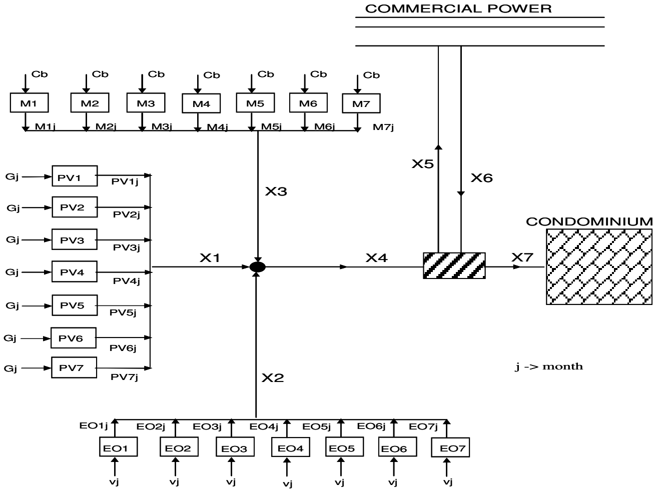

Figure 1 – Superstructure of the proposed system

In Figure (1) the following variables are identified: PV – photovoltaic panel (7 models); M – engine generator (7 models); EO – wind turbine (7 models); G – solar radiation; v – wind speed; Cb – fuel; PVj – electrical power of PV in the month (j); EOj - electrical power of EO no mês (j); Mj - electrical power of M no mês (j); X1 – electrical power of PVj; X2 – electrical power of EOj; X3 – electrical power of Mj; X4 – electrical power of all equipment installed; X5– electricity sold to the commercial power; X6 – Electricity purchased from commercial power; X7 – electrical power of the facilities of the condominium; j – identification of the months of the year analyzed.

See at Chapter 5 the mathematical expressions or constraints formed with those variables.

4 CASE STUDY – SURVEY DATA

The study refers to the horizontal residential condominium in Sao Jose dos Campos, SP for the common areas. Four electrical installations with individual meters for each installation were analyzed, considering lighting, cameras and computers pedestrian access for Entrance 2; lighting around the sporting areas and around of that, and house maintenance for the main leisure square; lighting, gates for vehicles, cameras and computers for Entrance 1; lighting of public alleys nearby the leisure square. For each of those facilities the data of monthly electricity consumption (in kWh) and the cost (R$) were tabulated and analyzed for the years 2007, 2008 and 2009. Table 1 presents the electric power consumed in the condominium common area and is based on the consumption of the monthly electric energy in kWh for 720 hours per month.

Table 1 – Electrical power to all facilities considered (W)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
2007	1840.28	1956.94	2258.33	1933.33	2165.28	2122.22	2302.78	2629.17	2269.44	2106.94	2229.17	2147.22
2008	2291.67	2211.11	2231.94	2454.17	2701.39	2613.89	2723.61	3287.5	4175	4004.17	3876.39	3579.17
2009	4229.17	4530.56	3755.56	4795.83	3808.33	5745.83	5787.5	4822.22	4904.17	4951.39	4286.11	4286.11

For adjusting the weather data relative to the wind and solar systems, environmental data from São José dos Campos were obtained in the site of the Center for Weather Forecasting and Climate Studies - CPTEC / INPE (INPE, 2010) - Station of Sao Jose dos Campos - SP, Agromet, code 30893: data on solar radiation and air velocity. Among the data collected, just the period from April to December 2008 were considered as representative, coherent and consistent. As for the month of April the available data were from the 15th day, the data for this month were multiplied by two.

The model considered the real values of energy tariff including taxes. Taxes such as ICMS, PIS and COFINS are present in the tariff (ANEEL, 2008). From the electric bills of residential condominium, relative to 2009, with monthly figures adjusted to the profile normal consumption of the month, and considering the nominal values of 0.30146 R$/kWh; PIS rate = 1.03%; COFINS rate = 4.71%; ICMS rate = 25.00%, the total annual cost of electricity is estimated to be R$ 17,920.59. This energy represents the portion shared among the residents of the Residential.

The amount to be charged to the consumer (V_c) is 0.44 R$/kWh or 0.25 US$/kWh. In terms of power it is assumed US$0.18/W (for the consumption of 720 hours per month and the exchange rate of US$ 1.00 equals R$ 1.75).

