Evolution towards a smart Energy Supply System in the Balearic Islands

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Abstract. The Balearic Islands are a typical example of centralized energy supply system based on the work of a large coal thermal power plant. Low reliability and high emissions are some the problems inherent to this configuration. Highly oscillating demand curves and increasing energy consumption are added problems in this case. Furthermore, many critical points have been identified in the power transportation grid that can cause the failure of the whole system. Many of these problems are inherent to isolated centralized energy systems. In the studied case the connection to the mainland grid is not solved, though options are being considered by the authorities. However neither of these solutions will fulfil all the needs of the Balearic power system nor profit the high potential in RES of these islands. That way, new solutions are needed for assuring the energy supply. One of these solutions is the application of the idea of the virtual utility (VU) configuration. Some of the advantages of this idea in front of other options are the high agility of the system to find the optimal operation point, the high integration of RES and the high reliability due to the use of distributed generation facilities.

Key words

Distributed generation; Virtual Utility; Energy management system; Renewable Energy Sources integration; Energy infrastructures.

1. Introduction

The world of energy has lately experienced a revolution, and new rules are being defined. The climate change produced by the greenhouse gases, the inefficiency of the energy system or lack of energy supply in most of the poor countries, the liberalisation of the energy market and the development of new technologies in the field of distributed generation (DG) are the key factors of this revolution. It seems clear that the solution at the moment is the DG, because it includes renewable energy sources and high efficiency technologies, such as co-generation and tri-generation, in the same system. The benefits of it are high reliability, high speed for assuming quick changes in the demand, correct integration of renewable energy sources and the decrease of fuel consumption. The next step in the DG world is the interconnection of different small distributed generation facilities which act together in a DG network as a large virtual power plant controlled by a centralised energy management system (EMS). The aims of the EMS are to reach the targets of low emissions and high efficiency. The EMS gives priority to renewable energy sources instead of the use of fossil fuels. This new concept is referred to as Virtual Utility (VU) [1].

This work considers the present state of the Balearic Islands energy system and makes a theoretical study of the implementation of the VU idea on this system.

The structure of this paper is as follows. The description of the actual situation (point 2), the description of the model used for the VU implementation (point 3), the new scenario result of the VU implementation (point 4), the comparison between the present situation and the new scenario (point 5). Conclusions of the work will be drawn.

2. Present Situation

The Balearic Islands energy generation and distribution system is composed of two independent electrical networks. The biggest one belongs to the Majorca and Minorca islands and represents 86% of the total energy generation on the islands. The smaller belongs to the rest of the islands. Only the system Majorca Minorca will be analysed here.

A. Energy generation

The Majorca and Minorca system is propriety of ENDESA. The utilities connected to this grid are listed in table I. The generation system is composed of a thermal power central responsible of the 46% of the demand on these two islands, and a combined cycle central which generates the 30%. The rest, 24%, is generated in 3 small distributed generation plants. The main thermal power central, with a nominal power of 510MW, constitutes the basis of the system. The other utilities assume the peaks of demand on the islands. The peak demand for 2001 was 831,8 MW and the total installed power is 1018,2 MW. It lets a security margin of 186,4 MW [2]. There are also some distributed generation facilities connected to the main grid propriety of different companies but at the moment do not represent a big influence on the whole system.

TABLE I. – Power generation in the system

NAME	TECHNOLOGY	NOMINAL POWER [MW]
Alcudia	Steam (coal)	510.0
	Gas Turbine	75.0
Sant Joan de Deu	Steam (Fuel)	195.0 (not in use anymore)
Son Molines	Gas Turbine	64.0
Maó	Diesel Engine	47.4
	Gas Turbine	76.0
Son Reus	Waste incineration plant	20.0
Son Reus	Gas Turbine Steam (C.C.)	225.8
DG facilities	Various	5.1

The renewable energy sources available on the islands are solar energy, wind and biomass. Recently studies show the possibility of geothermal energy but there is no installation on Balearic Islands at the moment for this energy. From the possibility of the use of solar energy, installations of solar thermal collectors and photovoltaic panels have been developed. In the last years a progressive grow in the use of thermal collectors due in part to the support programs developed by the local government and in part due to the high return ratio of this technology. The grow of photovoltaic panels on the islands in the last years have been exponential, due to the construction of the largest photovoltaic installation on the islands. The wind energy is also growing. Some new installations are being developed, like a new Wind Mill Park in Minorca, still under construction. Due to a strategic action of the Balearic Government and the supply company, old mills from Majorca are being recuperated and converted in wind electricity generators. Biomass is still the most used renewable energy source, due to the traditional heating systems.

