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Article

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A Complete Prefeasibility Evaluation of On-Site Energy Generation Systems

Gonzalo Romero García[1]*, Dora Villada Castillo[2], Jhan Piero Rojas[3]

[1]Department of Mechanical Engineer, Faculty of Engineering, Universidad Francisco de Paula Santander, Norte de Santander, Colombia, [2]Department of Agro-industrial Engineer, Faculty of Engineering, Universidad Francisco de Paula Santander, Norte de Santander, Colombia, [3]Department of Civil Engineer, Faculty of Engineering, Universidad Francisco de Paula Santander, Norte de Santander, Colombia. *Email: gonzalodelacruzrg@ufps.edu.co

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ABSTRACT

The recent global concern to mitigate the ecological impact on energy production has promoted the search for alternatives that allow a better use of resources. In this panorama, the cogeneration process appears as a solution seen with good eyes thanks to its great efficiency, which is why many institutions and companies have opted for the transition from the traditional system of energy production to cogeneration. This article develops the selection of the best alternative among different suppliers to implement a cogeneration system in an energy production plant, taking into account economic factors, selecting the one that represents the greatest profitability in the shortest time.

Keywords: Cogeneration, Internal Rate of Return, Net Present Value
JEL Classification: Q42

1. INTRODUCTION

Cogeneration is an energy-efficient technology for generating energy and heat (Vukašinović et al., 2016), defined as concurrent production in a process of conversion of sequential energy, mechanical energy, electrical (power) and useful thermal energy (heat) (Lozano and Ramos, 2010). A cogeneration plant could have an efficiency of more than 90%, which is much higher compared to conventional systems (Onovwiona and Ugursal, 2006).

Energy efficiency has become a major benchmark in mitigating climate change and reducing the cost of energy production (Hernández-Santoyo and Sánchez-Cifuentes, 2003). Due to the benefits of cogeneration, organizations such as the European Union have promoted guidelines to increase their implementation with the aim of increasing energy efficiency and primary energy savings (Frangopoulos, 2012).

Choosing the best alternative among different distributors in order to achieve a better relationship between the cost of implementing the technology and its future efficiency is of vital importance in the design process (Frangopoulos, 2012), is for this reason that studies approach the issue from the perspective of methodological guidelines for the selection of cogeneration schemes in the process industry using Pinch technology for example (Tovar and Balbis, 2007).

Cogeneration systems must be designed and constructed in terms of primary energy efficiency and savings for the purpose of being eligible for economic and financial benefits, accompanied by the amount of electricity generated and useful heat. All these parameters are fundamental to the economic sustainability of the system (Lund and Andersen, 2005). In order to obtain greater energy savings along with greater profitability in the construction of cogeneration systems, attention must be paid to plant dimensioning and operational strategies. These factors can be solved by complex numerical optimization programs (Lozano, 2001; Yokoyama et al., 1994; Manne, 1985), energy equilibrium models (Araújo and da Silva, 2010; Nagurney, 1987), economic models (Daniel and Goldberg, 1981; Wu and Fuller, 1995; Samuelson, 1983) or by analytical approximation (Heteu et al., 2002; Lucas, 2000). Despite the numerous criteria available, the most commonly used criteria for determining whether to reject or accept a project have been the net present value (NPV) and internal rate of return (IRR) that are used in this article, because they link and furthermore allow for the easy implementation of selection steps that are based on the technical and economic part as a whole, commonly known as thermo-economy (Frangopoulos, 1994; Tsatsaronis, 1993; da Gama Cerqueira and Nebra, 1999; Temir and Bilge 2004).

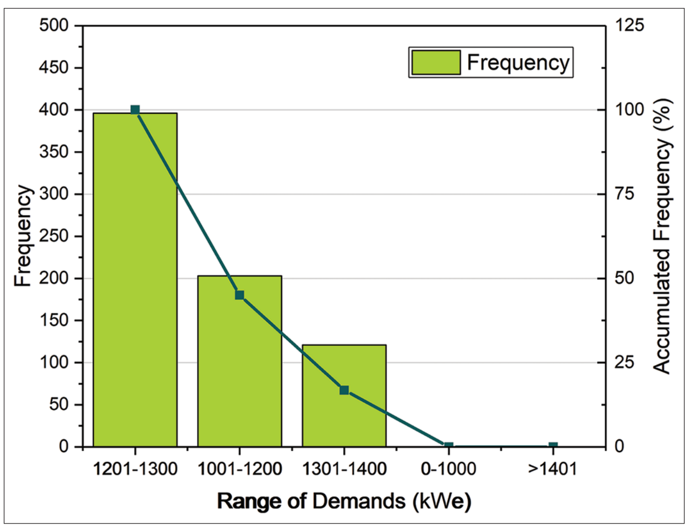
The projection over time of the implementation of a cogeneration system has a great influence on your choice, since these systems must have a large number of annual working hours to be profitable because a cogeneration system is normally measured in terms of its efficiency, availability, reliability, emissions and maintenance costs (Onovwiona and Ugursal, 2006; Cardona and Piacentino, 2003). If the utilization factor for cogeneration modules is high, greater savings and shorter payback times are achieved (Lozano and Ramos, 2010).

