Computer Science Tool for the calculation of technical-economical viability for the Integration of Renewable Energies in Pumping Stations (HIIER & CIBER)

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Abstract.

Large-scale integration of Renewable Energy Sources (RES), displays the disadvantage of its randomness [2, 3],. In this paper it's shown a computer science tool that studies the combination of a large pumping station for irrigation with renewable power supports.
This tool analyzes the optimal dimensions of all elements of the installation, as well as it considers the economic returns that will be derived from its operation. This study has been done in the area of "Alcalá de Gurrea" (Zaragoza, SPAIN)

Key words

Integration of Renewable Energy Sources, Pumping Stations, Automatization of the calculation, technical-economical viability.

1. Introduction

The short economical margin for dry land plantations, has led to turn vast extensions in Aragón into irrigated lands. Nevertheless, carrying water where there isn't any, means installation and operational costs that aren't affordable by irrigators.

Integration of RES in irrigation systems tries to palliate the costs in such installations, optimizing its use, increasing its efficiency, or moreover, becoming alternative income sources [1]. In this paper two developed computer science programs appear, HIIER and CIBER that allow making technical-economic analysis on different types from integration of RES in pumping facilities.

Main power backups studied are wind energy, hydroelectric energy and biomass as an alternate crop.

2. State of the Art

There are several programs developed in the scope of the integration of RES, specially in the denominated hybrid systems that mainly look for the optimization of systems of generation with renewable energies jointly working with diesel generators and storage systems [7] like batteries. Most important programs are:

A. HOMER: (Hybrid Optimization Model for Electrical Renewables)

The program uses a combination of wind, photovoltaic and diesel generators with batteries to replace the necessities of electricity of remote sites. The program shows us different combinations of generators-batteries that would cover an energy demanded. For his calculations, it counts on a series of models of different types of generators.

The inputs that it requires are measurements or estimations of renewable resources and the costs of generators. The outputs obtained are the combinations generators-batteries that would cover the demand, cost of each one of the alternatives and different analysis of correlations.

B. HYBRID2

This program allows obtaining the optimal combination of sources of electrical generation to cover a demand of certain energy. The university of Massachusetts with the purpose of finding a tool that allowed designing a hybrid system for the electrical generation developed it. [8, 9]

This system is more advanced than the HOMER since it allows obtaining a better model of the results combination and of optimizing the output based on the parameters that are desired.

The inputs to the program are: loads (defined according to its use and type of feeding), measurement of resources, power systems used, economic considerations.
The outputs of the program are: consumed and given energy, modelled of the diesel system, evolution of the batteries load, optimization of generation-storage systems, analysis of lifetime.

C. CARE

Advanced Control System for the operation and control of isolated generation systems, with a high wind energy penetration. Due to the presented problems in the power systems by the integration of wind generators (randomness mainly), this energy hasn't a high degree of penetration for replacing the demand of a system connected in island (isolated). This work tries that with a suitable control system, the maximum wind energy potential of a zone can be used to cover the power necessities, obviously integrated into a system of generation of good reliability as it can be a thermal one (diesel, oil-diesel or gas). [10, 11]

The development of this program is supported by the European Union, under project JOULE III, and initially was developed for the island of Crete, but soon it become general for any type of installation that adjusts to the treated characteristics. The system is developed with base in a series of models and prediction tools, applied so much to the projections of demands like of amount of resources; strategies like fuzzy logic, neuronal networks and evolutionary programming are used, in order to participate of all the process of optimization and control.

Our program can't be compared with other methods of solution [4, 5, 6], since this problem in concrete has not been looked at before from the perspective that has become in this work. A study that must follow as line of investigation from this development is the inclusion of genetic algorithms or evolutionary strategies in the search of maximums and absolute minimums in the considered space solution (Fig. 2), since the conformation of this, the nonlinearity of the variables, their independence and multiplicity constitutes an optimal space of work for these techniques.

3. HIIER computer science tool

A. Characteristics and work methodology

The calculation process of the program differentiates between new or already existing facilities, and makes the calculation hour by hour. The integration options of the program are:

1) *Pumping with wind support:* It consists of using the wind energy potential of a zone (obtained by means of meteorological study) to diminish the consumption of the pumping system.

2) *Pumping with wind support and generation:* It is like the previous case, but uses non-usable wind energy potential by the pumping system to generate electricity that will be spilled to the network.

3) *Pumping with hydroelectric generation:* Starting off of the installation of original pumping, it uses the dam like energy reserve, it means, it pumps at the moments that the pumping system is stopped in order to generate hydroelectric energy later.

4) *Total integration:* In this case all the options are combined. A pumping with wind support is made and in addition, during certain periods, we have electric energy generation by hydro or wind generators.