B. Power grid

The electricity grid on Majorca and Minorca is also propriety of the supply company ENDESA.

The main transport grid is a 220 kV aero power grid, communicating the Alcudia power thermal central and Son Reus with es Bessons, sa Pobla, LLubí, Palma and Valldurgent transformer centres.

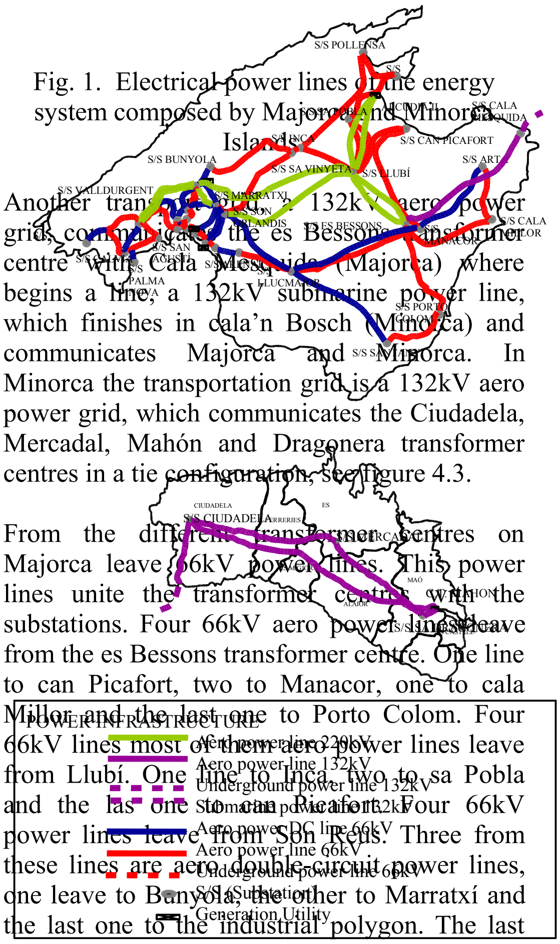


Fig. 1. Electrical power lines of the energy system composed by Majorca and Minorca Islands

Another transport grid is a 132kV aero power grid, communicating the es Bessons transformer centre with Cala Mesquida (Majorca) where begins a line, a 132kV submarine power line, which finishes in cala'n Bosch (Minorca) and communicates Majorca and Minorca. In Minorca the transportation grid is a 132kV aero power grid, which communicates the Ciudadela, Mercadal, Mahón and Dragonera transformer centres in a tie configuration, see figure 4.3.

From the different transformer centres on Majorca leave 66kV power lines. This power lines unite the transformer centres with the substations. Four 66kV aero power lines leave from the es Bessons transformer centre. One line to can Picafort, two to Manacor, one to cala Millor and the last one to Porto Colom. Four 66kV lines most of them aero power lines leave from Llubí. One line to Inca, two to sa Pobla and the las one to can Picafort. Four 66kV power lines leave from Son Reus. Three from these lines are aero double circuit power lines, one leave to Banyola, the other to Marratxí and the last one to the industrial polygon. The last 66kV power line which leaves form Son Reus is part aero and part underground line and it goes to Coliseo. Five power lines leave from the last transformer centre: Valldurgent. One line in part aero of simple circuit and in part aero of double circuit leave to Andratx. One double circuit aero line to Calvià. Another aero power line to San Agustí. One line in part aero power line in part underground to Santa Catalina. An aero double circuit power line to es Rafal. See figure 1.

