# GAS TURBINE SELECTION IN COGENERATION SYSTEM APPLIED IN OFFSHORE PLATFORMS

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***Abstract.*** *In Offshore Platform cogeneration systems are used for simultaneous generation of electricuty and heat in order to assist to the demands of the utility and process plants. The use of these systems is crescentily more knowledged, particularly, in atual energy saving context.*
*In these production units, electric generation and electric consumption are significant and the thermal energy has great importance, particularly in the process of separation of the oil, water and gas from the well. Software especially developed to perform the thermal economical analysis is able to evaluate cogeneration systems for some types of platforms.*
*In previous work were only considered the mean and maximum thermal and electric demands. In this paper, the analysis is also based on the annual evaluation of the demand curve obtained from the curve of expected production of the platform. Analysis of real case is presented and the results are compared with previous work.*

***Key Words****: Cogeneration, Offshore Platforms, Thermo-economical analysis, Petroleum*

## 1. Introduction

Cogeneration systems are based on utilization of the same fuel generating simultaneously electric and thermal energy. In these systems, the inefficiency in the electric generation, for example, is in some way "supplied" with the thermal energy production. This characteristic is particularly important in a context of great use in both types of energy.

In Offshore Units, the low cost of the natural gas and its availability do attractive its use. The observed continuous fire in the platforms flares is noticeable. This "in excess" natural gas is resulting from the existent unbalance between supply and demand and is bad energy use. The demand is divided in parts: injection in the well, export through gas pipelines and use in fuel gas form.

The availability of the natural gas can be shown by the world reservations proven that totaled 143 trillion $m^3$ in 1999. Among this total, 403 billion are in the Brazilian lands, being 151 billion $m^3$ onshore and 252 billion offshore.

While in previous work, Monteiro et al presents methodology for cogeneration system, in this paper thermal and electric platforms demands influences on system selection is discussed. Figure 1 shows a petroleum production unit. Several machines and equipments are observed. The generation and consumption of the electric and thermal power occur in great scale.

Figure 1. Offshore Platform Overview

## 2. Offshore Platform Energetic Characteristcs

Figure 2 presents a flowchart containing the main processes for which oil (with water and gas included) is submitted. It is important in energetic platform characteristics comprehension because shows thermal and electrical consumers.

The mixture comes from the well and after some processes the oil and gas are produced. The gas turbines (turbo-generator) are responsible for the electric energy generation and through the use of the exhaust gas energy in boilers (Heat Recovery Steam Generator) thermal energy is produced.

