FINANCIAL OPTIMIZATION OF MICRO COGENERATION PLANTS USING A TASK CONFIGURATION SYSTEM

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This work presents an ordinary financial calculation and optimization method for a new model of micro cogeneration plant with a task configuration system. Although the model is general, in this work the cogeneration system contains the following equipments: microturbine of 30 kW power, an Otto reciprocating engine of 30 kW power, an absorption chiller of 22 kW refrigerating power, a compression cycle air conditioning split system of 14 kW refrigerating power, a cold water tank and a warm water tank. The model includes one so called task configuration system, in which it's possible to force priorities over each one of the system components: production of cold water, electric power generation, electrical energy sell to the public grid etc. Further characteristics of the model are its ability to work with time variable electrical and thermal demands and to allow the choice of tariff. The optimization of the net present value is performed by the method of exhaustive search. For the case study is presented a typical daily variation of electrical consumption and conditioned air. Two configurations are confronted and the response of each component dictated by the task configuration system is analyzed.

Keywords: optimization, cogeneration, thermal systems

1. Introduction

Cogeneration systems are the most direct solution to the transition from fossil fuels to renewable sources of energy. Although cogeneration relies basically on hydrocarbons (fossil fuels or biomass) its two major contributions are its stress on energy usage efficiency and on distributed generation. The first characteristic decreases the energy dependency in general (renewable or not) and the second one prepares for the future full change of energetic matrix from fossil fuel to renewable sources. In Brazil, where more than 90% of the electrical energy is generated by hydro power plants constructed more than 20 years ago (so the electrical tariff is hardly influenced by the worth of the Brazilian currency), the thermal plant solution (strongly influenced by the worth of the currency because of the importation of equipment and natural gas from other countries) is almost unviable without the emphasis on cogeneration.

In the process of plant design optimization is quite important to take into account the daily demand variation and the possibility of change the behavior of a system (commanding a predominant electrical power generation or a predominant conditioned cold air production, for example). The modeling of thermal cogeneration plants has suffered several advances in the last decade. For example, Manolas et all (1996) presents the use of genetic algorithms in the optimization phase. Accadia (2001) presents a comparison between various operations modes in a steady state plant. Gamou et all (2002) optimize a cogeneration power plant with daily variations and with uncertainties in the energy demands.

The present work proposes the simulation and optimization of a micro cogeneration plant. The model takes into account the various tariff schemes used in Brazil. A daily variation of thermal load and electrical consumption is specified. The independent variables of the model are the nominal power of the devices and the state of the task configuration system switches. For each set of nominal power and switches state there is a financial evaluation of the net present value of the initial cost investments plus the natural gas and additional electrical energy bought from the grid.

For lack of space, the modeling of the equipments and the financial calculation are not shown. The stress is over the task configuration system that permits the change of the behavior of the whole system in response to the demand variations. The use of these task configurations systems permits, theoretically, the inspections of 335,544,320 operation modes for the same system. On another hand, the use of the switches transforms the system model in a non-linear algebraic-differential set of equations with discrete and continuous variables. The complexity of the model prohibits the use of classical optimization methods as Lagrange multipliers, search methods or linear programming. Therefore, to performing the optimization it was mandatory, in this stage of the method development, the use of the dull method of exhaustive search. With the use of this method it will be possible to run an extensive case study. Although the extensive case cannot be used in all applications, it is useful to determination of a judicious guidance in the choice of the relevant switches for optimization concerns.

2. Cogeneration plant specification

The cogeneration plant here presented as an example of the method was chosen because it is one that is going to be installed to research purposes in the campus of UFPE. This plant installation will be fully instrumented allowing the validation of results from modeling. The funds for the plant are from an initiative of UFPE, FINEP (Brazilian government), Petrobras (oil and gas Brazilian industry) and Copergas (Brazilian facility for distribution of Natural Gas in the state of Pernambuco). Since the main purpose of the plant is research, some solutions hardly will be found in a real micro cogeneration plant. For example, the plant has one 30 kW microturbine and one 30 kW Otto engine. Although this solution represents a great opportunity to compare the two engines, one better solution for real systems of this order would probably be the use of a unique 60 kW microturbine or a unique 60 kW Otto engine. However, it is important to stress that the whole method here presented can easily be applied in a case like that by simply specifying, for example, the nominal maximal power of the microturbine as 60 kW and the Otto engine power as zero.