3. Description of the model

The VU will be composed of local clusters managed by a central control system, each cluster composed of a group of basic utilities. For the sake of simplicity a single model has been used for these utilities. This model represents a good configuration for the case of Balearic Islands, including RES and DGs and it is an existing new utility [3].

Each basic utility is comprised of a tri-generation plant of 7,25 MW electrical power and a thermal production of 6210kW from the cogenerators and a maximal of 65MW/h of the solar thermal collectors. The utility will consist on five Diesel engines [4], a solar thermal installation [5] with high temperature collectors of 864 m2, a photovoltaic plant [6] of 8,6 kWp and two lithium bromide absorption chillers [7], one of 1.318 MW with a COP=0,64 and the other of 436 kW with a COP=0,64, both of them of simple effect. The thermal and cooling energy will be distributed by district heating and cooling network to the buildings around the plant. The power generation is connected to the general grid of distribution of the Island. The philosophy of running the energy plant is to give priority to the use of the solar plant over the use of the diesel engines. These engines will run only when maximal power is needed, and it coincides when maximal thermal energy is needed.

4. New Scenario

This point will only construct the hypothetical scenario based on the application of the VU idea to the Majorca-Minorca energy system. The evolution of the present system towards a VU will not be considerate, being out of the scope of this work.

To reach the total production of the actual system 140 basic utilities will be needed and distributed between the islands of Majorca and Minorca. The electricity produced will cover all the electricity needs of both islands. The location of these utilities will be determined by the thermal demand. Thermal production will be used in form of heating, cooling and sanitary hot water. The solar thermal collectors will no be taken into account and will be considerate as the backup of the system, to ensure the thermal supply in the worst case, but should be taking into account that the maximal thermal demand (in form of cooling) will coincide with the maximal energy production of the solar plant.

The whole system of clusters will have the same installed power than the centralized system. This consideration has been done for making clear the comparison. In a real case the installation of a VU would change also the total electricity consumption, due to the decrease in the use of conventional electricity heating and air conditioning systems.

A. Utilities location

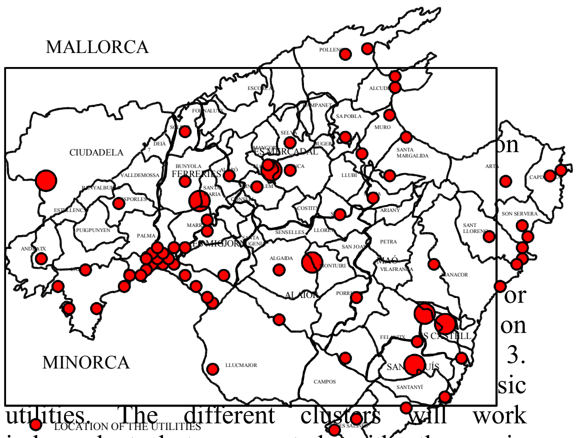
The study for the location of the local clusters will be the superposition of two maps. The first one is the fixed population on Majorca-Minorca and the second one the tourism. The utilities will be located in the areas where the thermal demand can be used, see on figure 2.

Some criteria have been considerate:

- Hotel occupation: 90% (worst case). In 2001 the occupation ratio was 78,1% [8].
- It is not possible to cover 100% of the thermal necessities.
- The election of the locations has been done choosing the higher thermal necessities (worst of the cases).

The total fixed population on Majorca in the year 2001 was 700.533 habitants. The total tourist places on Majorca are 275180 [9], the data basis used has information about 206849 of these places. The total utilities number necessaries for covering the thermal demand of the fixed population and these 206849 places is 331 utilities, the number of utilities assigned to Majorca are 130. Due to this the 39% of the thermal necessities within this system will be cover. It means the reduction of the energy consumption on Majorca for generating this thermal energy.

The thermal demand on Minorca will be determinate like in Majorca. The number of utilities assigned to Minorca are 10.



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utilities. The different clusters will work independent but connected with the main electricity grid. Both islands will be interconnected by a submarine cable.

The central control of the VU will be in the main building of the new infrastructure where the EMS will be located. From this building the data basis of energy demand, generation, climatologic of last years for every group of utilities, characteristics of the equipment, direct information of the actual behaviour,… will be analysed and the function of every single cluster (through its LMS) will be set, see on figure 3.