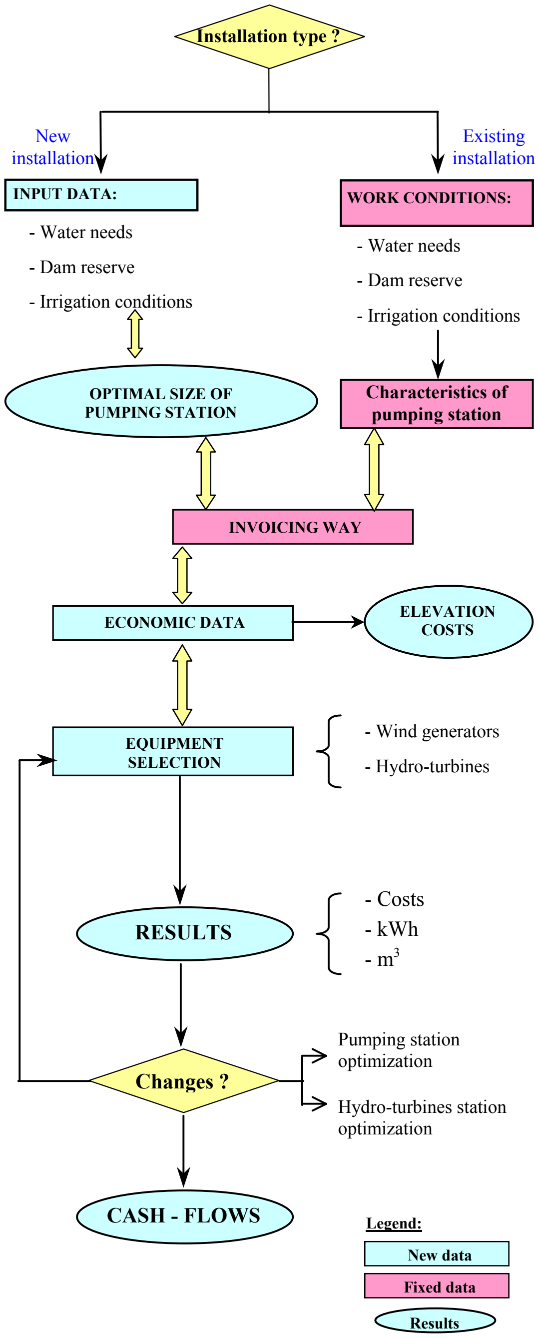

Fig. 1. Flux diagram from HIIER

In Fig. 1 the flow diagram of the program can be seen. We see the differences between new facilities and already existing ones. If the installation is new, the program calculates the parameters of the optimal installation of pumping by next way:

B. Optimization of pumping station

In case of new facilities, the program determines the optimal pumping station, conjugating the costs of investment and operation. The inputs for the program are data like monthly demand of irrigation, levels of reserve wished at every time and the existing limitations of irrigation in the zone. The output is an estimation of dam and pumping size. In Fig. 2, we can see the optimization curve that the program makes with the obtained results:

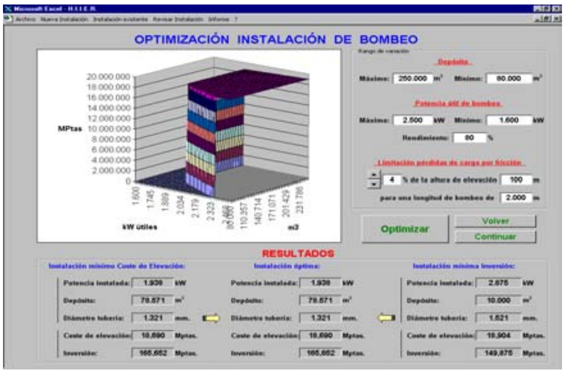

Fig. 2. Optimization sheet from HIIER

C. Technical-economical analysis of different integration options

Once known the physical parameters of pumping station because the installations already exists, or because it has been offered to us like optimal by our computer tool in the previous step, the program begins the study of the different integration of RES options.

1) *Invoicing way:*
First we have to introduce the invoicing type with which is going to work, it means, the cost of the electricity based on the certain day and hour (we differentiate between low, medium and high energy cost hours).

2) *Economic data:*
Later, financial data are settled (financing data, interest rates, periods of the loan and amortizations) that will allow to know the basic parameters of decision like Net Present Value (NPV), Internal Rate of Return (IRR) and Cash flows. These data are empirical, since they depend on the conditions of the market and a fixed guideline for its selection does not exist.