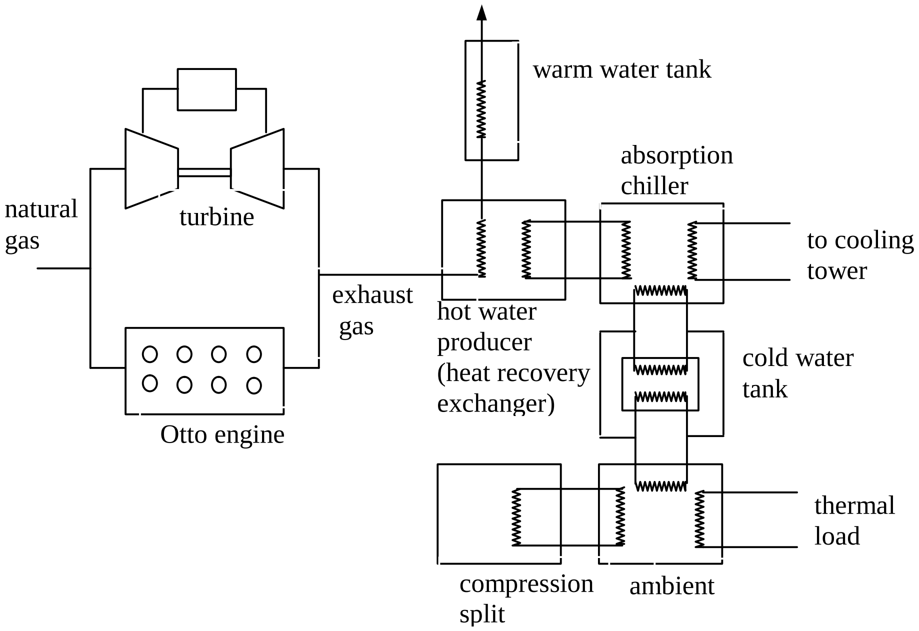

Figure 1. Cogeneration system: 30 kW microturbine, 30 kW Otto reciprocating engine, 22 kW absorption chiller, 14 kW compression cycle air conditioning split system, cold water storage tank and warm water storage tank.

The full specification of the plant is:

- A microturbine of 30 kW maximal nominal power
- An Otto engine of 30 kW maximal nominal power
- An absorption cycle chiller of 22 kW maximal nominal refrigerating power
- A compression air conditioning split system of 14 kW maximal nominal refrigerating power
- A cold water storage tank of 15000 liters
- A warm water storage tank of 3000 liters

Figure (1) shows the cogeneration plant with a scheme of the mass flow. Natural gas is burned in the microturbine and Otto engine. The exhaust gases both goes to a heat recovery heat exchanger where hot water is produced. After exiting this heat exchanger the exhaust gases flows to a warm water storage tank.

The hot water goes to the absorption chiller that dissipates heat to a cooling tower and produces cold water. The cold water flows to the storage tank. There is a bypass in the storage tank that permits one fraction of the cold water to go directly from the chiller to the acclimatized ambient. In the acclimatized ambient, there is a fan-coil that absorbs part of the thermal load. The excess of thermal load is absorbed by the evaporative unit of the compression air conditioning split system. When the thermal load is greater than the sum of the compression split and absorption chiller refrigerating power then the cold water coming from the absorption chiller is increased by water that flows directly from the cold water tank.

The values used for the efficiencies are found in the equipments data sheet. Since the main objective of this study is the optimization and simulation of the whole system, only constant efficiencies were used. The use of the whole curve supplied by the equipment data sheet would provoke the optimization processing time to become prohibitive. The thermodynamics analysis is classical, as in Bejan (1988), and the modeling of the system governing equations is based on Stoecker (1989). Although the components equations are quite simple, the whole set of the algebraic-differential non-linear equations with discrete and continuous variables is very complex. Specific details to analyze and design technically operational cogeneration plants can be found at Horlock (1997) and Orlando (1996), that present major guidelines.

3. Task configuration system

The system described in the anterior section has additionally five so called task configuration systems. Four of these are responsible to assign tasks to the turbine, Otto reciprocating engine, compression air conditioning split system and absorption chiller. In other words, the task configuration system will command a determined electrical or thermal power generation to each one of the above devices.

The additional task configuration system (not presented here) simply allows the choice of the primary engine (turbine or Otto engine) and the primary refrigeration system (split or absorption chiller). The primary device receive as input all necessary load (electrical in the case of engines and thermal in the case of refrigeration systems) while the secondary device receive the total necessary load minus the power generated by the primary device.