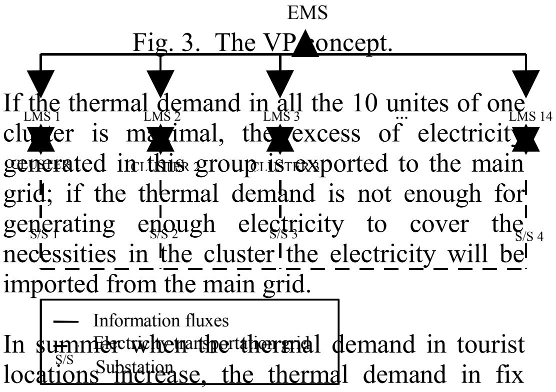

Fig. 3. The VP concept.

If the thermal demand in all the 10 unites of one cluster is maximal, the excess of electricity generated in this group is exported to the main grid; if the thermal demand is not enough for generating enough electricity to cover the necessities in the cluster the electricity will be imported from the main grid.

In summer when the thermal demand in tourist locations increase, the thermal demand in fix population locations decrease. The VU will take advantage of this fact; forming the clusters by tourist and fixed locations trying to cover the whole electrical necessities without exporting or importing electricity to the grid.

The clusters will be connected each other by 66kV power lines. The utilities belonging to the same cluster will be interconnected by 15kV power lines.

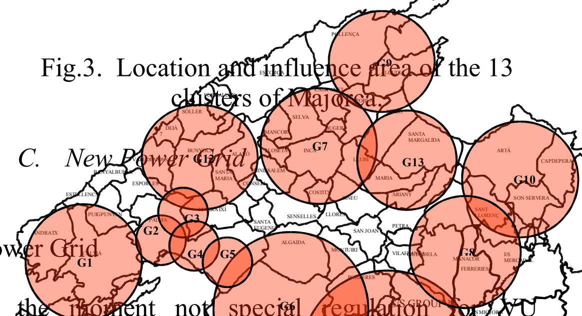

Fig.3. Location and influence area of the 13 clusters of Majorca.

C. New Power Grid

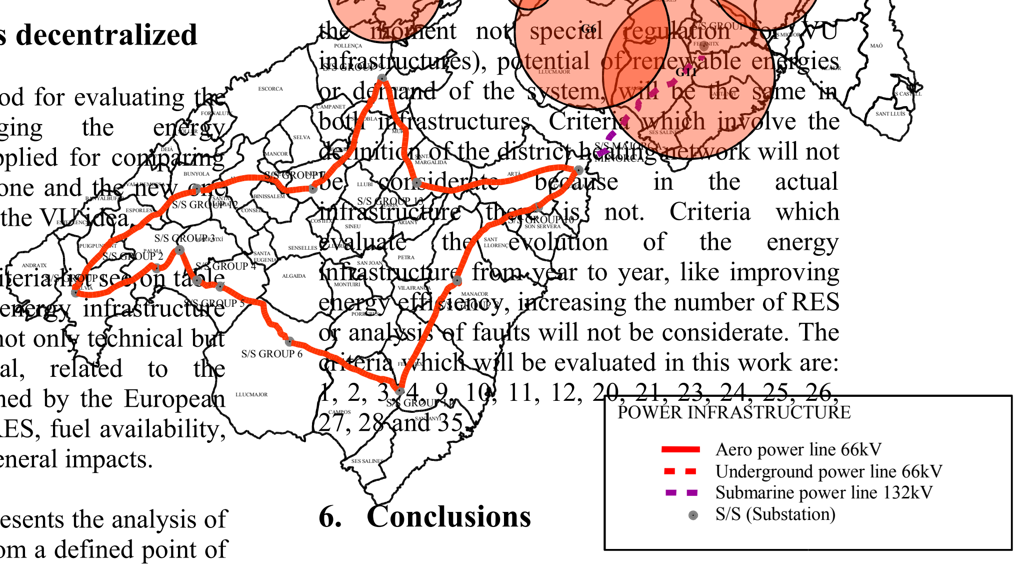

Fig.3. New Power Grid

5. Centralized versus decentralized

This point searches a method for evaluating the improvement of changing the energy infrastructure. It will be applied for comparing the two scenarios the real one and the new one after the implementation of the VU idea.