In this article, three alternatives were evaluated for the implementation of a cogeneration plant for energy supply and heat generation. These three alternatives were subjected to technical and economic study and the most viable option was chosen in a shorter time under the selected criteria.

2. METHODOLOGY

Based on the information collected on electricity consumption and demand (July and August) and comparing it with the growth plans for the next months and years of the cogeneration plant of electric and thermal energy in the form of steam, enabled to operate in synchronism with the public distribution network, the graph in Figure 1 was drawn up, which groups electricity demands by means of a histogram of frequencies.

Figure 1: Demand frequency analysis



The viability of a project of this type is based between the identified solution schemes and the electromechanical systems present. Factors such as fuel type, compatibility of heat/electricity ratio (Q/E) of demand and thermal engine, service availability, investment and operating costs.

Taking the data from Table 1 as a reference and taking into account that the maximum Q/E ratio (max thermal Dem/Dem max electrical) is approximately 1.6, it can be seen that according to this criterion the Internal Combustion Engine Technology (MCI) is the most suitable to supply the system needs.

Table 1: Cogeneration technologies according to Q/E ratio

Item	Characteristics
<2	Internal Combustion Engine
2–4.5	Gas turbine
>4	Steam turbine

To complement the reasons for selecting the ICE technology, additional factors such as equipment market supply, number of local suppliers, availability of equipment and delivery times and the possibility of using the open-loop system with

Table 2: General comparison of alternatives

Alternative	Base case	Alt I	Alt II	Alt II
Electricity generation				
Manufacturer	-	Waukesha	Jenbacher	Cummins
Motor-generator model	-	APG1000	JMS 320	QSK-60G
Installed capacity (kWe)	-	1.100	1.050	1.400
Available capacity (kWe)(1)	-	1.080	1.030	1.380
Generating production (kWh/month)	-	764.000	691.000	831.000
Purchase network or backup (kWh/month)	903.000	139.000	212.000	72.000
Gas consumption generation (m^3/month)	-	223.000	203.000	270.000
Thermal energy generation (steam)				
Boiler coal consumption (kg/month)	180.000	121.831	114.734	101.571
Consumption of natural gas boiler (m^3/month)(2)	105.801	76.610	67.439	59.702
Production steam generated (lb/h)	4.473	3.028	2.851	2.524
Cogenerated steam production (lb/h)	-	1.446	1.622	1.949

(1)Subtracted 20 kWe of self-consumption. (2)Estimated natural gas consumption for steam generation. It is currently made with coal the highest possible electrical efficiency for a long time are analyzed.

A cogeneration process is chosen based on the analysis of the data collected during the first stage of the study. The cogeneration process satisfies electrical and thermal needs by producing steam using the exhaust gases of the motor generator using a recovery boiler.

Table 3: Economic evaluation components and characteristics

Item	Characteristics
Investment	• Basic and detailed engineering studies • Main equipments (Motogenerator and Heat recovery system), auxiliary and the required connections • Assembly and start-up: civil, mechanical, electrical and instrumentation works • Nationalization, insurance and taxes • Natural gas supply • Team tests. Commissioning and Start up • Supervision of works • The system of administration, maneuvering, and control of sources (synchronism) • Equipment for sending information to the Network Operator • Application of tax benefits (law 1111 of 2006)
Operation	• Manpower of technicians and specialists with a permanent presence on site • Project management
Fuel	• Natural gas for electricity generation • Coal for steam generation in the base case • The missing steam is analyzed under the coal and natural gas use schemes
Maintenance	• Preventive and corrective • Change and replacement of consumables (oils and refrigerant). Change of parts • Major repairs (overhaul) • Other activities required to guarantee the useful life of the equipment
Others	• Coverage in the event of unforeseen events, service fees, applicable taxes, etc.
Evaluation period	• 10 years
Financial & other	• Discount rate: 15.0% ac • Annual projections for CPI (3.7% annual average), IPP USA (1.33% annual average) along the project horizon, according to publications from financial institutions • TRM: $ 2,200/US$ fixed on the project horizon • No financing

Unsatisfied electrical energy will be covered with the purchase of energy from the grid. In case of thermal insufficiency, it will be covered using the existing generation system (coal boiler in operation or natural gas boiler).

Three alternatives of cogeneration systems with equipment from different manufacturers with similar capacities were evaluated. The differences between these alternatives are in efficiency, investment cost, maintenance periods and costs, fuel consumption, system availability and purchase of energy in the network.