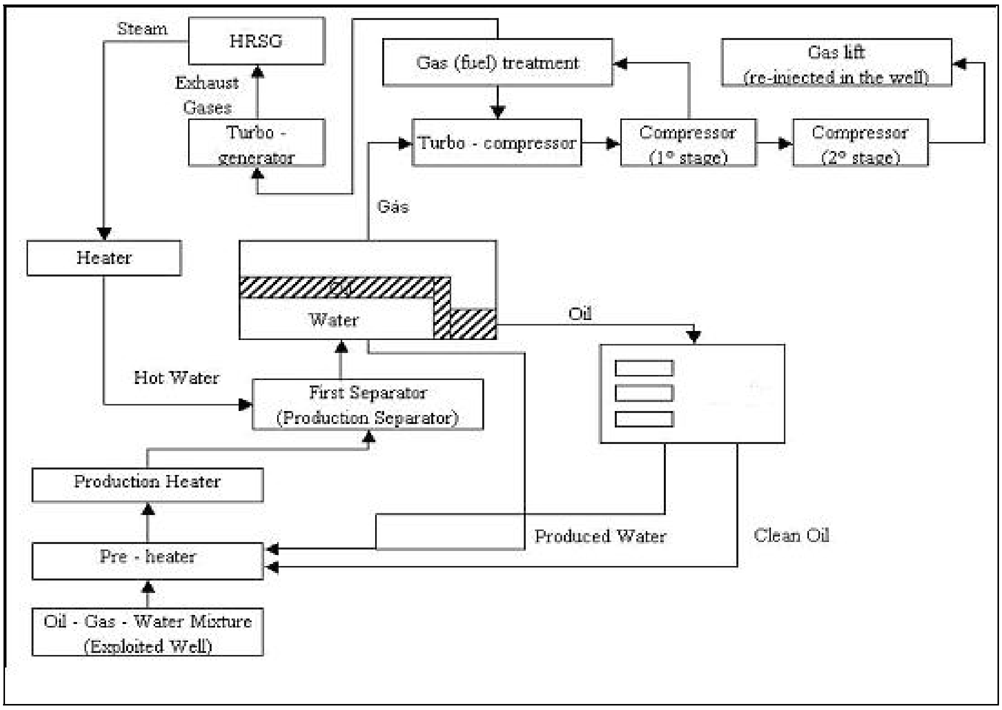


Figure 2. Typical Production Processes in Offshore Platforms

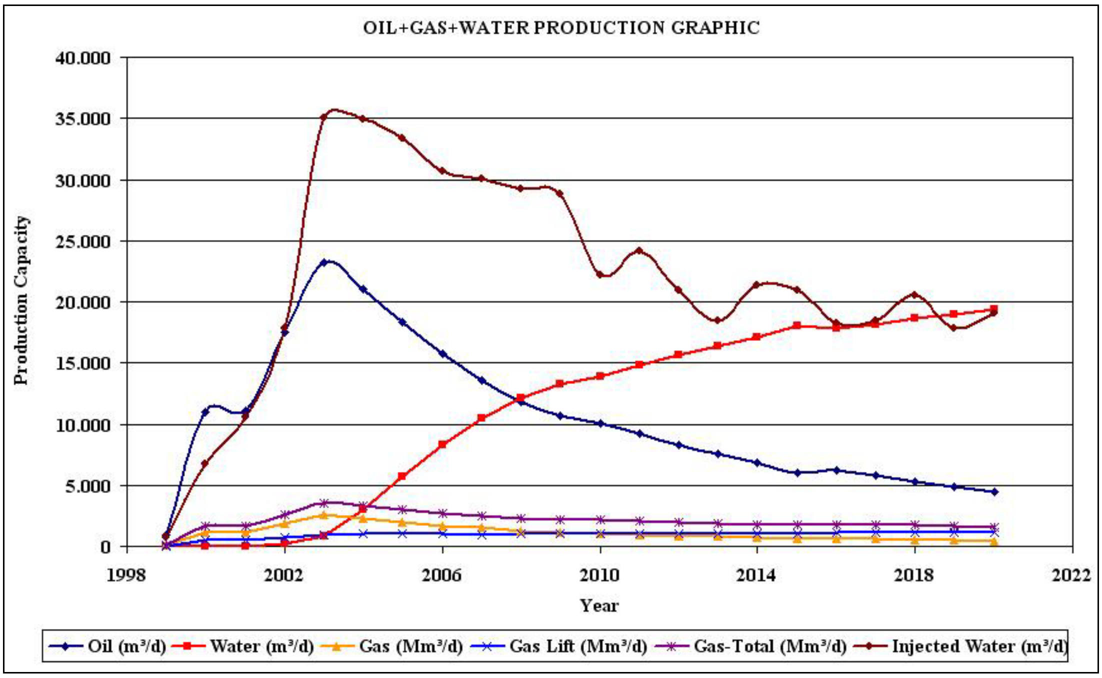


Figure 3. Production Curves of Offshore Unit

In a general way, the need of water and / or gas injection in an oil well is crescent with the time. In first stage of the production, the wells present enough pressure and the production happens without great injection need. Along the time, pumps and compressors utilization are necessary for water and gas injection, respectively. The driving of these machines (in energy levels every time larger) causes an increase of the electric energy consumption until a certain year of production. Later, there is a production fall due to the natural process of exhaustion of the well and, consequently, there is a decrease of the electric energy consumption. Figure 3 shows the production curve during the useful life of the platform used as example in this paper.

## 2.1. Electric Demand Analysis

The thermal and electric profiles are of fundamental importance for the definition of the appropriate equipments in order to operate in cogeneration system. This way, the demand curves must be available, including the operational conditions more critical (loading and off-loading, for example) in which is possible to identify consumption peaks.

In the cogeneration systems analysis for offshore platforms, the following considerations must be observed:

1. The total demands of thermal and electric energy of the Platform must be supplied by the cogeneration system, except in the final of the useful life of the platform, when petroleum production is reduced;
2. Priority service of the electric power;
3. The thermal and electric demands are directly related to the production of the platform (barrels / day);
4. GT+HRSG use is the most suitable option for production units of petroleum with great thermal and electric demands;
5. The system is projected to assist to the electric demand peak, but it operates very probably, with its maximum efficiency in a medium demand;
6. Use of hot water instead of steam in order to heat the petroleum, before the first separator of the Process Plant (Figure 2), however the water is heated by saturated steam generated in the HRSG;
7. The natural gas is used in gas turbines after treatment in small systems placed in the Process Plant;
8. Alternatively, the gas turbines burns diesel oil, in case of stop of production of the platform;
9. Possible use of thermal energy "in excess" for production of cold (using absorption systems) or reduction of the air inlet temperature of the turbines in order to increase of efficiency of the machines;

Figure 4 shows the curve of the thermal demand along the useful life of the platform.