The method consists in a criteria list seen on table III, which will define the energy infrastructure since all the point of view not only technical but also social, environmental, related to the sustainable objectives defined by the European Commission, potential of RES, fuel availability, economical, political and general impacts.

Every group of criteria represents the analysis of the energy infrastructure from a defined point of view, see on table II. The same importance will be given to every group in the evaluation.

TABLE II. – Group of criteria and correspondent number of criterion

Group of criteria	***Criterion number***
Structure of the existing generation, transmission and distribution system [10],[11]	1,2,3,4,5,6,7,8,9,10 ,11,12,13
Potential of Renewable Energies Sources	14
Fuel availability	15,16
Energy demand (electrical and thermal) to the system	17,18,19
Total yield of the energy system	20
Emissions policy [12]	21,22
Global Costs of the system [12]	23,24,25,26
Social Impacts [13]	27,28,29,30,31,32
Institutional and regulatory factors	33,34
Contribution to sustainable objectives [14]	35,36,37,38,39,40

Some of the criteria for evaluating energy infrastructures will not be used in this comparison for different reasons. Criteria like institutional and regulatory factors (there is at the moment not special regulation for VU infrastructures), potential of renewable energies or demand of the system, will be the same in both infrastructures. Criteria which involve the definition of the district heating network will not be considerate because in the actual infrastructure there is not. Criteria which evaluate the evolution of the energy infrastructure from year to year, like improving energy efficiency, increasing the number of RES or analysis of faults will not be considerate. The criteria which will be evaluated in this work are: 1, 2, 3, 4, 9, 10, 11, 12, 20, 21, 23, 24, 25, 26, 27, 28 and 35.

6. Conclusions

The conclusions derived from the comparison are as follows.

The centralised infrastructure is more stable and cheap but it pays a high price in CO_2 emissions, with the handicap that these emissions are concentrated in two main points: Alcudia (68% of the total emissions) and Son Reus (25% of the total emissions). Another added problem is that the system is based on the coal turbines work. The use of coal as fuel has an important effect not only in the climatic change but also acid rain, comparing to the VU system. The VU working with natural gas reduces in a 64% the

TABLE III. – Criteria list

Number	*CRITERIA-Definition*	*Metrics*	*INDICATORS*
Electrical power transmission and distribution system:			
1	- **Transmission and distribution infrastructure**	€/$kW_{electrical}$ + km of lines	• Length and definition of the electrical lines • Number and definition of Transformers • Number and definition of Substations • Electricity storage elements
2	- **Voltage levels of the system**	V	• Definition of the different voltage levels of the transmission grid
3	- **Transmission losses of the power distribution grid**	%	• Transmission losses of the power distribution grid with conventional copper or aluminium cables: - Conductor Losses: $W_c=R_c*I^2$ - Dielectric Losses: $W_d=wCU^2_0\tan\delta$
4	- **Grid Stability**	±Hz	• Grid stability: limits of the grid frequency
5	- **Analysis of fault levels. Causes and effects of these faults**	Minutes	• Number and causes of failures in the transformers in the year studied. • Number and causes of failures in the transmission line in the year studied • Number and causes of failures in the substations in the year studied • Number and causes of failure in the distribution system in the year studied • Number and causes of failures due transients: lightning's strikes, switching surges, etc. in the year studied
District heating network:			
6	- **Infrastructure**	€/$kW_{thermal}$	• Definition of the network topology: - Number, lenght and diameter of the pipes - Number and working point definition (pressure and flow diagram) of the Pumps • Definition of boundary conditions
7	- **Losses of the network**	%	• Calculation of the hydraulic losses of the network • Calculation of the thermal losses of the network
8	- **Storage tanks**	m^3/$kW_{thermal}$	• Size of the storage tanks • Isolation of the storage tanks
Generation system:			
9	- **Composition of the system**	%	• Installed power at the main power stations respect to the total installed power in the system
10	- **Power and thermal generation**	€/$kW_{thermal}$ + €/$kW_{electrical}$	• Description of the generation utilities: Power production • Description if it is the case of the energy efficiency technologies used by the utility: Thermal generation capacity
11	- **DG connected to the grid**	€/$kW_{thermal}$ + €/$kW_{electrical}$	• Description of the DG connected to the grid: number, description and power/hot/cold generation
12	- **Renewable energy input in the grid**	%	• Electricity production: curves of production • Thermal production: curves of production
13	- **Limits to penetration of RES and DG**	<%	• Defined by the managing company of the power grid
14	- **Potential of RES: Solar technologies, Wind, Water, Biomass, Biogas, Geothermal and other technologies such as hydrogen**	$kW_{thermal}$ + $kW_{electrical}$	• Study of the potential of RES in the studied scenario

