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Modeling and Simulation of Natural Gas Microturbine for Residential Complexes

A.B.M.Aguiar, J.O.P.Pinto and L.A.H.Nogueira

***Abstract*— In the paper, the authors have investigated the natural gas based microturbine of residential complex with the Matlab. The aim of this work is to present a daily simulation model for technical and economical analysis of natural gas microturbine application for residential complex. The main advantage of this model is the timeframe that is used, which is flexible, varying from hours, days, weeks, up to years. Therefore, the work granularity allows take into consideration details that conventional methodology does not. In this paper are given details of the model, and simulation results are provided to show it feasibility. The results from this work may be useful as a decision support system by investors.**

***Index Terms*— cogeneration, load curve, microturbine, residential building, simulation.**

I. Introduction

THE residential environment is favorable to cogeneration systems, because it presents an expressive thermal demand. The electrical energy consumption in the residential class is responsible for 25% of the total electrical energy consumed in Brazil and concentrates around 85% of the total consumers units.

CHIRADEJA defends that some DG technologies produce electrical energy almost as efficiently as large central-station power plants and at a cost competitive with centralized generation for certain applications with less environmental impacts and flexibility in siting. DG can be used to match increased customer demand where the upgrade or installation of new transmission/ distribution lines are not available for one reason or other.

The great attractive of the cogeneration is this high energetic efficiency. While a thermoelectric plant of combined cycle has a performance of 55%, a cogeneration plant performance can get around 90%. However, the cogeneration do not apply to all the energy's consumers, it is necessary a profile of electrical and thermal demand with some equilibrium and simultaneity.

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II. Cogeneration

Cogeneration applications to residential buildings have to satisfy either both the electrical and thermal demands, or satisfy the thermal demand and part of the electrical demand, or satisfy the electrical demand and part of the thermal demand. Depending on the magnitude of the electrical and thermal loads, whether they match or not, and the operation strategy, the cogeneration system may have to run at partial load conditions. In such case, the surplus energy (electricity or heat) may have to be stored or sold, and deficiencies may have to be made up by purchasing electricity (or heat) from other sources such as the electrical grid (or a boiler plant). [2]

The surplus heat produced can be stored in a thermal storage device such as a water tank or in phase change materials, while surplus electricity can be stored in electrical storage devices such as batteries or capacitors. In addition, the operation of a cogeneration system may be dependent on varying electricity prices, allowing cogeneration systems financially attractive in periods of high electricity prices. [2]

The electric efficiency of the system is defined by the electric power output to the fuel input, ratio as shown in (1). The efficiency of a cogeneration system is measured by the fraction of the input fuel that can be recovered in heat and electric power form, the remaining energy are loses, as given in (2).

$$Electric\ Efficiency = \frac{Electric\ power\ (kW)}{Fuel\ Input\,(kW)} \tag{1}$$

$$Total\ Efficiency = \frac{Thermal\ Energy + Electric\ power\ (kW)}{Fuel\ Input\,(kW)} \tag{2}$$

The efficiency of a cogeneration depends on the type of the primer machine, its size, and the temperature which the recovered heat can be used. Also, the efficiency depends on the condition and the operating point of the cogeneration unit. [3]

On the adoption line of new technologies of electric energy generation with natural gas, the microturbine detaches by the low emission level and the low maintenance, especially when compared with the gas engine.

The functioning of a gas microturbine is simple, the fuel is burned in a combustion chamber, and the proceedings gases of this burn are directed by the compressor to inside of the turbine, where its energy is converted to mechanical energy, that can be used for electric energy production via an alternator, as for prime mover of bombs and compressors, etc. In some case, if the microturbine has a regenerator, the exhaust gases preheat the inlet gas of the combustion chamber, so the efficiency of the machine can be doubled.