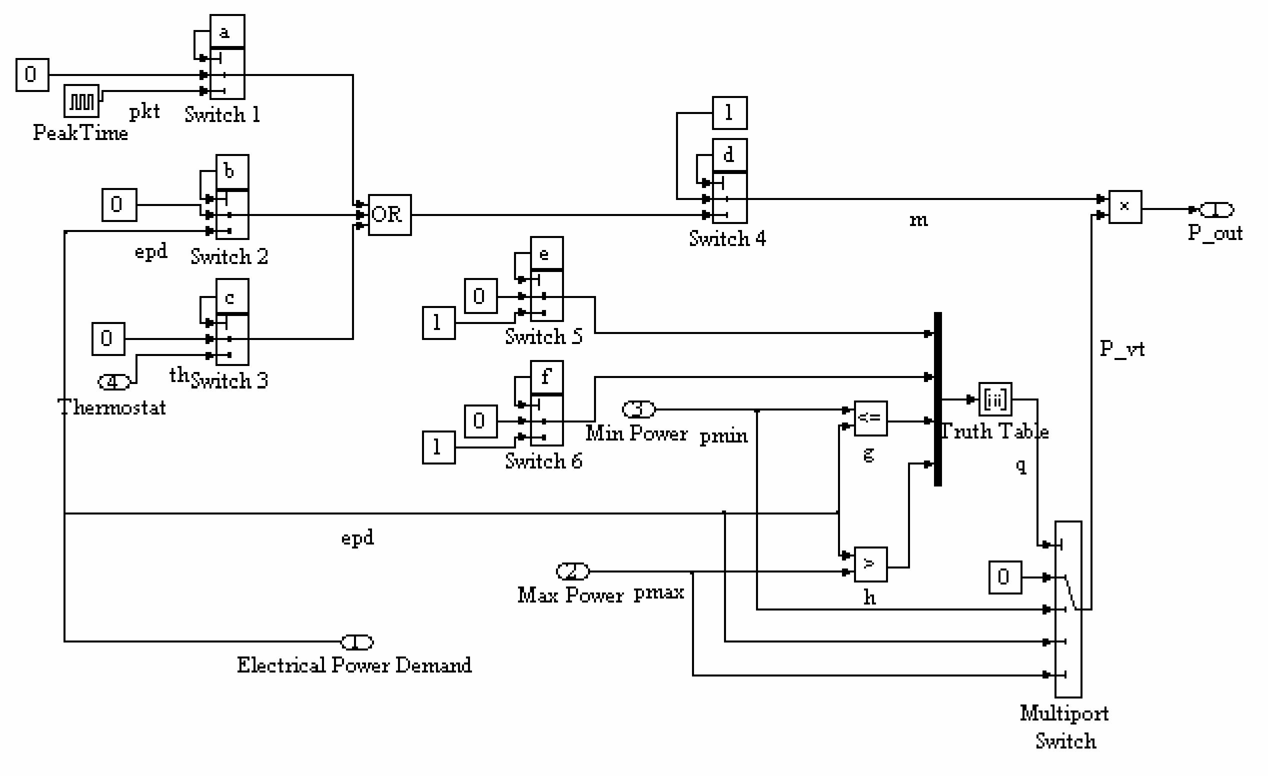

Figure 2. Block diagram representation of the task configuration system.

Figure (2) describes one of the task configuration systems in a block diagram representation. There it is possible to recognize five input signals: pkt, th, epd, pmin and pmax; six switches: a,b,c,d,e and f; and only one output: P_out. All those variables are described in Tab. (1) and Tab. (2). In Fig. (2), for example, if switch a is set to 0 its output signal is 0, if the switch a is set to 1 then the output signal is pkt. The same occurs in all the other switches with the exception of the multiport switch where the variable q can have values 0,1,2 and 3.

Table 1. Description of the input signals of the task configuration system.

pkt	A pulse curve that assumes value 1 when it's high demand period (17:30 to 20:30) and zero otherwise.
th	Thermostat relay that assumes value 1 if the temperature is over the minimal specified temperature for the cold water tank and zero otherwise.
epd	Signal that assumes the value of the electrical or thermal load.
pmin	Minimal power generation of the device.
pmax	Maximal power generation of the device.

P_out	Power generation commanded to the device.

The function of the task configuration system is to analyze the input signals and decide which value of power is to be commanded to the device. The decision is strongly influenced by the state of the switches.

Table.(2) indicates that the switches a,b,c and d will decide if the device will be shut on or shut off (neglecting the value of the commanded power), while the switches e and f will decide the value of the generated power when the device was decided to be shut on.

From the values of the input signs and the position of the switches a , b, c and d it is possible to calculate, by Eq. (1), the signal m, that assumes values 0 or 1. In Eq. (1) all the operations are Boolean. If m equals unity, the task configuration system is going to shut on the device, if m equals zero the device will be shut off.

$$m = d.\,(\,(pkt.a) \text{ or } (epd.b) \text{ or } (th.c)\,) \text{ or } (\sim d) \tag{1}$$

Table 2. Description of the switches of the task configuration system.