15	- **Gas network**	m^3/s	• Availability of gas
16	- **Fuel supply system**	List	• List and capacity of available supply of fuels
17	- **Fixed demand: Population**	$kW_{thermal}$ + $kW_{electrical}$	• Energetic demand of the population
18	- **Fluctuation demand:** - Annual visitors (ie Tourism) - Daily visitors (people who is working there)	± %	• Energetic demand of the floating population
19	- **Evolution of the quality of life**	± %	• Increase in the energy demand of the population
20	- **Total yield of the system**	%	• Total Yield= $\frac{Delivery\_energy}{Fuel\_consumption}$
21	- **Emission production**	Kg-CO_2/kW	• If there is emissions "counter machine": Emissions production • If not, calculate the emissions with approximation tools
22	- **Emissions savings technologies**	kg-emissions	• To describe the emission savings technologies
23	- **Initial investment**	€/$kW_{electrical}$	• Initial investment in €
24	- **Operation and Maintenance (O&M) costs**	€/$kW_{electrical}$	• If the information is available the O&M costs in € • If the information is not available. As an approximation the O&M can be calculated as a % of the initial investment.
25	- **Fuel consumption**	€/$kW_{electrical}$	• Cost of the fuel consumption per Year
26	- **Cost of energy purchased and sold**	€	• Cost of the energy purchased per Year • Benefits of the energy sold per Year
27	- **Employment**	Number of workers	• Employment, directly related to the utility
28	- **Prices of the energy**	€/$kW_{thermal}$ + €/$kW_{electrical}$	• Price of the electricity • Price of the thermal energy for heating and cooling applications
29	- **Population supplied with energy**	Number of people	• Number of the population who are supplied with energy by the infrastructure
30	- **Assets. Changes in the property value**	± %	• Changes in the price of the proprieties due to the work of the utility
31	- **Space occupation**	Km^2	• Area which is occupied by the energy generation installations.
32	- **Satisfaction grad of the population**	Number	• Request on the population for defining it, evaluation from 0 to 10
33	- **Environmental Impact**	+ / - level km^2 years years	• Environmental Impact Study. The evaluation of the results will be as follows: - sign - intensity (3 levels: high, medium, low) - extension - persistence - recovery
34	- **Laws. I.e.: EU, Central Government, Local Government**	List	• List of laws, which affect the work of the network
35	- **Support programs. I.e.: EU, Central Government, Local Government**	List	• List of support programs to the different activities involved
36	- **Energy security: Reliability of the system**	%	• Data from the government, about % of population and time without electricity per Year.
37	- **Improving energy efficiency**	Δ%	• Comparison between the total yield of the system in two consecutive years.
38	- **Using more renewable energy**	Δ%	• Increase in the use of RES in two consecutive years
39	- **Making markets work**	%	• % of the total energy sold in the whole energy system
40	- **Technology: research, development and deployment**	€	• Investment of the utility in technology every year in function