4.1 Survey of the characteristics of the power generation equipment

For the photovoltaic system modeling, the values of accumulated solar radiation and the corresponding electrical power are presented in Table 2.

Table 2 – Power supplied by the sun in 2008

	Apr	**May**	**Jun**	**Jul**	**Ago**	**Sep**	**Oct**	**Nov**	**Dec**
Accumulated solar radiation (MJ/m²)	496.4	494.3	538.1	689	624.5	607.9	455.3	388.3	362.8
Power (W/m²)	596.92	279.08	278.35	335.77	404.36	469.06	261.85	230.47	313.95

Source: Cptec Inpe - Station 30893 Agromet de São José dos Campos - SP

Applying equation (1) to the technical characteristics of each one of the seven selected photovoltaic panels (Table 3) and to the solar radiation incident on the region of Sao Jose dos Campos, in the period of April to December 2008, (Table 2), it was obtained the power provided by photovoltaic panels in each month of this period as shown in Table 4.

Table 3 – Technical characteristics of the photovoltaic panels selected for the modeling program

Características técnicas dos módulos fotovoltaicos selecionados							
Manufacturer / model	Kyocera Solar / KD205GX-LP	Kyocera Solar / KC-130TM	Kyocera Solar / KC40T	Kyocera Solar / KC-50T	Kyocera Solar / KC-65T	Kyocera Solar / KC-85T	BP Solar / BP380
Project max power (W)	205	130	43	50	65	87	80
Efficiency (%)	16	16	16	16	15	16	12.3
Module area (m²)	1.49	0.93	0.34	0.42	0.49	0.66	0.65
Weight (kg)	18.5	12	4.5	5	6	8.3	7.7
Cost (€)	–	–	–	–	–	–	362.50
Cost (R$)	3490.00	2035.00	703.00	901.00	1159.00	1390.00	837.38
Cost (US$)	1994.29	1162.86	401.71	514.86	662.29	794.29	478.50
Cost (US$/m²)	1342.95	1251.60	1171.34	1235.77	1352.56	1209.76	737.02
Cost (US$/W)	9.73	8.95	9.34	10.30	10.19	9.13	5.98
(*) Maint. cost (US$/W)	0.065	0.065	0.065	0.065	0.065	0.065	0.065

(*) YANG, H.; ZHOU, W.; LU, L. e FANG, Z. Optimal sizing method for stand-alone hybrid solar–wind system with LPSP technology by using genetic algorithm. Solar Energy, v. 82, p. 354-367, 2008;
Note: Exchange: dollar in 04/28/2010: R$1.75; euro R$2.31

Table 4 – Power of the photovoltaic modules in the analyzed months

Power generated by photovoltaic modules for local solar radiation in 2008 (W)							
Manufacturer / model	Kyocera Solar / KD205GX-LP	Kyocera Solar / KC-130TM	Kyocera Solar / KC40T	Kyocera Solar / KC-50T	Kyocera Solar / KC-65T	Kyocera Solar / KC-85T	BP Solar / BP380
Technology	Polycrystalline	Polycrystalline	Polycrystalline	Polycrystalline	Polycrystalline	Polycrystalline	Polycrystalline
Project max power (W)	205	130	43	50	65	87	80
April	197.4	124.4	40.8	51	61.4	82.2	55.9
May	88.5	55.8	18.3	22.9	27.5	36.8	25.1
June	88.3	55.6	18.3	22.8	27.5	36.7	25
July	107.6	67.8	22.2	27.8	33.5	44.8	30.5
August	130.9	82.4	27.1	33.8	40.7	54.5	37.1
September	153.1	96.4	31.7	39.5	47.6	63.7	43.3
October	82.8	52.1	17.1	21.4	25.8	34.4	23.4
November	72.3	45.6	15.0	18.7	22.5	30.1	20.5
December	100.2	63.1	20.7	25.9	31.2	41.7	28.4

The parameter values of equation 1 (α, β, γ, n , R_s) are those adopted by Yang et al. (2008) and the values of the parameters (I_{sco}, V_{oco}) were obtained from technical information module BP Solar / BP380.