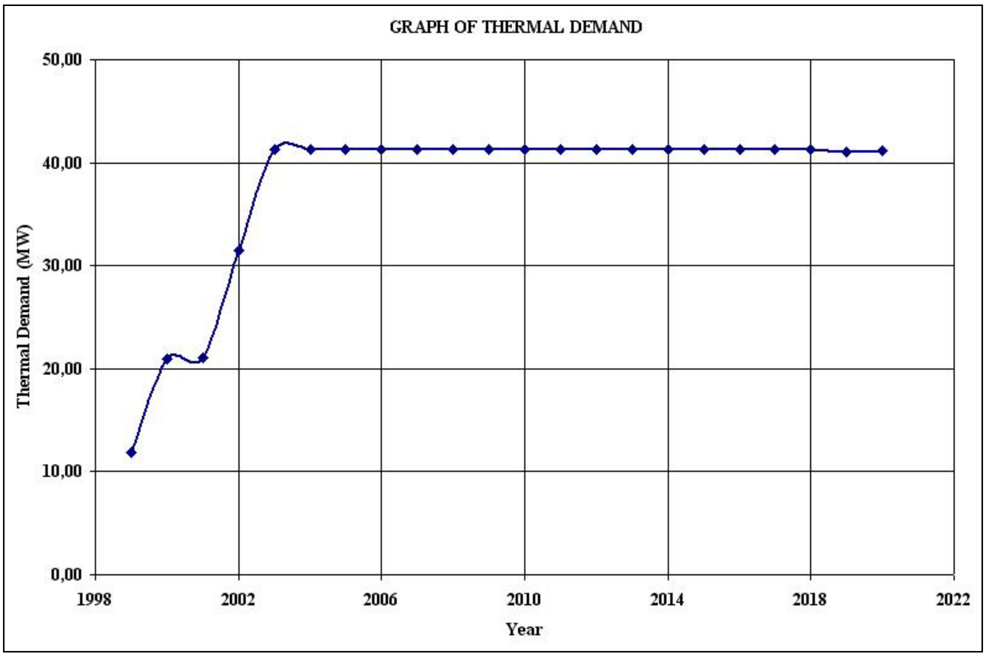


Figure 4. Thermal Demand Curve of Offshore Platform

### 2.1. Mean and Anual Demands

Since the cogeneration system supplies before to the electric demand, the selection of the gas turbine and the costs of the electricity and of the saturated steam will depend on the methodology adopted to evaluate the demand curve. In this paper, two different methodologies will be used to extract necessary information in order to perform thermal and economic analysis.

First Methodology: Consists in to consider that the gas turbine will supply, along the useful life, a medium demand of energy (operational point). Although assisting to the maximum and minimum demands, the gas turbine is projected to present maximum efficiency in the operational point. This way the fuel consumption (and consequently the fuel costs) is constant along the useful life.

The mean value can be calculated in two ways (Montgomery, Runger, 1999). The first is an average of samples, according to the eq. (1).

$$\bar{x} = \frac{1}{n}\sum x_n \tag{1}$$

The second ( eq. 2), through a model of probability, where f(x) it is the function density of probability.

$$\mu = \sum_x x \cdot f(x) \tag{2}$$

In both equations "x" represents the known values of the demand and f(x) can be obtained from a histogram.

Figure 5 presents the curve of electric demand and the operational point corresponding to the medium demand.