Table 2 shows a general comparison of some characteristics of each alternative.

Table 3 shows the main aspects considered in the analysis of the economic proposals for the selected alternatives.

To calculate the economic feasibility of the proposed alternatives, the criteria of net present value (NPV) and internal rate of return (IRR) were used, the respective formulas are shown in (1) and (2).

$$NPV = -I + \sum_{i=1}^{n} \frac{Q_i}{(1+TI)^i} \quad (1)$$

Where I is the initial investment, Q_i the calculated cash flow or profit, n the number of years and IT the interest rate.

$$NPV = -I + \sum_{i=1}^{n} \frac{Q_i}{(1+IRR)^i} \quad (2)$$

Where IRR is cleared by equating the NPV to zero.

3. RESULTS AND DISCUSSION

3.1. Missing Coal Steam Generation

Table 4 presents the summary of the results of the evaluation carried out taking into account the Annual Cost Equivalent (ACE) of the three pre-selected alternatives, comparing them with the current scheme of buying energy from the grid and generating missing steam with coal.

Table 4: Annual cost equivalent for alternatives

Concepts	Base case	Alt I Waukesha	Alt II Jenbacher	Alt II Cummins
Gas consumption Moto generator (US$)	-	246.040	225.712	300.525
Electricity Network (US$)	679.596	91.347	135.213	42.552
Backup Contract Fee (US$)	-	4.897	4.896	4.897
Street Lighting (US$)	-	5.516	7.952	2.896
Environmental Impact Charge (US$)	-	5.560	5.076	6.099
Operation and Maintenance (US$)	-	85.840	100.540	113.655
Other - Interruptions (US$)	2.612	-	-	-
Coal Steam Generation (US$)	76.154	50.676	48.542	42.973
Operation and Maintenance Cogen System (US$)	-	6.474	6.474	6.474
Total, ACE (US$)	758.362	496.350	534.406	520.071

Table 5: NPV & IRR values for alternatives

Concepts	Alt I Waukesha	Alt II Jenbacher	Alt II Cummins
NPV Analysis			
NPV @ 3 Years (US$)	–172.397	–210.377	–232.913
NPV @ 5 Years (US$)	278.038	87.710	150.466
NPV @ 8 Years (US$)	758.830	463.778	615.511
NPV @ 10 Years (US$)	1.001.594	733.123	861.629
IRR Analysis			
IRR @ 3 Years (US$)	5.96%	4.53%	2.92%
IRR @ 5 Years (US$)	24.50%	18.15%	20.28%
IRR @ 8 Years (US$)	32.62%	26.74%	29.44%
IRR @ 10 Years (US$)	34.58%	29.75%	31.79%

Table 6: Annual cost equivalent (ACE) for alternatives

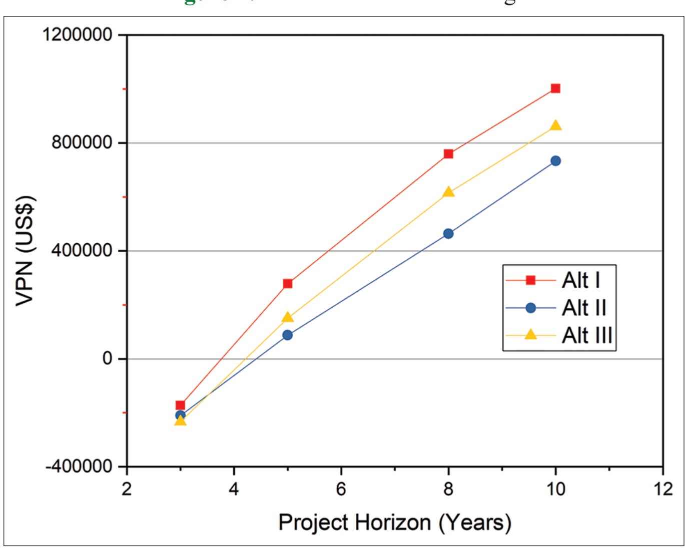
Concepts	Base case	Alt I Waukesha	Alt II Jenbacher	Alt II Cummins
Consumption Gas N. Equipment Generator (US$)	-	246.040	225.712	300.525
Electricity Network (US$)	679.596	91.347	135.213	42.552
Backup Contract Fee (US$)	-	4.897	4.896	4.897
Street Lighting (US$)	-	5.516	7.952	2.896
Environmental Impact Charge (US$)	-	5.560	5.076	6.099
Operation and Maintenance (US$)	-	85.840	100.540	113.655
Other - Interruptions (US$)	2.612	-	-	-
Fuel Steam Generation (US$)(3)	76.154	90.279	86.478	76.556
Operation and Maintenance CHP (US$)	-	6.474	6.474	6.474
Total, ACE (US$)	758.362	535.954	572.342	553.655