With equation (2) and the data presented in Table 5, the monthly power is calculated for wind generator system, as shown in Table 6. Seven models were selected and the wind power calculated, according to local wind conditions in the region of Sao Jose dos Campos. For an optimization analysis devoted to the components synthesis of the superstructure proposed, to adopt the values of air velocities calculated on the basis of simple arithmetic was considered suitable. A better approach would be to apply the method of cumulative statistical distribution of "Weibull" to describe the variations of wind speed (Yang et al., 2008); however, it is not feasible for this modeling structure, although this simplified method resulted in some inconsistent values relative to the power produced in some wind turbines, for certain months. The efficiencies of mechanical and electrical system (η) adopted are equal to 0.3 (Reis, 2003). The coefficient of aerodynamic performance (c_p) is equal to 0.3507 and 0.4407, depending on the wind turbine model (Vaz, Silva, Pinho, Branco, Mesquita, 2009) and technical specifications of wind turbines Altercoop.

Table 5 - Technical characteristics of the selected wind tubines for the program modeling

Technical characteristics of the wind turbines							
Manufacturer / model	Altercoop - Batuira 500	Altercoop - Batuira 1000	Altercoop - Abatroz 15000	Notus 112	Notus 138	Gerar 246	Verne 555
Nominal power (W)	500	1000	15000	250	350	1000	6000
Propeller Diameter (m)	2	2.4	6.8	1.12	1.38	2.46	5.55
Cost (R$)	3045.00	5959.00	68000.00	2990.00	2990.00	5990.00	29500.00
Cost (US$)	1740.00	3405.14	38857.14	1708.57	1708.57	3422.86	16857.14
Cost (US$/W)	3.48	3.41	2.59	6.83	4.88	3.42	2.81
(*) Maint. cost (US$/W)	0.095	0.095	0.095	0.095	0.095	0.095	0.095

(*) Yang et al (2008);

Note: Exchange: dollar in 04/28/2010: R$1.75; euro R$2.31

It is observed in Table 6 that nominal power calculated for the wind turbine Batuíra 500, in September, October, November and December indicate capacity factors inconsistent with the practice. Moreover, in November 2008, for models of wind turbines Batuíra 500, Batuíra 1000, Notus 112, Notus 138, Gerar 246 and Verne 555 the calculated powers were greater than their nominal powers. To model the system of wind turbines it will be assumed that in cases where the calculated power is greater than the wind turbine nominal power, the wind turbine nominal power will be adopted.

Table 6 – Power obtained by wind turbines in selected months

Power generated by the wind turbines with respect to local wind in 2008 (W)							
Manufacturer / model	**Altercoop - Batuira 500**	**Altercoop - Batuira 1000**	**Altercoop - Abatroz 15000**	**Notus 112**	**Notus 138**	**Gerar 246**	**Verne 555**
Nominal power (W)	500	1000	15000	250	350	1000	6000
April	128.18	184.58	1481.73	50.51	76.69	243.69	1240.35
May	159.49	229.67	1843.74	62.85	95.42	303.22	1543.39
June	130.28	187.60	1506.02	51.34	77.94	247.68	1260.69
July	164.75	237.24	1904.52	64.92	98.57	313.22	1594.26
August	241.98	348.45	2797.29	95.36	144.77	460.04	2341.60
September	426.08	613.56	4925.49	167.91	254.92	810.05	4123.11
October	495.81	713.97	5731.60	195.39	296.64	942.62	4797.90
November	750.43	1080.62	8675.00	295.73	448.97	1426.69	7261.81
December	412.79	594.42	4771.84	162.67	246.96	784.78	3994.49

The power generated by motor generator units depends only on the technical features of design of these systems. Seven models of combustion engine integrated to electric generator are presented in Table 7. In this case, local environmental conditions do not affect the power results over the years.

5 MODELLING OF HYBRID SYSTEM

The main objective of present synthesis modeling is to minimize the investment and maintenance costs of equipments selected to compose the final configuration stated to supply the electricity demanded in the common area of a horizontal residential condominium. For this purpose, a modeling optimization program computer was developed with the use of LINGO software (version 10) (Britto, 2010).