Switch\state	0	1
a	Neglects if it is high demand period or not. If the other switches b and c are 0 and d is 1 then the device will be shut off.	Tries to shut on the device in case of high demand period (in the case of the compression system this switch is inverted so the device is shut off in high demand period).
b	Neglects if there’s a load to be generated or not. If the other switches a and c are 0 and d is 1 then the device will be shut off.	Tries to shut on the device in case of a non null load (electrical in the case of engines and thermal in the case of refrigerating systems)
c	Neglects if the temperature of the cold water tank is over or bellow the specified minimum. If the other switches a and b are 0 and d is 1 then the device will be shut off.	Tries to shut on the device in the case where the temperature of the cold water tank is over the specified minimum.
d	Tries to shut on the device all the time, independently of the above switches state.	Does nothing. If the other switches a, b and c are 0 then the device will be shut off.
e	Tries to command the maximal power permissible to the device.	Tries to adjust the power generation to be equal the load.
f	Does not allow the power generation to be greater than the load.	Does allow the power generated to be greater than the load.

Two auxiliary signals are calculated by Eq. (2) and Eq. (3), where the operations are Boolean. If the load (epd) is smaller than the minimum permissible power generation to that device (pmin) then g=h=0. If the load (epd) is greater than the maximal permissible power generation to that device (pmax) then g=h=1. Otherwise, when the load is between the minimal and maximal, g=1 and h=0.

$$g = (pmin <= epd) \tag{2}$$

$$h = (epd > pmax) \tag{3}$$

In the block diagram of Fig. (2) there is a representation of a truth table that examines the values of e, f, g and h to decide what should be the value of the commanded power to the device. Table (3) reproduces the truth table in its first and last columns. The output of the truth table, called signal q, is used as the set of the multiport switch showed in Fig. (2).

Transforming the truth table in a Boolean algebra representation, the P_vt (the generation power that will be commanded to the device if it is shut on, i.e., m equal unity) can be calculated by Eq. (4). The 2nd, 3rd and 4th columns of Tab. 3 show the values of some terms of Eq. (4) as functions of the values of e, f, g and h.

$$P\_vt = [e \text{ and } f \text{ and } (\sim g)]*pmin + [\sim((\sim e) \text{ and } f) \text{ and } (g \text{ and } (\sim h))]*epd + [((\sim e) \text{ and } f) \text{ or } (g \text{ and } h)]*pmax \tag{4}$$

It is worth noticing the values of m, g and h change all over the simulation as pkd, epd and th suffer their daily variation. So, the value of P_vt changes during the day, as will be shown in the case study of section 5. Another way to show the P_vt determination is by Eq. (5) and Eq. (6) bellow:

$$q = [e \text{ and } f \text{ and } (\sim g)]*1 + [\sim((\sim e) \text{ and } f) \text{ and } (g \text{ and } (\sim h))]*2 + [((\sim e) \text{ and } f) \text{ or } (g \text{ and } h)]*3 \tag{5}$$

$$P\_vt = \begin{cases} 0 & \text{if } q = 0 \\ pmin & \text{if } q = 1 \\ epd & \text{if } q = 2 \\ pmax & \text{if } q = 3 \end{cases} \qquad (6)$$

For any way chosen to P_vt calculation, the final generation power commanded to the device is the algebraic product:

$$P\_out = P\_vt*m \qquad (7)$$

Table 3. Truth table of the task configuration system.

Input				Minimum	Load	Maximum	Output
E	f	g	h	e and f and (~g)	~((~e) and f) and (g and (~h))	((~e) and f) or (g and h)	Switch
0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	0
0	0	1	0	0	1	0	2
0	0	1	1	0	0	1	3
0	1	0	0	0	0	1	3
0	1	0	1	0	0	1	3
0	1	1	0	0	0	1	3
0	1	1	1	0	0	1	3
1	0	0	0	0	0	0	0
1	0	0	1	0	0	0	0
1	0	1	0	0	1	0	2
1	0	1	1	0	0	1	3
1	1	0	0	1	0	0	1
1	1	0	1	1	0	0	1
1	1	1	0	0	1	0	2
1	1	1	1	0	0	1	3

Table (4) shows the data used in the construction of the truth table and multiport switch shown in Fig. (2). In bold letters are the output (P_vt, the generation power that will be commanded if m equals unity) of the multiport switch presented in Fig. (2).