III. Electrical and Thermal Demand

According to Guttromson, as the number of consumers connected to the feeder system, the load peak by consumer will fall. This is a direct result of the diversity increase. [4]

When applying BCHP (Building Combined Heating and Power) systems to a certain building, the ideal case would be that the building has a uniform demand ratio between power/heating/cooling throughout the year (Fig. 1), so that no adjustment will need to be made and the system can run year round to obtain more savings. [5]

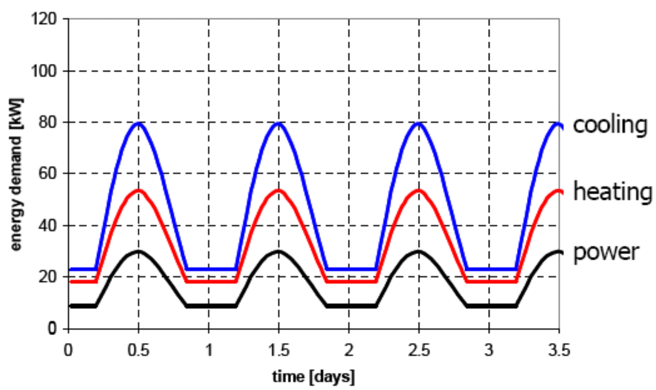


Fig. 1. Idealized load profile for cooling, heating and power [5]

To determinate the typical curve of electrical energy demand of the residential class was utilized the consumers' data supplied by CERCHIARI (2006) exposited in his master's thesis. [6]

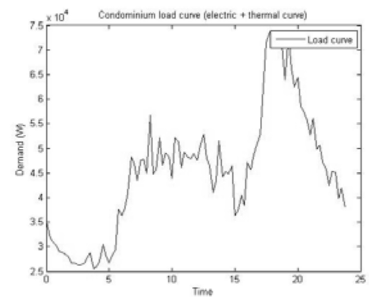
In his work CERCHIARI determinates the typical demand curves of low voltage consumer using of Self Organized Maps (SOM) and Rough Sets. The measurements had occurred in 413 energy consumers of Brazilian state Mato Grosso do Sul. The residential clients represents 43,34 % of the sample.

CERCHIARI realized simulations to 10, 20 and 40 groups with the construction of typical demand curves, from the average and the standard deviation of the measured curves belonging to each group, as well as the rules' set of classification of the consumer to the group. Face to the proximity of the performance of the results in the three configurations, he recommends the methodology with 10 groups by the substantial reduction of the number of typical curves.

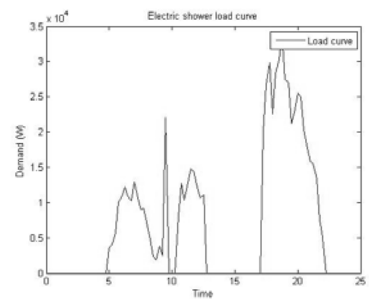
In these typical curves, the electric and thermal demands are grouped. Therefore it will be necessary to subtract from each typical curve the consumption of electric energy responsible for water heating.

To simulate a real building, measurements were made in a building of Campo Grande. This building has 48 occupied apartments. Measurements were done in the entire building and the part of the condominium. It was used the condominium's data.

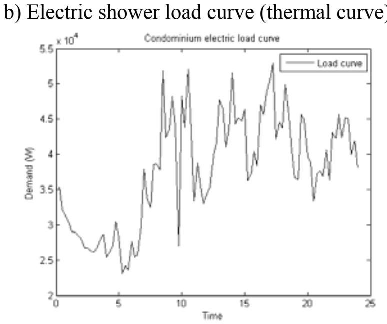
The average electric consumption of the inhabitants was calculated, 540 kWh / month. Using the typical curves, the consumption per apartment was calculated. The thermal curve of the electric shower was estimated by the Brazilian habits of consumption. Fig. 2 shows the electric and the thermal curve of the building and the sum of both.



a) Load curve (electric + thermal) of the entire condominium



b) Electric shower load curve (thermal curve)



c) Electric load curve (c= a-b)

Fig. 2. Load curve of the residential building

IV. System Configuration

In order to evaluate the use of microturbine natural gas based for residential buildings, two different configurations were analyzed, dimensionally wise:

Configuration 1- The system was dimensioned to attend the thermal demand side (hot water). The electrical generation becomes a byproduct of this process. In this case, it is necessary to buy electricity from the grid to completely attend the electricity demand.

Configuration 2 -The system was dimensioned to attend the electric demand side. The thermal generation becomes a byproduct of this process. In this case, there will have an excess of thermal energy.

