European Association for the Development of Renewable Energies, Environment and Power Quality

International Conference on Renewable Energies and Power Quality (ICREPQ'11)

Las Palmas de Gran Canaria(Spain) 13-15 April, 2011

Energy Efficiency in Data Processing Centers:

TECHNICAL-ECONOMIC VIABILITY STUDY FOR A TRIGENERATION

Redondo Gil, Carlos (1) (2)

(1) Scientific Manager, **Castile and León Technological Center for Supercomputing (FCSC)**
Edificio CRAI-TIC, Campus de Vegazana s/n.
University of León. E-24071-León (Spain)
carlos.redondo@fcsc.es http://www.fcsc.es
(2) Electrical Engineering & Systems Engineering and Automatic Control Department
Faculty of Industrial and Computer Engineering, **University of León**. E-24071-León (Spain)
carlos.redondo.gil@unileon.es http://www.unileon.es

Fernández González, Alvaro (3)

(3) Administrative Financial Manager, **Castile and León Technological Center for Supercomputing (FCSC)**
Edificio CRAI-TIC, Campus de Vegazana s/n.
University of León. E-24071-León (Spain)
alvaro.fernandez@fcsc.es http://www.fcsc.es

Abstract

This article explores the case of the viability for a trigeneration system, consisting in the production of electricity to provide energy, in a Data Processing Center, both in economical terms and in environmental protection.

Furthermore it is analyzed the present and future situation of IT center energy consumption and associated environmental effects, and also looks at how state-of-the-art technology, correctly implemented, could ensure significant rationalization of data processing center energy consumption. The article will examine optimization techniques, specific problems and case studies.

KEY WORDS

Energy Management. Data Processing Centers.
Energy Efficiency. Trigeneration

1. Principles and antecedents of absorption cycle for refrigeration

The system of refrigeration for absorption is a way of producing cold, that, similar than systems of refrigeration for compression, use the heat generated by certain substances while changing from liquid to gas. Compression systems make the cycle using a compressor and the absorption system is based on the capacity of certain substances as lithium bromide to absorb other substances as steam of water through an interchanger of heat.

Microcogeneration systems are consolidating as an alternative solution to the progressive reduction of natural resources, because offer high energetic efficiency due to the centralized generation of heat and electricity, avoiding losses of Energy for reasons of transportation [1].

2. Device for Cycle of double effect water/ lithium bromide

The device of double effect water / lithium bromide lets a performance both in cold and hot conditions, as in described below [2].:

Working in cold condition:

Constructive items of a double effect device are the same that those of a simple effect device, just adding a low temperature generator.

The concentration of the substances is realized in two different stages (in terms of thermodynamics are different effects). First stage is similar than this of simple effect. Second stage consists on a concentration of substances inside the generator in a low temperature, that finally is sent to the absorption system.

Working in simultaneously:

The system lets produce simultaneously hot water (80/60 º C) and cold water (7/12 º C) adapting it everytime to the necessities of every season, so during the winter it produces hot water for heating, and using an interchanger it could produce cold water.

3. Energy management model (case study: Castile and León Technological Center for Supercomputing), antecedents

One of the most active non-profit making organizations, the Green Grid, has proposed a metric which is becoming the standard when measuring this type of efficiency. It comprises two different parameters, and two equivalent forms of measurement: **PUE** (*Power Usage Effectiveness*), that represents the total power consumed by the installation, divided by the power consumed by the

IT equipment and **DDCiE** (*Data Center Infrastructure Efficiency*), that is the opposite of PUE [3].

With energy efficiency in mind, the Castile and León Supercomputer Center has designed a server system which has not been adopted to date in similar facilities. Not only was the computer calculating power considered, but also an energy consumption objective which makes the Center the most energy efficient in Spain with a PUE equivalent to 1,2.

The Center's mission is to provide a central reference point for the application of the latest-state-of-the-art ideas and developments in these systems of renewable energy with high potential technically and economically [4,5,6].

3.1. Calculation Infrastructures

The heart of the Foundation is a super computation unit installed in the Center for CIT Resources for Learning and Research at the University of León. The unit contains the following features: Parallel computation cluster, Visualization cluster, Share memory system, Development nodes.

The Equipment described provides a calculating capacity of 30 Tflops, situating it in second place among all such centers in Spain[1], and among the top 150 worldwide[2].

The Center in León center has a 170 Kw capacity, for a calculating power of 33 Tflops.