Table 4. Decision table utilized to construct the truth table and multiport switch shown in Fig. (2).

	g = 0 h = 0	g = 1 h = 0	g = 1 h = 1
e = 0 f = 0	epd<pmin maximal epd <=pmax no excess **0**	epd >=pmin maximal epd <=pmax no excess **epd**	epd >=pmin maximal epd >pmax no excess **pmax**
e = 0 f = 1	epd <pmin maximal epd <=pmax excess **pmax**	epd >=pmin maximal epd <=pmax excess **pmax**	epd >=pmin maximal epd >pmax excess **pmax**
e = 1 f = 0	epd <pmin load epd <=pmax no excess **0**	epd >=pmin load epd <=pmax no excess **epd**	epd >=pmin load epd >pmax no excess **pmax**
e = 1 f = 1	epd <pmin load epd <=pmax excess **pmin**	epd >=pmin load epd <=pmax excess **epd**	epd >=pmin load epd >pmax excess **pmax**

For example, if the cogeneration system is totally isolated from the grid and does not have an electrical resistance battery to dissipate the excess of electrical power generated, then the switch f should be set to 0. In this case, it is irrelevant how switch e is set. If switch f is set to unity, so the set of switch e turns relevant. In this case, the switch e should be set to 0 (always try to command full generation power) if the engine is to be primarily devoted to generate electrical energy to sell to the grid or to generate exhaust gases to an absorption chiller that will diminish the temperature of a cold water storage tank. Otherwise, if the priority of the turbine is to be electrical generation adjusted to the demand, so the switch e should be set to 1 (tries to adjust the power to the load).

4. Optimization

The optimization scheme used in this modeling is quite ordinary. The exhaustive search method was used in the following way:

1. The curves of electrical demand, thermal load and warm water are given.
2. Various sets of nominal powers for the devices (microturbine, Otto engine, compression split and absorption chiller) are specified.
3. The characteristics (efficiencies, volume of tanks etc.) of each device are specified, as well its specific cost.
4. The initial state of each switch is chosen.
5. The varying switches are chosen. Since it's impossible to perform all the simulations, only some switches vary their states during the optimization process.
6. All the possible combinations of the sets of nominal powers and the varying switches are generated.
7. For each one of the combinations, the model calculates the net present value of the initial investment and of the electrical energy and natural gas costs. For the NPV – net present value calculation, a classical calculation, one could see Pansini (1995).
8. The model calculates the net present value of a so called conventional system where there is neither cogeneration nor accumulation.
9. The model results, among all the possibilities and the conventional system, the configuration of the system that has the smaller NPV.

The tariff modeling used in this study allows the choice between five different types used in Brazil. Each one of those differentiates between dry/wet weather period, high demand period and working day. The tariff scheme, as imposed in Brazil, considers the total energy consuming and the maximal consumption power reached inside the period. The five tariffs considered in this modeling apply to different electrical tensions. Therefore, depending on the chosen tariff there is a change in the initial investment of the plant caused by the electrical transformer. This difference is fully considered in the modeling. The natural gas tariff is fixed for consumption smaller than 1000 m3/day. It's possible to set the price of sold energy for the periods when the market is disposed to buy electrical energy from small producers. In the cases studied here the value of the sold energy was set to zero.

The mathematical representation of the present system could be classified as: a differential-algebraic non-linear system with discrete and continuous variables. These characteristics prohibit the use of classical optimization method (better than exhaustive method) as linear programming, Lagrange multipliers and steepest descent. Two strategies are been envisaged to further advances in this model: a) after an intense case study analysis, elaborate one guide to choose the most important switches in an optimization and b) implementation and test of another methods as genetic algorithms, adaptation of design of experiments or combinatorial optimization.

5. Case study

The main aim of this section is to present the effect of the switches state on the behavior of the system. Although the method is general and the model can do the calculations for all the possible switch sates, for lack of space we have chosen only one switch change.

The nominal maximal power of the devices studied here are shown in Tab. (5). It is assumed that the minimal power of the two engines is zero, the minimal power of the compression split is 75% of its maximal power and the minimal power of the absorption chiller is 50% of it's maximal. In this study only one set of nominal maximal power was specified. The financials values of currency and tariffs used in this work were those from May of 2002.

Table 5. Nominal electrical and refrigeration power of the devices

Device	Case 1 and 2
Microturbine nominal maximal power [kW]	30
Otto engine nominal maximal power [kW]	30
Absorption chiller nominal maximal refrigeration power [kW]	22
Compression refrigeration split system nominal maximal refrigeration power [kW]	14

Table (6) shows the states of the switches in the task configuration system in each one of the devices in the first and second cases simulated. In bold letters and shadowed is the unique switch that is varied between the two cases. As will be seen, only one switch can strongly vary the behavior of the system. It is worth remembering there are 335,544,320 ((2^26)*5) possibilities.

Table (7) shows three more switches that, for lack of space, were not presented. The preferential engine switch sets the primary and secondary engine. The primary engine perceives the total electrical demand while the secondary one perceives only the net electrical demand (the total electrical demand minus the power generated by the primary engine). The same occurs with the preferential refrigeration system switch that sets the primary and secondary refrigeration system.

In the case studied here the microturbine and the absorption chiller were chosen as primary devices. The tariff switch with value 3 is set to represent the Brazilian "Tarifa Azul A4 (13.8 kV)".