V. Modeling the System

The most common configurations of cogeneration' plant consists in a turbine moved by natural gas connected to a generator that produces electricity. The hot exhaust gases of the turbine are used directly in the process or, more commonly, pass through a recovery chamber that generates steam. This stream can go to a heat exchanger producing hot water and/or an absorption chiller producing cold air.

Equation (3) shows the efficiency of cogeneration system [3]:

$$\eta_{PROCESS} = \eta_{electric} + \eta_{thermal} \tag{3}$$

A. Microturbine Model

The electric efficiency of the microturbine ($\eta_{electric}$), given in Equation (4) is function of the electric power (W) and of the fuel consumption (X), and therefore it varies with the demands [3]:

$$\eta = \frac{W_0 \cdot CF}{X_0 \cdot PCI[B + (1-B)\cdot CF]} = \frac{\eta_0 \cdot CF}{B + (1-B)\cdot CF} \tag{4}$$

Where: Wo = nominal power of the microturbine (kW), CF = capacity factor of the operating condition, being a relation between the medium power developed and the maximum power. Xo = specific fuel consumption in the normal conditions. PCI = inferior power calorific of the fuel utilized for the generation (kJ/kg). B = emptiness consumption to realization of the work. η_0 = microturbine income in normal conditions

The electric power produced by the microturbine can be calculated by Equation (5):

$$W = \frac{W_0}{(1-B)\cdot X_0} \cdot X - \frac{B \cdot W_0}{(1-B)} \tag{5}$$

The thermal efficiency is calculated by the heat reused by the boiler. The output gases of microturbine are directed to the boiler and the process' useful heat is given by Equation (6):

$$Q = \frac{Q_0}{(1-D)\cdot X_0} \cdot X - \frac{B \cdot Q_0}{(1-D)} \tag{6}$$

Where D = emptiness consumption to realization of the heat and Qo = useful heat at the normal condition

In this system the environment temperature, atmosphere pressure and relative humidity has been used for the real simulation of the process, and Equations (7) and (8) give their relationship.

$$X_{CORR} = X_0 \cdot \frac{PCI_{PROJ}}{PCI} \cdot \frac{P}{1{,}03} \cdot \frac{\sqrt{T}}{\sqrt{288{,}15}} \tag{7}$$

$$W_{CORR} = W_0 \cdot FCU \cdot \frac{P}{1{,}03} \cdot \frac{\sqrt{T}}{\sqrt{288}} \tag{8}$$

Where: PCI_{PROJ} is inferior calorific power used by the manufacturer, P is the atmosphere pressure, T is the environment temperature, and FCU is a unit conversion factor, related to the relative humidity (UR), as in (9).

$$FCU = 1{,}01715 - 2{,}85856 * 10^{-4} \cdot (UR) \tag{9}$$

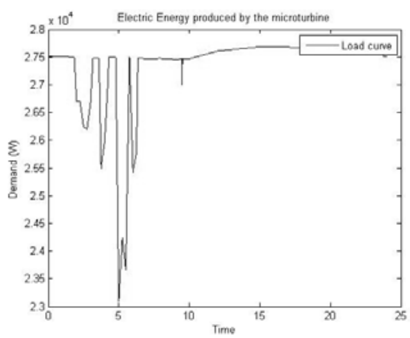
VI. Simulation Results

The model was built using MATLAB Simulink®. An ODE 45 solver and a relative tolerance as 1e-3 are chosen.

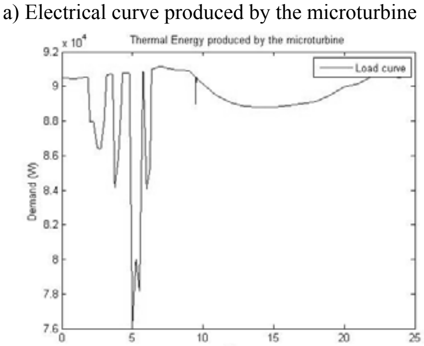
Configuration 1:

Initial results are shown in the Fig. 3. The Fig. 3a the electrical curve produced by the microturbine according to the environment conditions. The deficit is supplied by the grid, and it is showed by the Fig.3c. Fig.3b illustrates the thermal curve produced by the microturbine according to the environment conditions, the thermal energy is totally supplied by the cogeneration system.