TABLE IV. – Results of the comparison

Nº	Criterion	Indicator	Centralised	VU	∆(VU-C)
1	Definition of the structure of the existing generation, transmission and distribution system	Lenght of power lines: 220kV 132kV 66kV	 165 km 31 km 131 km	 0 0 325 km	 -165 km - 31 km 194 km
		Number of Substations	36	15	-21
2	Voltage limits	High power	66kV-220kV	66kV	
3	Transmission losses		8,5% [15]	<1%	-8,5%
4	Grid stability	Variation in the grid frequency	High	Medium-High	
9	Decentralisation degree	% of the system belonging to the main power station	51,7%	0,7%	-51%
10	Power and thermal generation	Power	1018,2 MW	1015 MWel	-0,31%
		Thermal	0[1]	869,4 MWth	100%
11	DG connected to the grid		31 MW	1015 MW	3274%
12	RES input	Solar thermal collectors	56.541 m^2	120.960 m^2	64.419 m^2
		Photovoltaic panels	326 kWp	1204 kWp	879 kWp
		Wind energy	461 kWp	461[2] kWp	0
20	Total yield of the system	Energy production/fuel consumption	34%	82%	48%
21	Emissions[3]	Middle CO_2	637.594	228.480	-64%
		Middle SO_2	3.186	7	-99,8%
		Middle NO_X	2.119	498	-77%
		Middle SP	318	0	-100%
23	Initial Investment		999[4] M€	6.597 M€	660%
24	O&M		21 M€	165 M€	780%
25	Fuel consumption	Coal Waste Fuel-BIA Diesel-C Natural Gas	1,239,308 tm 317,805 tm 118,035 tm 65,193 tm 0	0 317,805[5] tm 0 0 577,287 tm	- 1,239,308 tm 0 - 118,035 tm -65,193 tm 577,287 tm
		Total [TOE]	961.006 toe	708.489[6] toe	-26%
26	Energy purchased and sold	Electricity	100%	100%	0%
		Thermal energy	0%	100%	100%
27	Direct Employment		349	358[7]	103%
31	Space occupation	Area occupied by the infrastructure	$120*10^3$ m^2	$840*10^3$ m^2	700%
35	Electrical security		99,96%[8]	100%	0,04%[9]

[1] The thermal production in the centralised infrastructure depends on the user side.
[2] The wind energy production has not been taking into account in the design of the cluster, because it does not affect to the global function of the VU.
[3] The VU working with Natural Gas
[4] Only for electricity production
[5] The waste treatment plant would be keep in the new infrastructure.
[6] Working with Natural Gas
[7] The same administrative structure but a team of 3 technicians for every cluster.
[8] Data from the supply company. Similar infrastructures have a security of a 97%.
[9] Using data from the IEA would be 3%

CO_2 emissions and almost has no emissions of SO_2 and NO_X. The use of fossil fuel in the utilities which form the VU clusters would be another possibility. The reduction in emissions would in this case about 21% of CO_2 and 81% of SO_2 but increasing the NOx emissions in a 1%. The SP using gas or diesel fuel would be 0.

The direct employment generated by the centralised system is lower, having as a direct consequence that the cost of management and operation of this infrastructure is much lower than the VU one.

A problem of this centralised infrastructure is that the energy security generally is lower than the VU one.

The transportation grid in the VU works at lower voltage than the centralised one. This fact avoids problems with high electrical power fields. It is quite surprising that the longitude of the distribution grid is similar in both cases: VU (325km) and centralised (327km) on Majorca. This fact can be explained because of the geography of the islands. The number of substations is lower in the VU, because of the less necessity of large amounts of electricity transportation. Obviously the transmission losses decrease in the VU because of the lower electricity transportation.

The yield is an important point for evaluating an energy infrastructure. In the case of the centralised system without adequate energy efficiency technology is much lower (34%) than the VU (82%). The direct consequence is that for the same fuel consumption the benefits of the VU exploitation company will be much higher.

The integration of RES in the centralised system energy infrastructure is just symbolic but in the VU is a real integration in the thermal side as well as the electrical side.

Obviously changing the energy infrastructure is not the solution of all the energy problems of our society, but a necessary improvement of the actual situation. The solution could be finding another process for electrical generation. Until these new energy sources or processes will be available, it is important to find the way to take maximal advantage of the existing processes and this is what this work is about.

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