Table 7 – Technical characteristics of the engine generators

Technical characteristics of the engine generators							
Manufacturer / model	**Draper 77006**	**Draper 43726 - Expert**	**Draper 43728 - Expert**	**Draper 43729 - Expert**	**Agrale Force4**	**Agrale Force6**	**Agrale Force8**
Technology	Motor Lombardini 15 LD 225 - Diesel	Motor 5HP Honda GX160 ohv-gasoline	Motor 9HP Honda GX270 ohv-gasoline	Motor 13HP Honda GX390 ohv-gasoline	Motor Agrale M80 - Diesel / Gerador Force4	Motor Agrale M85 - Diesel / Gerador Force6	Motor Agrale M90ID - Diesel / Gerador Force8
Power (CV/kW)	_	_	_	_	7/**5.1**/ 2300rpm	9.1/**6.7**/ 2300rpm	13/**9.5**/ 2500rpm
Power (kVA/kW)	2.6/2.1	2.7/2.2	5.0/4.0	7.5/6.0	4 kVA	6 kVA	7.5 kVA
Fuel tank (l)	3	3.6	6	6	_	_	_
Fuel density (g/l)	842	750	750	750	842	842	842
Fuel consumption (g/Wh)	0.00032	0.0004	0.0004	0.0004	0.00032	0.00032	0.00032
Fuel cost (US$/W)	0.088	0.137	0.137	0.137	0.088	0.088	0.088
Dimension (mm)	800x520x522	600x410x400	845x490x530	845x490x530	1000x696x830	1000x696x830	1000x696x830
Weight (kg)	78.8	40	60	75	230	245	260
Cost (£)	2513.33	652.13	1351.25	1586.25	_	_	_
Cost (R$)	6610.06	1715.10	3553.79	4171.84	11900.00	12700.00	13300.00
Cost (US$)	3777.18	980.06	2030.74	2383.91	6800.00	7257.14	7600.00
Cost (US$/W)	1.80	0.45	0.51	0.40	1.33	1.08	0.80
(*) Maint. cost in 1 mounth (US$)	308.40	308.40	308.40	308.40	308.40	308.40	308.40
Maint. cost (US$/W)	0.15	0.14	0.08	0.05	0.06	0.05	0.03

Note: Exchange: dollar in 04/28/2010: R$1.75; Pound in 05/12/2010: R$ 2.63; diesel price: R$2.00/liter; gasoline price: R$ 2.50/liter;
(*) Valente; Almeida (1998).

The following parameters and variables are used in the modeling program:

j – month from April (1) to December (9)/2008;
i –equipment model;
t_i – photovoltaic panels number;
PV_{ij} – panel electrical power, in W;
CPV - relative cost of the photovoltaic panel in US$/W;
CPVM – maintenance cost of the PV in US$/W;
k_i - number of wind turbines;
EO_{ij} - wind turbine electric power generator in W;
CEO - relative cost of the wind turbine in US$/W;
CEOM – maintenance cost of wind turbine in US$/W;
n_i – number of engine generators;
M_{ij} – engine generators electrical power, in W;
Ma_{ij} - nominal engine generators electrical power, in W;
CM - relative cost of the engine generators in US$/W;
CMM - maint.. cost of the engine generator em US$/W;
CMCb – fuel cost - engine generator in US$/W;
X1; X2; X3; X4; X5; X6; X7 – nomenclature of Figure 3;
CEV - cost of electric power sold to the grid in US$/W;
CEC - cost of electric power purchased from the grid in US$/W;

The problem was modeled considering the data of installed electrical power of the condominium (X7) over the years 2008 and 2009 (resulting from expansion projects of these facilities) according to the Table 1; cost of purchased electricity from the commercial power (Chapter 4), CEC = 0.18; cost of electricity sold to the commercial power - CEV, representing 75% of CEC, or CEV = 0.135; and the investments and maintenance costs of the respective models of photovoltaic panels, wind turbines and engine generators, from April to December 2008 as - tables 3, 4, 5, 6 and 7.