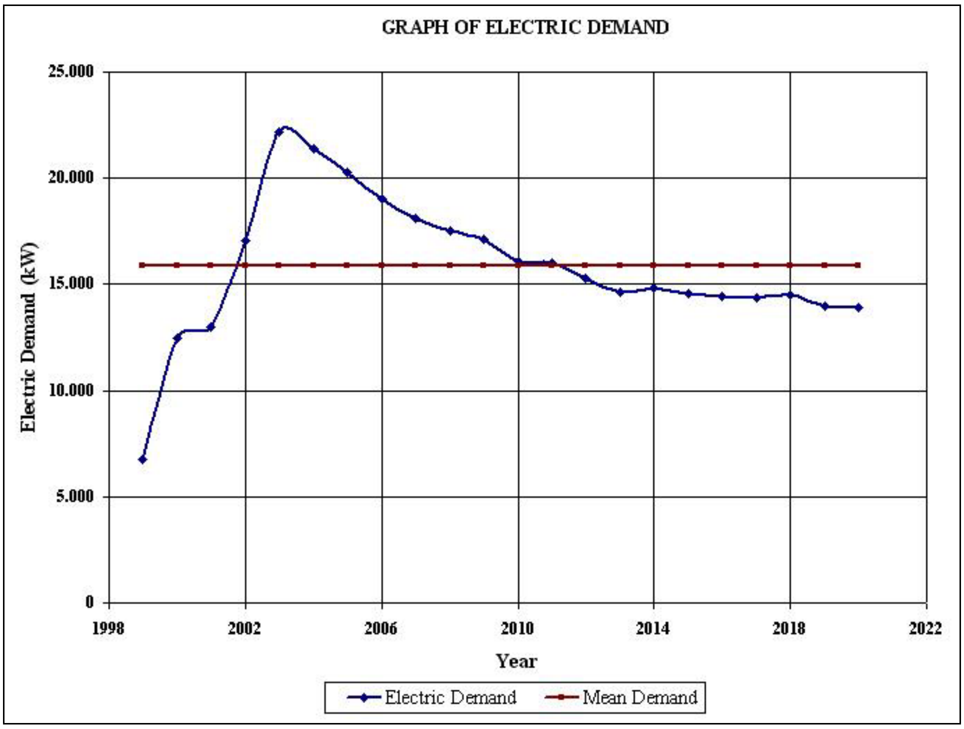


Figure 5. Electric Demand Curve of Offshore Platform

Second Methodology: Represents another case where instead of defining a medium demand, the gas turbine would assist to the peak of the electric demand in each year, in agreement with figure 5. Then, the fuel consumption changes annually and the final result can be presented in terms of the medium and / or maximum efficiency of the cogeneration system, of the medium and / or maximum costs of the products, etc. In this example an annual analysis of the electric demand was used, but the analysis of the curve of demand monthly, weekly or daily is not excluded.

## 3. Gas Turbines and HRSG Selection

The cogeneration system selection using gas turbines and HRSG follows the steps:

1. For each gas turbine available in database, the produced power is calculated being considered the local conditions of operation, being only selected the alternatives that supply to the maximum demand of electricity;
2. The saturated steam production from the exhaustion gases is calculated. Supplementary burns of fuel is allowed (when necessary) to assist to the thermal demand;
3. Exhaust gas boiler that supply to the thermal demand is selected;
4. Exergetic Analysis of the selected groups (TG+CR) is performed;
5. Economical analysis for the selected groups is performed, without forgetting that there will always be one gas turbine and one exhaust gas boiler in stand-by;
6. Thermal-economical analysis is performed, being selected the equipments that take at the smallest total cost of the products (electricity and saturated steam);

For the equipments selected in the item 6, the technical data will be presented (including equipment type, manufacturer, fuel consumption, operational efficiency of the gas turbines, cogeneration system efficiency) and economic factors (initial cost estimation, fuel cost, operational cost and maintenance cost, electricity and steam costs).

The methodologies of exergetic, economical and thermo-economical analysis used in the equipments selection were presented in Monteiro et al. (2004).

The figure 6 shows the sketch of the GT+HRSG (Gas Turbine + Heat Recovery Steam Generator) cogeneration system.