The space occupied by the supercomputer, 90 m2, also constitutes a technological challenge of the first magnitude, as the installation of such a high calculating power in such a reduced space necessarily implies the need to dissipate the great heat generated by the machines rapidly. This is only possible thanks to the installation of an efficient

3.2. Infrastructure design criteria

A key feature to the design of this supercomputer has been energy efficiency. Electricity consumption is the decisive factor in running costs, and represents a growing concern due to its environmental impact. The supercomputer's electrical power is approximately 120 Kw, a long way from the 683 Kw of the "Mare Nostrum" or the 267 Kw of the "Finis Terrae", placing it amongst the first 5 installations worldwide which have overcome the 500 Mflops/w barrier.

Moving from "room cooling systems" to "dynamic smart (rack) cooling", to use cooling economizers, to scale appropriately through the use of modular power and cooling equipment, to employ high efficiency UPS and to implement dynamic control of the cooling plant.

3.2.1. Hot and cold aisles technique

The **hot and cold aisles technique** was implemented, which prevents the hot air leaving the machines from mixing with the cold air being generated to cool others, avoiding a reduction in cooling performance, as room temperature rises and capacity for cooling the units drops. In turn, efficiency is reduced due to a lower differential between input/output temperatures.

3.2.2. Elimination of "*hot points*"

The temperature and humidity requirements of data centers are conditioned by the characteristics of the most demanding units. Thus, the existence of hot points dictates cooling for the entire installation. If these "hot points" were eliminated, producing a constant thermal load in the center, this would create a relative reduction in temperature and humidity requirements, thus contributing to a reduction in energy required for cooling the center.

3.2.3. Rack cooling. Water cooling. "*In-row*"

Cooling the rack on which the servers are mounted, in order to eliminate heat as close to the source as possible. Move from room cooling to dynamic rack cooling. The expression "**In-row**" is applied to new techniques being developed by CIT unit manufacturers, which generally comprise the inclusion of **cooling as an integral (internal) part of the unit**. Just as a unit incorporates a supply source, so too can a cooling system be integrated.

Water cooling. Instead of cooling the equipment with air, the units can be cooled directly using chilled water circuits. Use of **cooling economizers**. This cooling system provides a more efficient thermal circuit, enabling water flow to operate at temperatures higher than would be possible with the air alternative, and thus increases the possibility of using "free cooling".

3.2.4. "*Free Cooling*"

"*Free cooling*" is possible when the external temperature is very low in comparison with that of the interior. It consists in exploiting external air to cool the DPC, thus obviating the need to use the chilling systems

Energy savings through the use of "*free cooling*" depend on the climate of the DPC location, and as would seem obvious, the colder the climate, the higher the energy savings. This is one of the principle arguments currently being applied when selecting sites for new DPCs.

3.2.5. Virtualization

At present, one of the best solutions for preventing a large proportion of the CO_2 emissions generated by data centers – apart from improving cooling systems - is server virtualization.

Virtualization creates a simpler and more intuitive virtual reality parallel to the real world, capable of providing technological services to organizations, the management of which is more agile thanks to a "software layer" which is then transferred to the real world.

[1] The center occupying first place is the "Mare Nostrum" in Barcelona with a capacity of 94 Tflops. The CESGA "Finis Terrae" installation in Galicia has a capacity of 21 Tflops.
[2] Top500 June 2008, 53rd place worldwide and 131st in May 2009.

One of the consequences of virtualization is a drastic reduction in the number of units needed in a server farm, with all the associated savings in maintenance and energy costs and reductions in the emission of toxic gases that this implies.

In this way, a company's computing resources are used in a more efficient manner whilst at the same time, offering greater flexibility in the management of such resources.

3.2.6. Modular design

To establish independent compartments for the installation of CIT units, in such a way that the operation of one does not affect the others, so that each of the rooms can be adapted to the scale required at any specific moment, rendering DPC resources responsive to actual needs [7].

Similarly, it should be pointed out that any electromechanical device that generates heat should be housed away from CIT units in order to avoid overloading the cooling systems.

4. Microcogeneration Project in special regime.

The project follows the normal development of an engineering document [8, 9] in relation with the stages of preparation and evaluation.

4.1. Description of the installation

The installation consists of a trigeneration system with natural gas, based on an alternative engine of internal combustion that provide at the same time electricity and heat. The electricity is exported completely to the electrical network as an installation of special regime. Heat generated will be used in a device for producing cold for absorption to keep in a good level of refrigeration the clusters of the High Performance Computing Center [10, 11].

The main characteristics of the equipment are the following:

The cogeneration device is connected directly to a device that generates cold based on absorption with no other contribution of heat.

At the same time that the equipment is producing heat, is producing electricity of high quality, that is injected to the low tension network.