Table 6. Switches state in the task configuration system (shown in Fig. (2)).

	Microturbine		Otto engine		Absorption chiller		Compression split	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
switch a	0	0	1	1	0	0	1	1
switch b	0	0	**0**	**1**	1	1	1	1
switch c	1	1	0	0	1	1	0	0
switch d	1	1	1	1	1	1	1	1
switch e	1	1	0	0	1	1	0	0
switch f	0	0	1	1	0	0	1	1

Table 7. Switches state in the task configuration system (not shown in this paper).

	Case 1	Case 2
Preferential engine	0	0
Preferential refrigeration system	0	0
Tariff	3	3

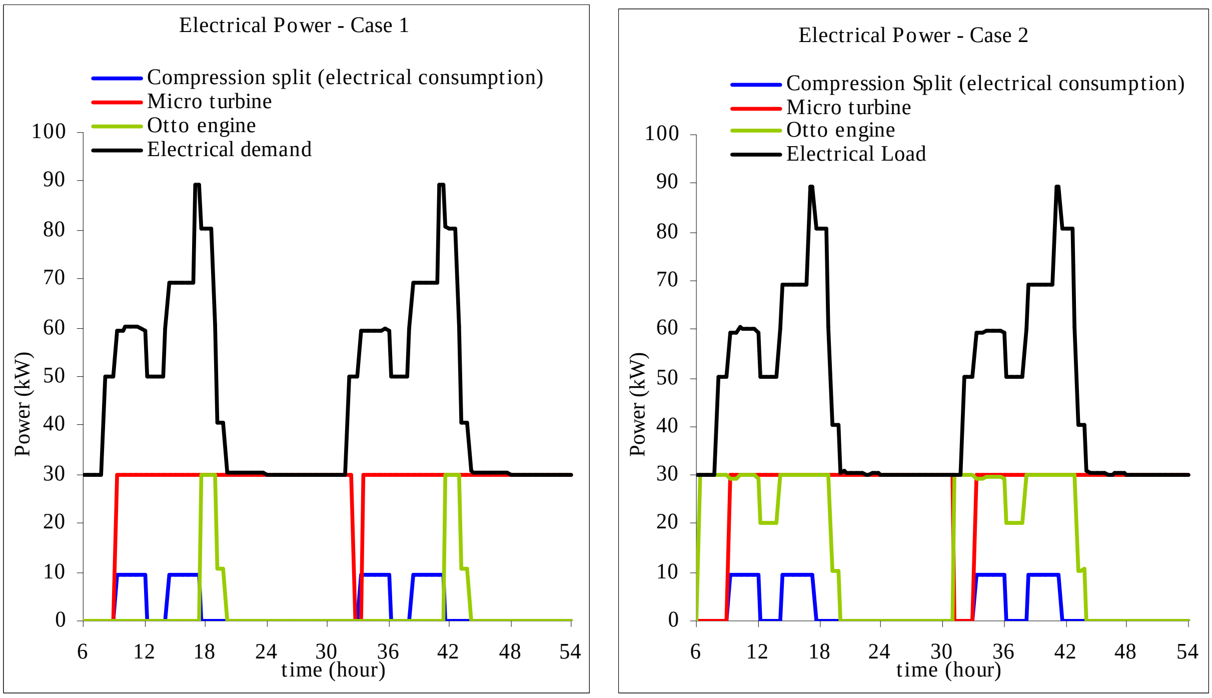

Figure 3: Electrical power generation and demand – case 1 and case 2.

Figure (3a) shows the electrical power demand and generation. The microturbine task configuration system (a=0, b=0, c=1 and d=1) was set to command the microturbine to be shut on every time that the temperature of the cold water storage tank is above 9.1 C. In this same Fig. (3a) it is possible to see the Otto engine behavior (a=1, b=0, c=0 and d=1) that was set to shut on every high demand period occurrence and to neglect the temperature in the cold water tank. Figure (3b) shows the same configuration for the microturbine, however in that case the Otto engine (a=1, b=1, c=0 and d=1) was set to be shut on every time there is a net electrical demand (total electrical demand minus electrical power generated by the microturbine), since the microturbine was set as the primary engine. In Fig. (3a) and Fig. (3b) both, after 20:00 the Otto engine is shut off because the electrical power demand (30 kW) equals the electrical power generated by the microturbine. The compression air conditioning split system was set (a=1, b=1, c=0 and d=1) to shut off every high demand period occurrence.

In Fig. (3) it's possible to see two main differences: the period the Otto engine remains shut on (from 17:30 to 20:00 and from 41:30 to 44:00 in the first case and 06:00 to 20:00 and 31:00 to 44:00 in the second case) and the period in which the turbine remains shut off (32:30 to 33:30 in the first case and from 31:00 to 33:00 in the second case).