5.1 Constraints on the problem of modeling LINGO

Based on Superstructure proposal, Figure 1 and the variables presented in section 3.1 are defined the following constraints: for j ranging from 1 to 9 (April-December 2008) and i varying from 1 to 7 (models of equipment):

$$X1 = \sum_{i=1}^{7}\sum_{j=1}^{9} X1(i,j) * y1(i)$$, where y1(i)=BIN; binary values (0 ou 1);

$$\sum_{i=1}^{7} y1(i) = 1 \quad \text{or} \quad \sum_{i=1}^{7} y1(i) = 0$$ (as selected scenario);

$$X1(i,j) = t(i,j) * PV(i,j)$$; for t(i,j) photovoltaic panels of the model (i), needed in the months (j);

$X2 = \sum_{i=1}^{7}\sum_{j=1}^{9} X2(i,j) * y2(i)$, where y2(i)=BIN; binary values (0 ou 1);

$\sum_{i=1}^{7} y2(i) = 1$ or $\sum_{i=1}^{7} y2(i) = 0$ (as selected scenario);

$X2(i,j) = k(i,j) * EO(i,j)$; for k(i,j) wind turbines of the model (i), needed in the months (j);

$X3 = \sum_{i=1}^{7}\sum_{j=1}^{9} X3(i,j) * y3(i)$, where y3(i)=BIN; binary values (0 ou 1);

$\sum_{i=1}^{7} y3(i) = 1$ or $\sum_{i=1}^{7} y3(i) = 0$ (as selected scenario);

Constraints to the engine generator to operate at partial or maximum load: L3(i,j) is the percentage of nominal power “Ma”, (de 25 % a 90 % - satisfactory range for thermal machines of this nature), which defines the partial load "M " for the engine generator:

$M(i,j) = Ma(i, j * L3(i,j))$; $L3(i,j) \geq 0.25 * y3(i)$; $L3(i,j) \leq 0.90 * y3(i)$;

$X3(i,j) = n(i,j) * M(i,j)$; for n(i,j) engine generators of the model (i), needed in the months (j);

General constraints:

$X4(j) = X1(j) + X2(j) + X3(j)$;

$X4(j) + X6(j) = X5(j) = X7(j)$: Relationship between the electric power of all equipment installed (X4), electric power provided by the condominium to the commercial power (X5), the electrical power available from the commercial power to the condominium (X6) and the powers of the electric facilities of the condominium (X7), see Figure 1.

$X4(j) \geq 0$; $X5(j) \geq 0$; $X6(j) \geq 0$;

The numbers of equipment (t, k, n) are integer variables. In the format of LINGO software, they are understood as general integer (GIN) variables:

$t(i,j) = GIN$; $k(i,j) = GIN$; $n(i,j) = GIN$;

5.2 Objective function

The objective function of minimizing costs is equated as follows: for j ranging from 1 to 9 (April-December 2008) and i varying from 1 to 7 (models of equipment):

$$Min = \sum_{i=1}^{7}\sum_{j=1}^{9}\begin{bmatrix} X1_{ij} * CPV_{ij} + t_{ij} * PV_{ij} * CPVM_{ij} + X2_{ij} * CEO_{ij} + k_{ij} * EO_{ij} * CEOM_{ij} + \\ \\ + X3_{ij} * CM_{ij} + n_{ij} * M_{ij} * \left(CMM_{ij} + CMCb_{ij}\right) \end{bmatrix} + \sum_{j=1}^{9}\left(X6_j * CEC_j\right) - CEV * \sum_{j=1}^{9} X5_j \qquad (3)$$

6 ANALYSIS OF RESULTS OBTAINED

In addition to running the program with data from the installed power of 2008, the program was also run with 2009 data, at the same scenarios (Britto, 2010).

6.1 First scenario: the program sets the equipment, and number of units to operate in the month, buying or selling electricity from the commercial power. These results are consistent with the real values practiced by the condominium.

- Constraints: $\sum_{i=1}^{7} y1(i)=1$; $\sum_{i=1}^{7} y2(i)=1$; $\sum_{i=1}^{7} y3(i)=1$; $X5(j)\geq 0$; $X6(j)\geq 0$;
- 2008 results: objective function: US$5294.75; all electricity is purchased by the commercial power;
- 2009 results: objective function: US$7923.25; all electricity is purchased by the commercial power;

6.2 Second scenario: same as first scenario except that no electricity can be brought from commercial power, see details in table 8.

Table 8 – Results of the second scenario

Second scenario: the program sets the equipment, and number of units to operate in the month, it can sell but no buy electricity from the commercial power.