The electrical installation begins on the engine continuing to a general installation in the cogeneration area. General line will be connected with the local of the company of electricity in a low tension connection.

The absorption system will be connected in series with the conventional system of cold production for compression. Cold water produced will be deposited on an "inertia deposit" with a capacity of 1.000 litres situated on the return area of the refrigeration circuit of the clusters, so a previous cooling of the water is done before entering in the cooling system, reducing their use.

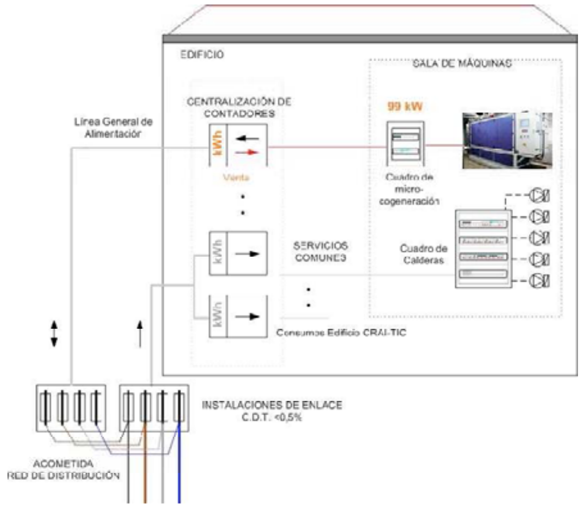


Figure 1. Electrical installation

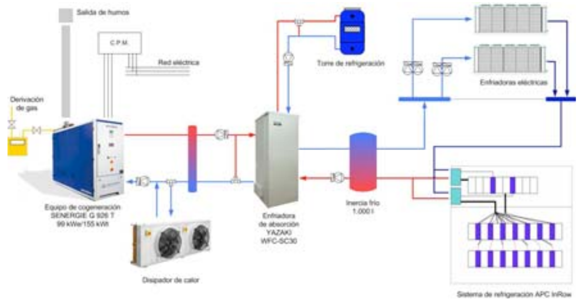


Figure 2. Hydraulic Integration

4.1.1. Normative

The installation fulfills the requirements of norms applicable (UNE-, IEC-, DIN-, VDE-) and norms EN- about security of electrical equipments, following the indications of several laws, both in the national and European level.

4.1.2. Generating installation

4.1.2.1. Electrical generator

The cogeneration installation is based on an engine of internal combustion that drives directly a synchronous generator. It has a circuit for recovering the heat of the refrigeration of the engine and the gases that feeds the installation of cold for absorption. The engine works when it is a thermal demand, always in a total load, generating the electrical power. The excess of heat in transitory regimes is evacuated through an aerothermus of refrigeration.

4.1.2.2. Generating installation in low tension

According to the normative ITC-BT-40, the installation works always in parallel with the Public Distribution Network, and is classified as a generating installation interconnected, fulfilling the following conditions:

- The total amount of nominal power will not have to exceed of 100 kVA; in this case the amount is 99 kVA, so it follows the condition.

- The power of generators should not be higher than half the capacity of the evacuating line of the transformation center of the Public Distribution Network connected to the central. The capacity of this line is 250kVA, which follows the condition

4.1.2.3. Protections of Network

The installation has the protections indicated in the normative of September 5th of 1985, as relays for controlling the intensity, controls of tensions, controls of maximum and minimum frequency, etc.

4.1.2.4. Foreseen supply of energy

The electricity to be transferred to the Network, is calculated in the potential of the installation and the working hours estimated per year. The device of microcogeneration is going to work 5.384 hours per year in total load, producing 834.520 kWh of heat and 511.695 kWh of electricity every year, exported totally to the Network. It consumes 1.534.440 kWh of natural gas. The device of cold for absorption will have a regime of working 5.226 hours, generating 550.820 kWh of cold, consuming 786.886 kWh of residual heat produced for the cogeneration.

4.2. Financial and economic study

4.2.1. Operation of the installation

The analysis of viability was based on the production of cold for the refrigeration system of the Supercomputing Center, not considering providing cold to the rest of the building, due to reasons as complexity and cost.

The proposal is the use of the cogeneration system in peak hours (form 8 am to 12 pm), stopping during off-peak hours. It is more optimum in terms of profit, due to the higher price paid by the electrical company in peak hours.

The objective of cold production is 80 %, having in consideration that the reduction of electrical consumption is a goal of the Supercomputing Center.

The production of electricity is of 511,7 MWh, exported totally to the Electrical Network and the thermal production of the engine is 834,5 MWh, of which 786,9 MWh are used in the cooling for absorption device, and the rest are dissipated through the aerothermus.