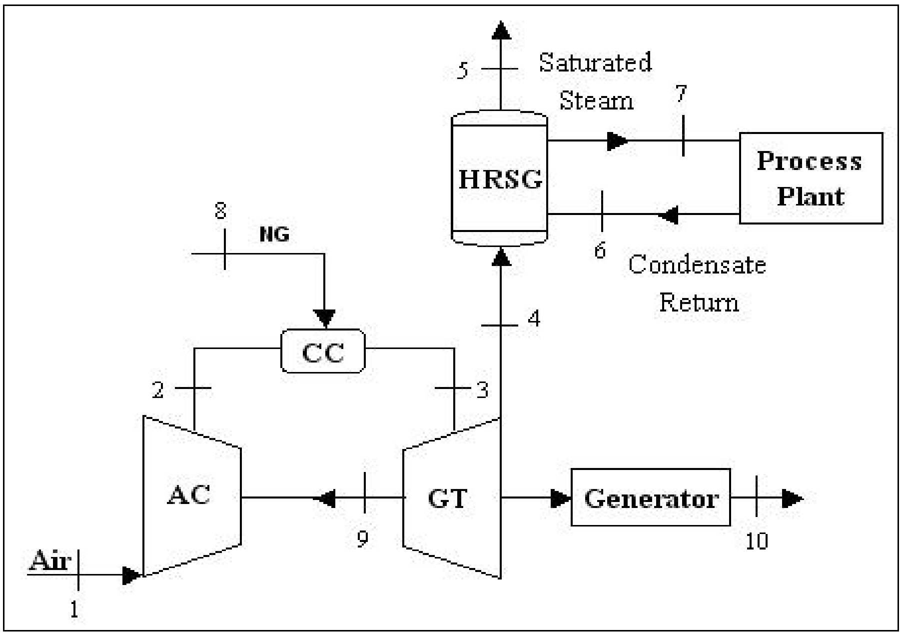


Figure 6. Cogeneration System: Gas Turbine + HRSG

## 4. Pratical Case: Semi-submersible Offshore Platform

Since the principal objective of this study is to demonstrate the curve of the electric demand influence in the selection of the gas turbine and in the cost formation of the products, the case study presents the obtained solutions when is considered each one of the methodologies of analysis of the demand curve: *Methodology 1* (Medium Demand Analysis) and *Methodology 2* (Annual Variable Demand Analysis)

The software was developed in the graphic interface ambient (LabVIEW ®) and it is resultant of the application of the method of the exergetic cost (BEJAN et al., 1996) in the selection of the gas turbines and HRSG to operate in the cogeneration system.

The table 1 presents the input data to perform of the thermo-economical analysis of the cogeneration system. The values of the demands presented in the table were obtained through the analyses of the respective curves.

Table 1. Offshore Platform Input Data

| **Operational Conditions** | **Input Data** |
|---|---|
| Maximum Electric Demand | 22.160 kW |
| Mean Electric Demand | 15.847 kW |
| Maximum Thermal Demand | 41.300 kW |
| Continuous Operation Time | 8760 hours by year |
| **Ambient Conditions** | |
| Pressure | 1,013 bar |
| Temperature | 35 °C |
| Relative Humidity | 80 % |
| **Economical Factors** | |
| Project Useful Life | 20 years |
| Tax Rate | 12 % by year |
| Natural Gas Production Cost | 0,03 US$/$m^3$ |

The figure 7 presents the input data software module that allows performing a thermo-economical analysis of the system based on a medium demand along the useful life (Methodology 1) or in a demand that varies annually (Methodology 2).

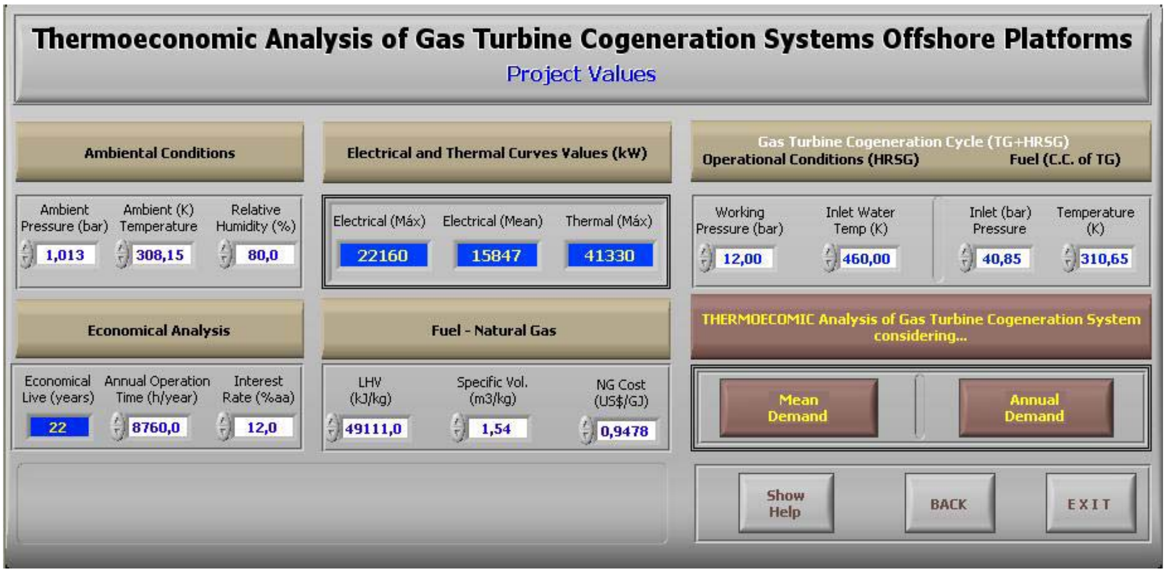


Figure 7. Project Values Input

Figure 8 presents the results for the operational conditions of the equipments selected by the analysis based on the medium demand (Methodology 1). The gas turbine selected would be a 25200 kW ROLLS-ROYCE type, model RB211-6556.