In the first case, the Otto engine task configuration system is set to shut on only in high demand period. In case two, the Otto engine is set to shut on every time there is a non zero net electrical load (total electrical load minus the power generated by the turbine). As a consequence, in case two, the absorption chiller works with greater refrigeration power (gases from turbine and from Otto engine during a larger period) forcing the cold water storage tank temperature to reach its minimal sooner, as can be viewed in Fig. (4), therefore shutting off the turbine sooner.

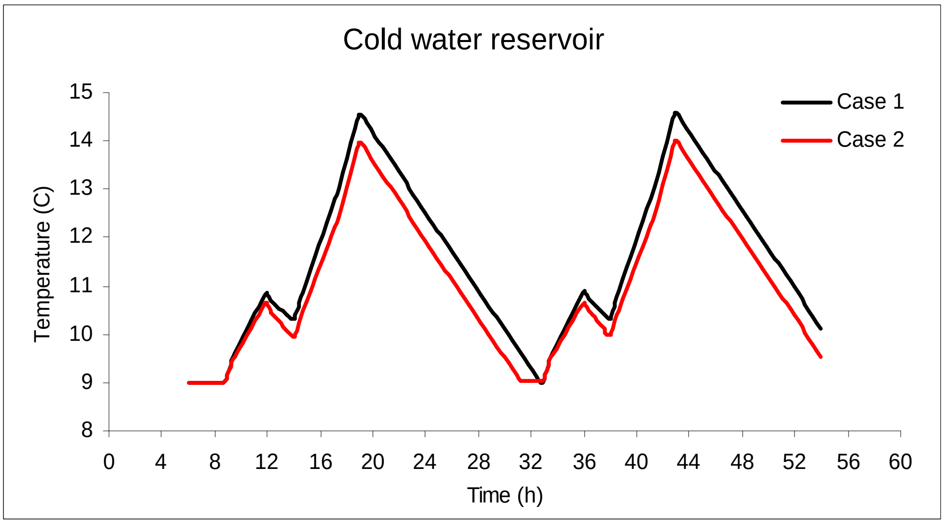

Figure 4: Daily variation of the cold water tank – case 1 and case 2.

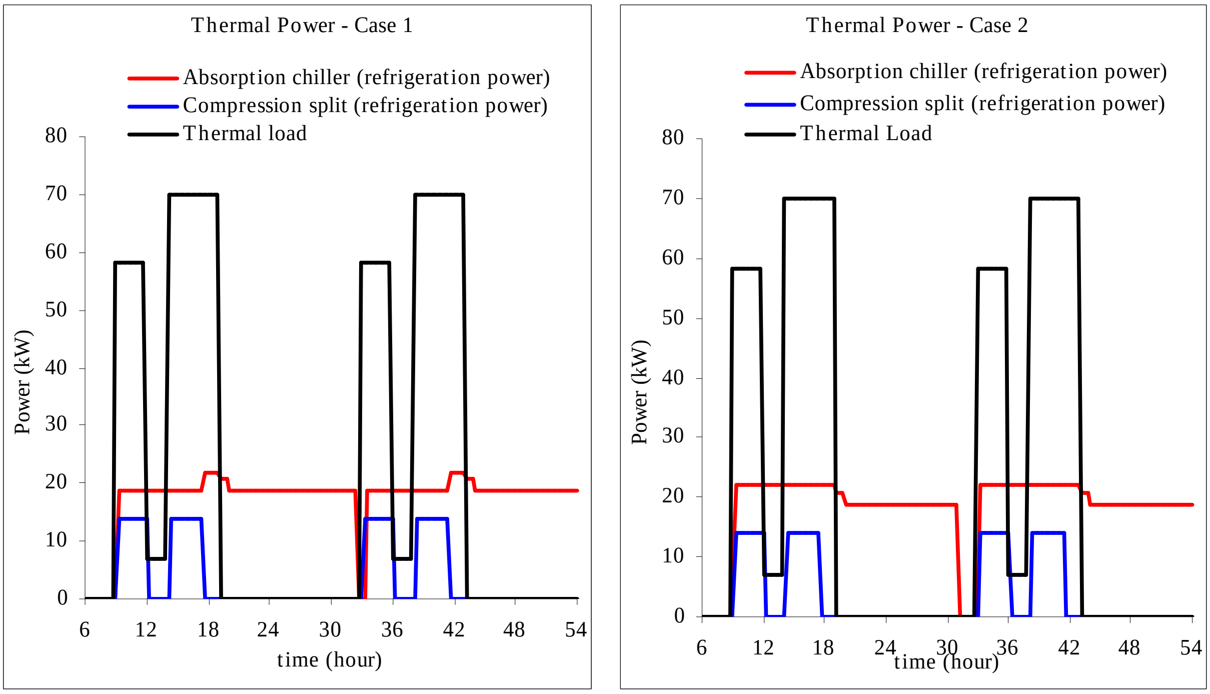

Figure 5: Cold air demand and production – case 1 and case 2.