4.2.2. Economic analysis

To realize the economic analysis, we have to consider the prices of electricity, the gas consumption, maintenance and the expenses of representation in the electrical market.

The price of sale of the electricity generated is published in the last revision of fees, made on July 1st of 2010. The fee is incremented with a complement for energetic efficiency. The price of sale is multiplied by 1,37 in peak hour, and multiplied by 0,64 in off-peak hours.

The price of buying the electricity for the mechanical cooling devices is estimated in 0,11 €/kWh and 0,035 €/kWh for the gas. The cost of commercialization of the electricity is 0,0035 €/kWh.

The net result is 35.505 €/year of profit, which results in a simple amortization of 8 years if we consider the total amount of the investment (295.000 €). If we consider a subvention of 20 % of the investment, the simple return would be of less than 7 years.

4.2.3. Financial Analysis

To realize the financial analysis, is important to consider the cost in relation with time and price variation through indexes.

The values for analyzing the annual evolution are the following:

- 3,5 % of increment in sale price of electricity to the Network
- 6 % of increment in costs of electricity
- 3,5 % of increments in costs of natural gas
- 2 % of increment in maintenance costs and other costs.
- The rate of discount of the investor is 6,5 % per year.

With the conditions mentioned above, we described 2 situations: Financing of 100 % with own resources and Financing 20 % with own resources and 80 % external resources (loan). In both cases is studied the case of having a direct subvention of 20 % or not having subventions.

4.2.3.1. Financing of 100 % with own resources

As a result, if the financing of the project is done all with own resources, with no subvention, the return of the investment is calculated in 10 years. If we consider a subvention of 20 %, the return is 8 years.

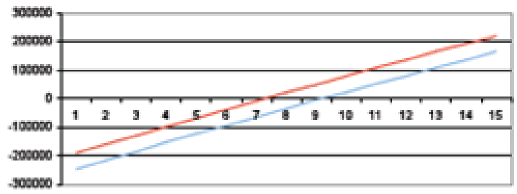


Figure 3. Comparison of NPV self- financing.

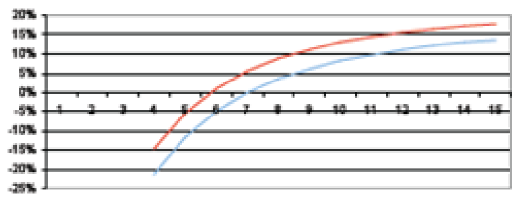


Figure 4. Comparison of IRR self- financing.

4.2.3.2. Financing 20 % with own resources and 80 % external resources (loan).

The support of a financial institution through a loan is habitual in this type of investments.

If we consider a loan for the 80 % of the total amount, in a period of 10 years with 5 % of interests, and an initial commission of 0,5 %, the return of the investment is 7 years without subvention and 4 years with subvention.

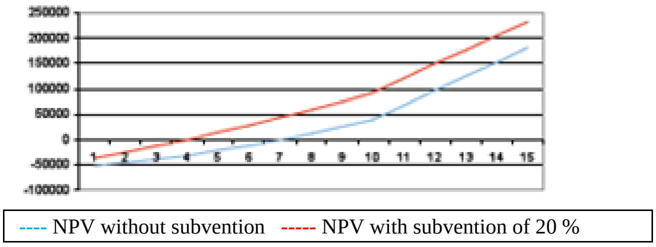


Figure 5. Comparison of NPV external resources.

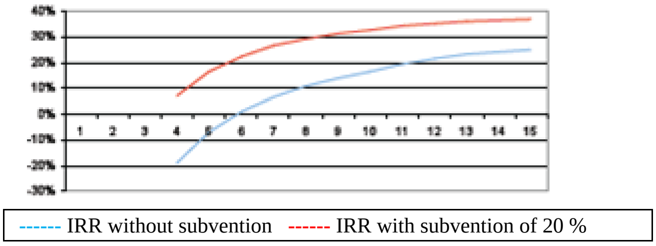


Figure 6. Comparison of IRR external resources.

4.2.3. Economic Optimization

During the study we considered as an objective a rate of cover of 80 % of the cold needs of the Supercomputing Center, for reducing the electrical consumption and reducing the PUE.

However, it is essential to study the economical criteria, mainly because the profit of using the installation in peak hours is 10,5 €/h, and just 0,55 €/h in off-peak hours. If we consider the use only in peak hours, the total use per year is 3.378 hours and the conservation is better, incrementing the live of the installation and reducing the overhaul, and maintenance costs.