In this configuration it was used parameters from a microturbine model 330 Capstone with a rated power of 28 kW.



a) Electrical curve produced by the microturbine



b) Thermal curve produced by the microturbine

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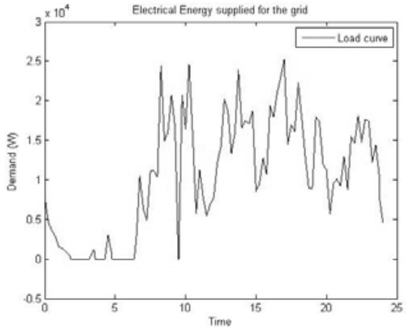


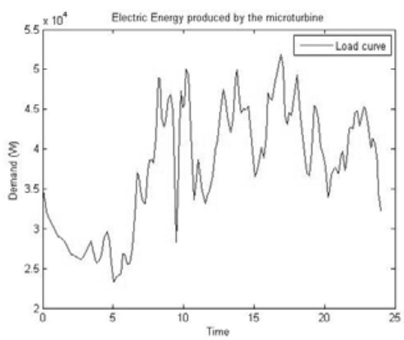
c) Deficit on the electrical power (in this case it will be necessary to buy grid electriciyt

Fig. 3. Microturbine 30 kW – simulation results

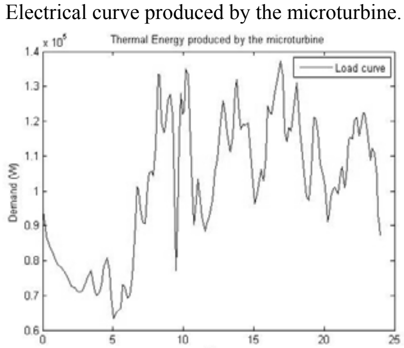
It is important to compare the Fig. 3.a and the Fig. 2.c, the microturbine works at full load in a good part of the day. The thermal was completed attended.

Configuration 2:

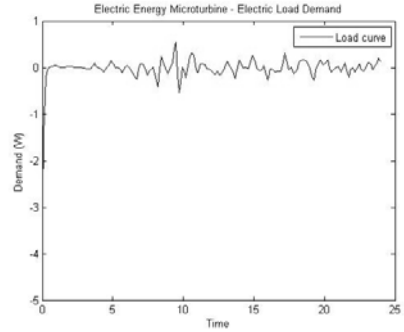
Initial results are shown in the Fig. 4. In Fig. 4a the electrical curve produced by the microturbine according to the environment conditions. The deficit is supplied by the grid, and it is showed by the Fig. 4c. Fig. 4b illustrates the thermal curve produced by the microturbine according to the environment conditions; the thermal energy is totally supplied by the cogeneration system.



a) Electrical curve produced by the microturbine.



b) Thermal curve produced by the microturbine



c) (electric energy supplied for the microturbine – electric load demand)

Fig. 4. Microturbine 60 kW – simulation results

In this configuration, it was used a microturbine Capstone model with a rated power of 60 kW. Comparing Fig. 2c and Fig.4a, the electric load is attended, the difference between the two is seeing in Fig. 4c, and it is less than 1W.

VII. CONCLUSION

In the paper, the authors have investigated the natural gas based microturbine of residential complex with Matlab. The residential electric curve was the base to separate electric and thermal load, and therefore the thermal and the electric curve were accomplished. The microturbine was simulated in the environment conditions.

In the first configuration, the thermal demand curve was completely supplied by the microturbine; on the other hand, it was necessary to buy electricity from the grid because the microturbine could not supply the whole electric demand of the building.

On the second configuration, the electric curve was fully supplied by the microturbine; on the other hand, an exceeding thermal energy is wasted to the atmosphere.

Therefore, the results from this work may be useful as a decision support system by investors. The investor will evaluate the best option between these two configurations, and for that, it will be necessary to make an economical analyze, considering the investment, operation and maintenance cost of the microturbine and the price of the electricity supplied for the grid. With the economical analyze in hands, the best configuration will choose.

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