Figure (5) shows the thermal load demanded and the refrigeration power generated by the absorption chiller and compression split. The absorption chiller was set (a=0, b=1, c=1, d=1, e=1 and f=0) to shut on in maximal refrigeration power always there is a thermal load or every time the temperature of the cold water tank is above 9.1 C. The absorption chiller will not necessarily reach the power commanded by the task configuration system. The refrigeration power of the chiller depends additionally on the presence of enough exhaust gases from the turbine or the Otto engine. The compression air conditioning split system is set (a=1, b=1, c=0, d=1, e=0 and f=1) to shut off in every high demand period occurrence and shut on in adjusted power every time a net thermal load exists. After 19:00, when there is no more thermal load, the absorption chiller remains turned on because the temperature is above 9.1 (see Fig. (4)). Between 17:30 and 20:30 the compression split must be turn off because it is high demand period. After 20:30 till the next day it must be shut off because there is no net thermal load. Between 19:00 and 20:30 the compression split must be shut off because of both conditions above.

In Fig. (5) two main differences may be noticed between the two cases: the total refrigeration power of the absorption chiller during diurnal period (from 08:30 to 17:30 and from 32:30 to 41:30 in the second day) and the shut off time of the absorption chiller (32:30 in the first case and 31:00 in the second case).

The cause of the greater refrigeration power of the absorption chiller during diurnal period in case two is the greater amount of exhaust gases. This occurs because in case two the Otto engine is shut on from 09:00 to 20:00 instead of from 17:30 to 20:00 as in the first case. The raise in the refrigeration power of the absorption chiller is short because the percentage of energy that flow trough the exhaust gases in a Otto engine is something like 20% and that percentage in the case of a turbine can reach 45%. That difference is caused by the greater efficiency of the Otto engine. Also, in the case of a turbine almost all the heat is removed trough the exhaust gases while in the case of an Otto engine that heat is removed both trough the exhaust gases and trough the cooling water.

As the refrigeration power of the absorption chiller is greater during diurnal period this provokes a smaller temperature at the final of that period. So the absorption chiller expends less time to turn down the temperature to the minimal.

Table (9) shows the results (NPV: net present value) of the two cases studied, besides one called conventional system. In this conventional case there is no microturbine, Otto engine, absorption chiller and cold or warm water storage tanks. The only device is the compression air conditioning split system. In the conventional system, as there are no storage tanks, the compression split is chosen so its nominal refrigeration power equals the maximal thermal load (70 kW). Since there are no engines, in the conventional system all the electrical energy is bough from the utility vendor.

Table (9) shows that, for the data used in the simulation, the better choice is case 2 for its smaller NPV value. The difference between the NPV for the two cases amounts to 8%. Another important result is the greater initial payment for the cogeneration option. This well known characteristic of cogeneration plants can prohibit its choice to clients with any difficult to get credit.

Table 9. Financial results for the conventional system and studied cases.

System	Amount
NPV conventional	$ 175,062
NPV case 1	$ 178,783
NPV case 2	$ 164,145
Initial payment for the conventional	$ 19,583
Initial payment for the cogeneration (both cases)	$ 74,177

7. Conclusions

This work has presented a task configuration system to be implemented in each one of the devices of a cogeneration system. By varying the state of the switches it's possible to change the whole behavior of the system. In the studied cases, the change in the state of a unique switch has changed the NPV by 8%.

It is worth noticing that this comparison was made between cases in which only one switch was changed. For the system in study there are 335,544,320 ((2^26)*5) possible configurations to be examined. The method here present could do all those calculations if time enough was provided. The authors have preferred to explain in detail the importance of the task configuration system instead of a multitude of cases that are only fodder to the dull method of exhaust search. It is clear the force of the task configuration system to generate millions of possibilities, while there is the weakness of the method of exhaustive search in dealing with all them.

In the personal computer utilized in these simulations (1 GHz) each case run demand 20 seconds so the examination of all the possibilities would demand 194 days. Because of this prohibitive processing time two strategies are being envisaged: study of major guidelines to the choice of the varying switches and the application of another optimization method that permits to obtain the optimized state of a non-linear system in which there are mixed discrete and continuous variables. Anyway, the importance of computational optimization it is obvious in this case with so many possibilities. The solution is not to give away from one model that generates so many possibilities, but in developing an efficient optimization method.

The task configuration system can be easily adapted to an operational optimization instead of the design optimization described here. In that case, the system could change its behavior every time a change in the electrical or natural gas tariffs happens.

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9. References

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