In case of considering the use of the installation in rush hours, the results of the situations described are the following:

- Financing 80 % of the investments without subventions: return in 7 years.
- Financing 80 % of the investments with a subvention of 20 %: return in 4 years.

This is the optimal way of using the installation. In any case, the objective of reducing the PUE is essential and will be done mainly by the higher contribution of cold for the absorption device.

A continuación se muestran las gráficas de comparación de indicadores:

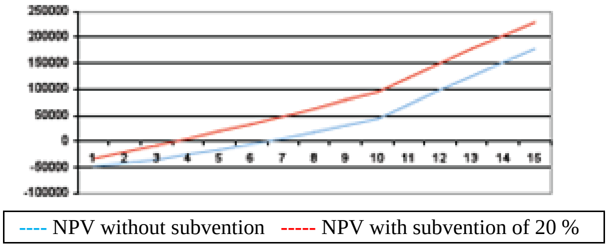


Figure 7. Comparison of NPV with or without subvention.

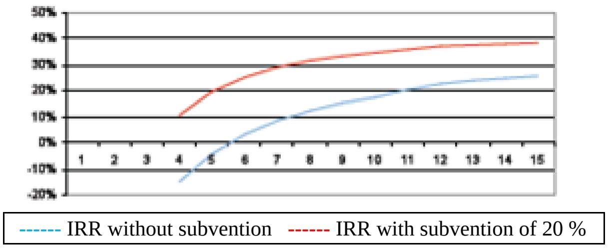


Figure 8. Comparison of IRR with or without subvention.

4.3. Analysis of sensitivity

It is interesting to verify the influence of different parameters used in the economic analysis.

Neutral situation will register the following values:
- 3,5 % of increment in sale price of electricity to the Network
- 6 % of increment in costs of electricity
- 3,5 % of increments in costs of natural gas
- 2 % of increment in maintenance costs and other costs.

There are two additional situations:

Pessimistic
- 2 % of increment in sale price of electricity to the Network
- 4 % of increment in costs of electricity
- 2 % of increments in costs of natural gas
- 2 % of increment in maintenance costs and other costs.

Optimistic
- 4 % of increment in sale price of electricity to the Network
- 8 % of increment in costs of electricity
- 4 % of increments in costs of natural gas
- 1 % of increment in maintenance costs and other costs.

The results, in a situation of covering 80 % of refrigeration needs, financing 80 %, but without subvention in terms of return of the investment, are:

Neutral: 7 years
Pessimist: 9 years
Optimistic: 7 years

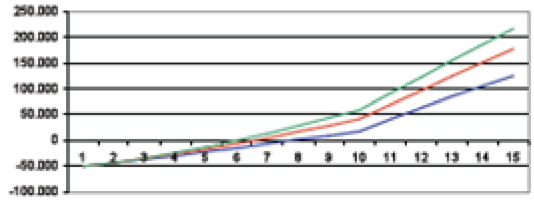
In the case of considering the economic optimization (using the installation in peak hours), the results are:

Neutral: 6,5 years
Pessimist: 8 years
Optimistic: 6 years

The solution providing 80 % of cold is more sensitive to the variation of the parameters, because it is used more time saving electricity.

In any case, economic optimization is the most profitable solution in all the situations described. Just in case of increase of electrical costs more than other parameters, the solution with the higher contribution of cold should be more attractive.

The cost of energy provision has a big influence in the profitability of the installation. IN this analysis we have considered a cost of 11c€/kWh, that is the average cost of the electricity in the building CRAI-TIC, where is hosted the Supercomputing Center.



---- NPV pesimistic ----- NPV neutral ----- NPV optmistic

Figure 9. solution of economic optimization (80% financing, without subvention): results of different situations

Conclusions

The main conclusions of the Financial and Economic study of the installation of trigeneration are the following:

- The economic optimization solution is the one that presents better profitabilities, but the reduction of PUE (which is an important parameter of decision for the Center) will be less than other alternatives.

- In case of financing 80 % of the investment the rate of return in 10 years for the capital invested is incremented form 8 % to 17 % without a subvention and from 13 % to 35 % with subvention. It is a key element in the profitability of the project.

- The direct subvention of 20 % increments considerably the profitability of the project, reducing the return time form 7 to 4 years in the case of economic optimization solution.

- The project could be considered as an attractive investment in economical terms, with a rate of return of 16 % or 17 % in a period of 10 years, depending on the type of operation, but considering financing.

- In terms of strategy, the installation will reduce from 50 % to 80 % the needs of electrical energy for producing cold depending on the type of operation chosen. It is a technological advantage that has an important impact for the Center, improving the image of a High Performance Computing Center efficient energetically.

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