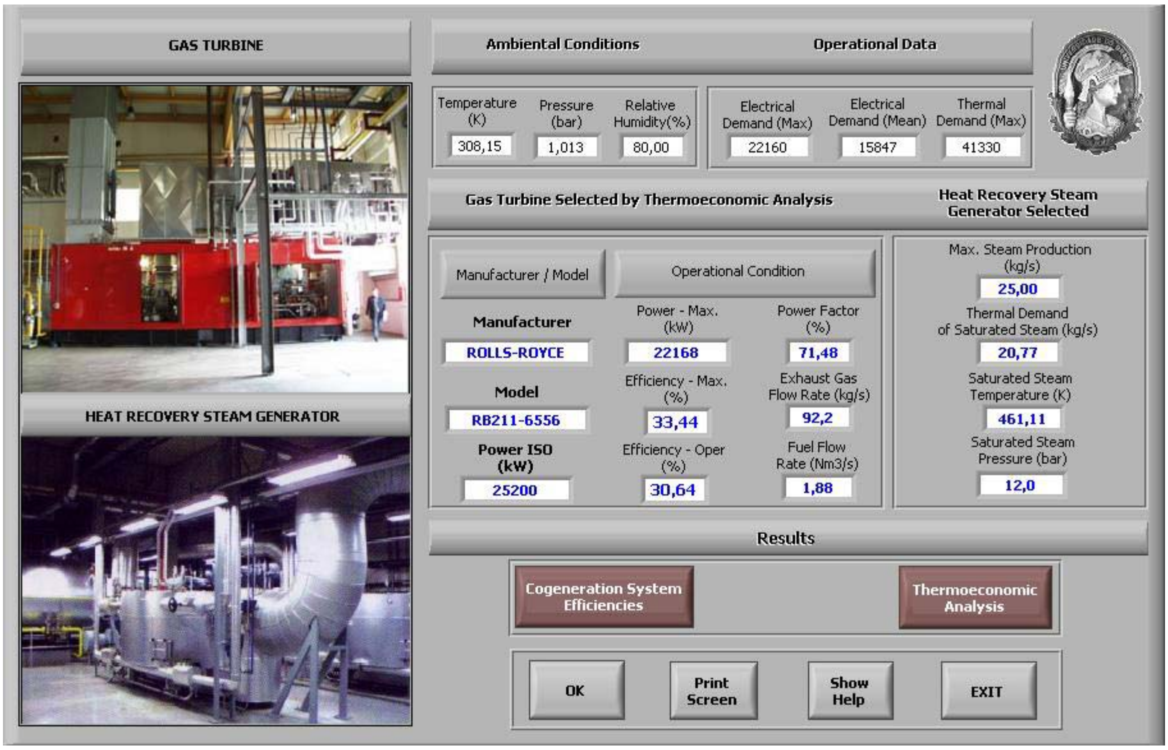


Figure 8. TG+HRSG Operational Data – Medium Demand (Methodology 1)

Figure 9 presents the result of the thermo-economical analysis for the medium demand example. The total cost of the products was of 245.1 US$/h. In this case, 129.78 US$/h corresponds to the saturated steam and 115.27 US$/h to the electricity.