(3)Steam generation in the base case is coal-fired. The new scheme proposes natural gas for missing steam

Table 7: NPV and IRR values for alternatives

Concepts	Alt I Waukesha	Alt II Jenbacher	Alt II Cummins
NPV Analysis			
NPV @ 3 Years (US$)	–280.582	–310.006	–324.653
NPV @ 5 Years (US$)	115.054	–68.410	12.257
NPV @ 8 Years (US$)	533.064	247.512	424.056
NPV @ 10 Years (US$)	744.171	486.540	643.335
IRR Analysis			
IRR @ 3 Years (US$)	–0.15%	–1.02%	–2.23%
IRR @ 5 Years (US$)	19.06%	12.45%	15.44%
IRR @ 8 Years (US$)	27.77%	21.57%	25.23%
IRR @ 10 Years (US$)	30.00%	25.13%	27.86%

Figure 2: NPV of investment savings



The financial evaluation of the alternatives yielded the data shown in Table 5 according to the net present value (NPV) of savings and the internal rate of return (IRR) criteria.

A graphical representation of the behaviors obtained in the NPV and IRR analyses shown in Table 5 is shown in Figures 2 and 3.

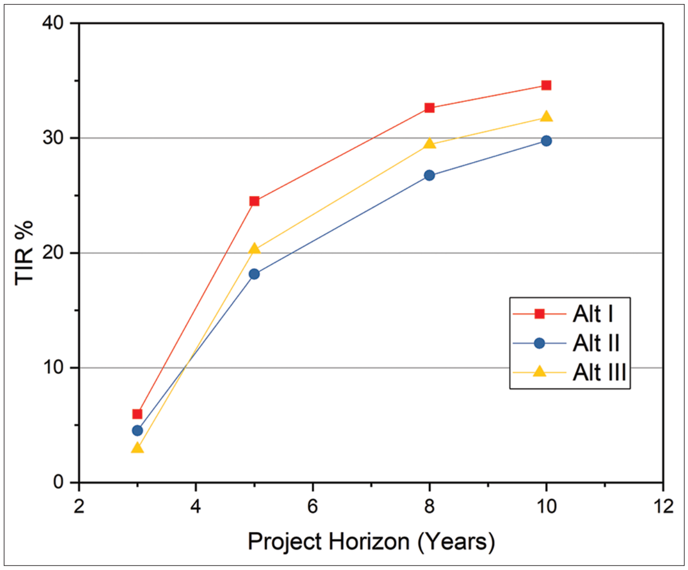
Where the Waukesha brand's alternative I show the most convenient results.

3.2. Missing Steam Generation with Natural Gas

The analysis of the cogeneration scheme with missing steam production using natural gas boilers presented the results indicated in Tables 6 and 7.

These results of missing steam production through the use of natural gas boilers were obtained using the evaluation criteria

Figure 3: Savings and investment IRR



of annual cost equivalent (ACE), net present value (NPV) and internal rate of return (IRR).

4. CONCLUSIONS AND RECOMMENDATIONS

After carrying out the pre-feasibility study to implement a cogeneration system in a power generation plant, it is concluded that due to the operating conditions and energy costs of natural gas, it is technically and economically feasible to implement the cogeneration system.

According to the analysis carried out taking into account the NPV and IRR criteria, the implementation of a cogeneration system for electric energy and steam with an additional steam generation with coal is presented as the best scenario compared to the production of additional steam with natural gas.

The nominal capacity of the pre-selected internal combustion engines must be in the range of 1000–1400 kWe, although a control system must always be in place to ensure synchronism with the public distribution network and cover 100% of the requirements. In cogeneration, the need for steam fluctuates between 30 and 40% of the total average hourly hours, forcing to always have generation systems for missing steam.

The annual cost equivalent (ACE) analysis showed that this indicator is at least 25% lower for any of the three alternatives versus the current system. The same proportion shows the difference between the indicators per kWh calculated in each case. Taking into account the NPV and IRR criteria for different years on the project horizon, they indicate that any of the three alternatives are financially viable for periods longer than 4 years. The Waukesha brand alternative is the one that shows the best figures.

Based on the results of the feasibility analysis, it is recommended that basic and detailed engineering studies be carried out, as well as optimizing the purchase, transport, and installation of components, applying and complying with the current technical standards for electrical and thermal installations and for the operation of the systems. On the other hand, it is recommended the logical and safe structuring of the control architecture of the system and the coordination of electrical and thermal protections, as well as the optimal installation and supervision of the works and monitoring of the changes that have occurred during the assembly. Training and evaluation of the operators of the implemented system and finally the correct application of the procedures and administration of the system maintenance operation.

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