Constraints	$\sum_{i=1}^{7} y1(i)=1$	$\sum_{i=1}^{7} y2(i)=1$	$\sum_{i=1}^{7} y3(i)=1$	$X5(j)\geq 0$	$X6(j)=0$

	Objective function (US$)	**Equipment (n°, model, month)**			**(*) Power (W)**
		PV	**EO**	**M (n°, model, month; % of load)**	**X5**
2008	17266.8	0	0	1-M4(1); 40.9; 1-M4(4); 45.4; 1-M4(7); 66.7; 1-M4(2); 45.0; 1-M4(5); 54.8; 1-M4(8); 64.6; 1-M4(3); 43.6; 1-M4(6); 69.6; 1-M4(9); 59.6;	0
2009	32001.1	0	0	6-M2(1); 36.3; 9-M2(4); 29.2; 5-M2(7); 45.0; 5-M2(2); 34.6; 5-M2(5); 43.8; 5-M2(8); 39.0; 6-M2(3); 43.5; 5-M2(6); 44.6; 5-M2(9); 44.7;	0

(*) Power (W) - electricity to be sold to the commercial power

In this scenario, for the solution to the year 2009, the models of engine generators selected are different than those indicated for 2008, i.e., the solution is not called "robust". To improve this result, a simulation was done considering a single set data from nine months of 2008 and data from nine months of 2009, or 18 months, assuming that wind and solar conditions are similar.

The solution of this simulation indicates that with the acquisition of six engine generators, models "M2", serves up the installed capacity in 2008 and 2009. The workloads of engines generators "M2" range from 33% to 53% of the nominal load (2200 W). In this condition (2008 and 2009 - 18 months), the objective function is US$53,386.04. As the engine generator operates with a load corresponding to the monthly demand required by the Condominium, in any month there is plenty of electricity, and there is therefore the possibility of selling electricity to the commercial power.

6.3 Third scenario: not using engine generators and does not buy electricity from commercial power. See details in table 9.

Table 9 – Results of the third scenario

Third scenario: the program cannot select engine generators and does not buy electricity from commercial power.

Constraints	$\sum_{i=1}^{7} y1(i)=1$	$\sum_{i=1}^{7} y2(i)=1$	$\sum_{i=1}^{7} y3(i)<1$	$X5(j)\geq 0$	$X6(j)=0$

	Objective function (US$)	**Equipment (n°, model, month)**			**(*) Power (W)**
		PV	**EO**	**M**	**X5**
2008	109992.50	14-PV7(5);	2-EO3(1); 2-EO3(2); 2-EO3(3); 2-EO3(4); 1-EO3(5); 1-EO3(6); 1-EO3(7); 1-EO3(8); 1-EO3(9);	0	509,29 (1); 986,09 (2); 398,15 (3); 1085,43 (4); 29,19 (5); 750,49 (6); 1727,43 (7); 4798,61 (8); 1192,67 (9);
2009	140028.60	3-PV2(1); 3-PV2(2); 2-PV2(4); 3-PV2(9);	3-EO3(1); 2-EO3(2); 4-EO3(3); 3-EO3(4); 2-EO3(5); 1-EO3(6); 1-EO3(7); 1-EO3(8); 1-EO3(9);	0	22,56 (1); 46,55 (2); 278,25 (3); 61,66 (4); 772,36 (5); 21,32 (6); 780,21 (7); 4388,89 (8); 44,47 (9);

(*) Power (W) - electricity to be sold to the commercial power

As the solution to the year 2009 is different from the solution presented for 2008 relative to the photovoltaic panels selected, the solution is not "robust". To improve this result, a simulation was done considering a single set, data from nine months of 2008 and data from nine months of 2009, 18 months.

In the solution presented for the simulation of the 3rd scenario, with the acquisition of fourteen photovoltaic panels model "PV7 and four wind turbines models" EO3 "serves up the installed capacity in 2008 and 2009. In this condition (2008 and 2009 - 18 months), the objective function is US$258,098.70.

6.4 *Fourth scenario*: only the wind turbines provide electricity; and *Fifth scenario*: only photovoltaic panels provide electricity. See details in table 10.