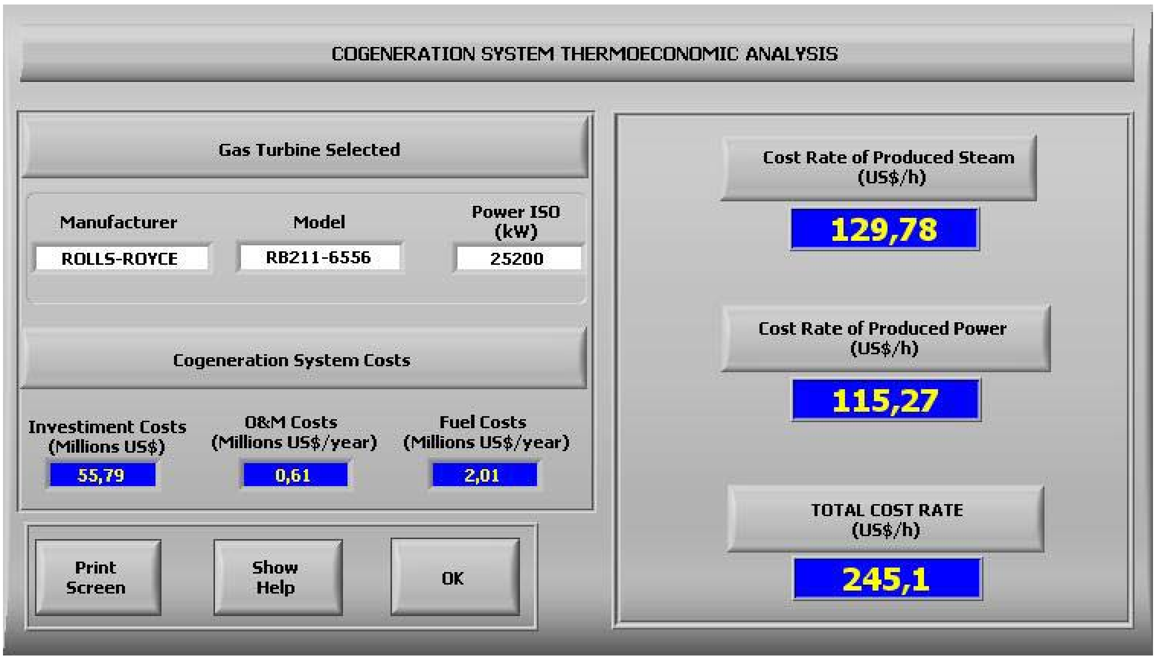


Figure 9. Thermo-Economical Analysis – Medium Demand (Methodology 1)

Figure 10 presents the results for the operational conditions of the selected equipments by the annual analysis of the electric demand curve (Methodology 2). The selected Gas Turbine was 29100 kW ALSTON GT 10C type. When in operation, the energy efficiency of the cogeneration system is 92.91%, while the exergetic efficiency is 46.69%. In this case, an average efficiency is calculated since these vary annually with the demand.

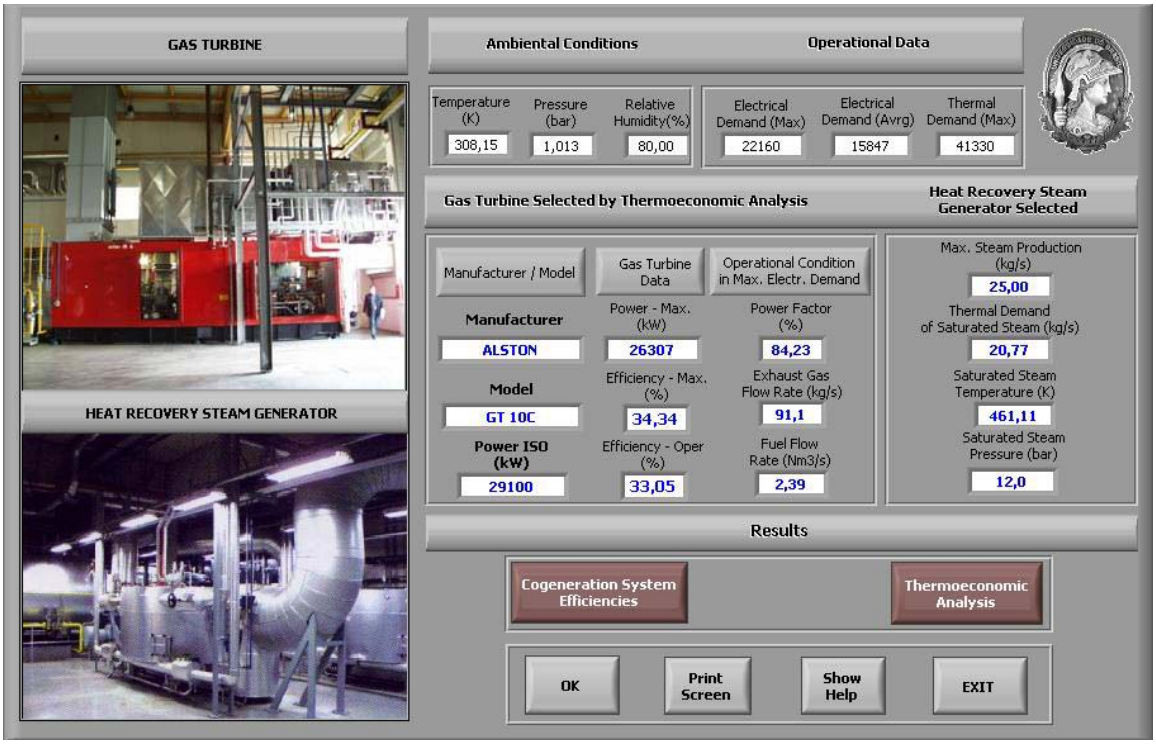


Figure 10. TG+HRSG – Annual Demand (Methodology 2)

Figure 11 presents the result of the thermo-economical analysis for the annual evaluation of the demand curve. The total cost of the products was of 226.1 US$/h. In this case, 125.53 US$/h corresponds to the saturated steam and 100.61 US$/h to the electricity, being considered the medium costs along the useful life.

The largest obtained costs were 282.5 US$/h for the total cost, 139.61 US$/h for the saturated steam and 142.86 US$/h for the electricity cost.

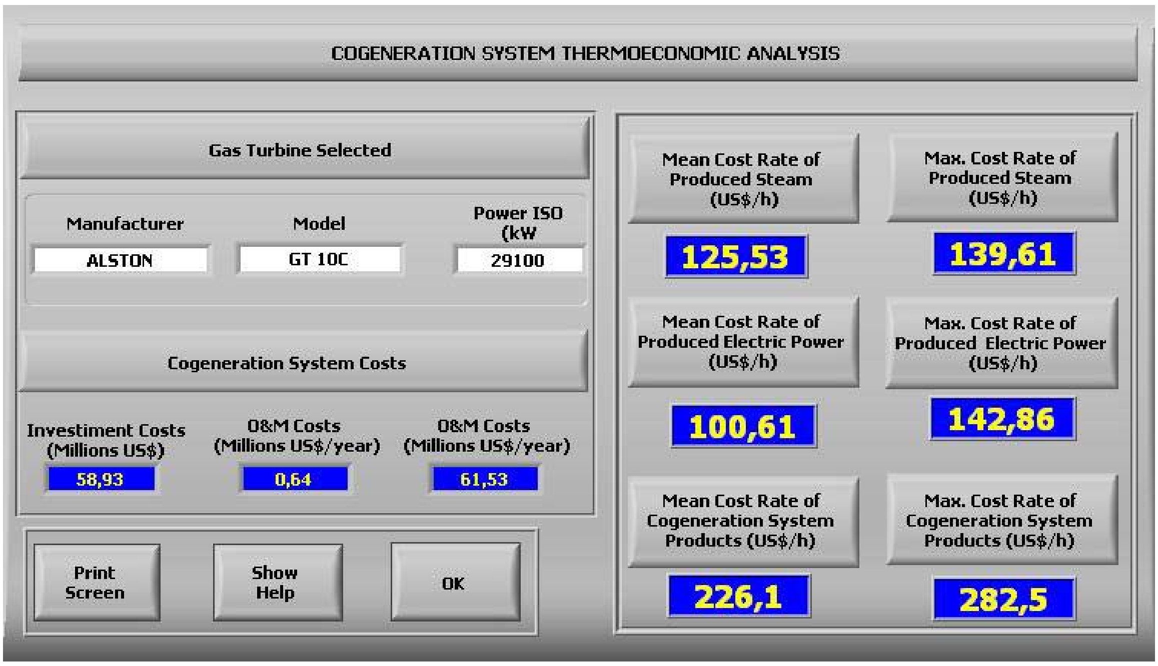


Figure 11. Thermo-Economical Results for Selected Cogeneration System – Annual Demand

The table 2 resumes the products costs obtained by application of the two methodologies.

Table 2: Thermo-Economical Results

| **Item** | **Products Costs (US$/h)** | | | |
|---|---|---|---|---|
| | **Medium Demand** | **Annual Demand** | | |
| | | *Minimum Values* | *Medium Values* | *Maximum Values* |
| **Steam** | 129.78 | 107.77 | 125.53 | 139.61 |
| **Electricity** | 115.27 | 42.62 | 100.61 | 142.86 |
| **Total** | **245.1** | **150.45** | **226.1** | **282.5** |

## 6. Conclusion

The analysis considering annual demand variation provides more information for decisions of the cogeneration system and of the process of formation of the steam and electricity costs during the useful life of the project.

When is considered the mean demand, the costs are calculated being considered that the gas turbine will operate in mean demand. Since is considered that the gas turbine will supply to the maximum demand, then it will operate in part load during all production period. Therefore, it is obtained a single value for the costs.

However, when the average of the costs of the products is obtained (annual demand) and compared with the costs obtained for the mean demand, it can be verified that the difference between total costs is of 7.8%. The main responsible for this difference is the electricity cost that is 14.6% smaller, favorable for annual demand analysis.

The largest costs of the cogeneration system occur in maximum electric and thermal demands and this happens in the fifth year of operation (figures 4 and 5). In this case, the largest difference is due to the costs of electricity (19.3%).

This paper considers the analysis of the demand curve influence in the cogeneration system evaluation. Considered only the medium values of the costs obtained for each method the difference between the costs (steam + electricity) is 166.000 US$/year. This represents US$ 3.661.680 during the useful life of the Platform in approximately 22 years.

## 7. References

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## 8. Responsibility notice

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