Table 10 – Results of the fourth and fifth scenarios

	Fourth scenario: only the wind turbines provide electricity.			
Constraints	$\sum_{i=1}^{7} y1(i) = 0$	$\sum_{i=1}^{7} y2(i) = 1$	$\sum_{i=1}^{7} y3(i) = 0$	$t(i, j) = 0$
	$X5(j) \geq 0$	$X6(j) = 0$		$n(i, j) = 0$

	Objective function (US$)	**Equipment (n°, model, month)**			**(*) Power (W)**
		PV	**EO**	**M**	**X5**
2008	114055.90	0	2-EO3(1); 2-EO3(2); 2-EO3(3); 2-EO3(4); 2-EO3(5); 1-EO3(6); 1-EO3(7); 1-EO3(8); 1-EO3(9);	0	509.29 (1); 986.09 (2); 398.15 (3); 1085.43 (4); 2307.08 (5); 750.49 (6); 1727.43 (7); 4798.61 (8); 1192.67 (9);
2009	157847.60	0	4-EO3(1); 3-EO3(2); 4-EO3(3); 4-EO3(4); 2-EO3(5); 1-EO3(6); 1-EO3(7); 1-EO3(8); 2-EO3(9);	0	1131.09 (1); 1722.89 (2); 278.25 (3); 1830.58 (4); 772.36 (5); 21.32 (6); 780.21 (7); 4388.89 (8); 4627.01 (9);

	Fifth scenario: only photovoltaic panels provide electricity.			
Constraints	$\sum_{i=1}^{7} y1(i) = 1$	$\sum_{i=1}^{7} y2(i) = 0$	$\sum_{i=1}^{7} y3(i) = 0$	$k(i, j) = 0$
	$X5(j) \geq 0$	$X6(j) = 0$		$n(i, j) = 0$

	Objective function (US$)	**Equipment (n°, model, month)**			**(*) Power (W)**
		PV	**EO**	**M**	**X5**
2008	178723.90	44-PV7(1); 108-PV7(2); 105-PV7(3); 90-PV7(4); 89-PV7(5); 97-PV7(6); 172-PV7(7); 190-PV7(8); 127-PV7(9);	0	0	5.43 (1); 9.41 (2); 11.11 (3); 21.39 (4); 14.4 (5); 25.1 (6); 20.63 (7); 18.61 (8); 27.63 (9);
2009	266775.60	86-PV7(1); 152-PV7(2); 230-PV7(3); 190-PV7(4); 130-PV7(5); 114-PV7(6); 212-PV7(7); 210-PV7(8); 174-PV7(9);	0	0	11.57 (1); 6.87 (2); 4.17 (3); 7.5 (4); 0.78 (5); 32.03 (6); 9.41 (7); 18.89 (8); 24.93 (9);

(*) Power (W) - electricity to be sold to the commercial power

- In the fourth scenario the solutions for the years 2008 and 2009 are "robust". The same models of wind turbines were selected. With the acquisition of four wind turbines "EO3", the installed capacity in 2008 and 2009 can be met.

- In the fifth scenario the solutions for the years 2008 and 2009 are "robust". The same models of photovoltaic panels were selected. With the acquisition of two hundred and thirty photovoltaic panels "PV7", the installed capacity in 2008 and 2009 can be met.

7 CONCLUSIONS

The proposal of developing a technical and economic study of alternatives of electrical energy supply by self-production, based on photovoltaic, wind generation and engine generation with internal combustion engines, in a residential condominium of Sao Jose dos Campos city, Sao Paulo state has been satisfactorily answered.

The research of the electrical needs of the common areas of the condominium was expressed in time basis. The monthly average power installed in 2008, in the nine months set for the study was of 3012.50 W.

The optimization model using the LINGO software, version 10 was successfully tested in five different scenarios, and provided the conditions in which renewable technologies are able to compose the final configuration of the system of electricity self-generation.

At first the program run with the data of installed power in 2008 and then with 2009 data (due to increased facilities expansion projects). Both of these solutions were obtained, satisfactory and compatible with the installed power. In 2008, the monthly electric power installed ranged from 2454.17 to 4175 W. In 2009, this variation was from 3808.33 W 5745.83 W, corresponding to an annual increase in installed capacity of 49.6%.

Analyses for the determination of "robust" solutions to serve up simultaneously the years 2008 and 2009 were satisfactory for the second and third scenarios.

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