3) *Equipment selection:*
In this section are different integration options or study conditions.
Thus, for example, wind power support it's calculated from the meteorological study made on the zone, marking the wished percentage of penetration and the unitary power to install.
The hydroelectric support is obtained from the pumping system and the dam size, by means of an iterative process that calculates hour by hour the hydroelectric generation, always considering the premise to give priority to pumping process and the contribution of wind energy in the case of total integration.

4) *Results:*
The obtained results are the economic optimization of the pumping station on the one hand, and by another one and more important results of each case of integration, which are expressed in terms of equivalent hours, energy and operation costs. This information is displayed in tables and comparative panels like those of Fig. 3. Also viability parameters are offered such as Payback, NPV and IIR.

Fig. 3. Results chart from HIIER

4. CIBER computer science tool

A. Characteristics and program methodology

Program CIBER, "Economic calculations for pumping facilities with renewable energies", was developed with the aim of a real approach of the costs of the different elements that a pumping station has, as well as of the different renewable power supports that they could be integrated in the same one.

The program basically consists of six sections based on the different parts of a pumping station with RES supports that are needed to calculate:

1) *Calculation of the dam*
2) *Calculation of the pumping pipe*
3) *Calculation of the pumping station*
4) *Calculation of electrical lines*
5) *Calculation of the wind power support*
6) *Calculation of the hydroelectric generation*

Each one of them has been made from obtained real budgets of different suppliers, catalogues and Internet.

The inputs in this program are independent of the HIIER. Nevertheless, both applications are complementary, since

HIIER establishes the dimensions of the system and CIBER generates the functions of costs of these systems or similar, so that an optimization process can be made in the surroundings of these values.

B. Calculation of the dam

The system requires for the calculation of the costs, constructive parameters such as capacity, depth, slopes and closings. These data are entered in a form as the one of Fig. 4. All these parameters have the premise of the optimal design of the dam, in the meaning that the earthwork and surface to waterproof are minimum.

Fig. 4. Calculation of the dam

The CIBER tool has the particularity of having in the same screen the entrance of data and the exit of results. In addition it obtains a curve of regression based on the capacity parameter, curve that is introduced in program HIIER for the optimization of the pumping system.

C. Pumping pipe

For the calculation of the pipe, different calculation parameters are used, among them: type of material of the pipe, lost calculations, technical legislation about it, etc...

With these conditioners, the user introduces the flow, the height and the geometric length as design parameters, and the system displays different alternatives, based on the different calculation ways used. This is reflected in Fig. 5.

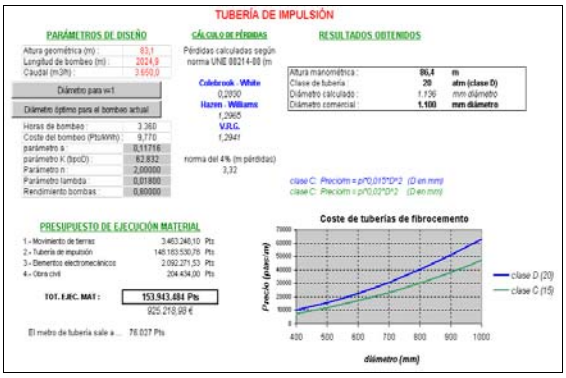

Fig. 5. Calculation of pumping pipe

Like previous case, also the curves of regression based on the diameter appear, to be introduced in program HIIER like support to the optimization process.

D. Pumping station

To calculate the pumping station costs, different manufacturers were asked, as well as the technical characteristics of such installations. With these data, was settled what type of pumping system adjusts better to the power levels, height and flow more common in pumping stations for irrigation. The design parameters, in addition to already mentioned are: number of pumps, efficiency and real power. With the provided costs the correlation curve is obtained, based on power parameter. This can be seen at Fig. 6.

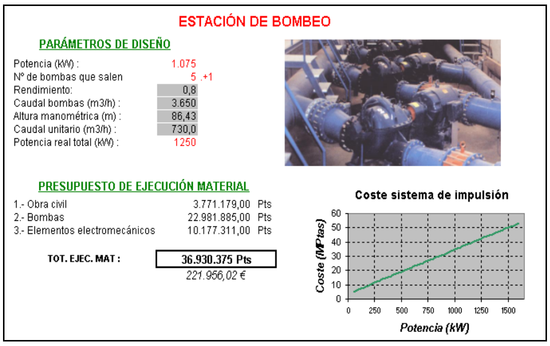

Fig. 6. Calculation of pumping station

E. Wind energy support.

The curve of Fig. 7 was processed from prices extracted of catalogues of commercial wind generators. In this curve we can observe the wind power cost by kW installed based on the power of the wind generator. The oscillations of prices are dues fundamentally to the implantation in the market of certain powers more than others, for example, 600 and 1.000 kW.

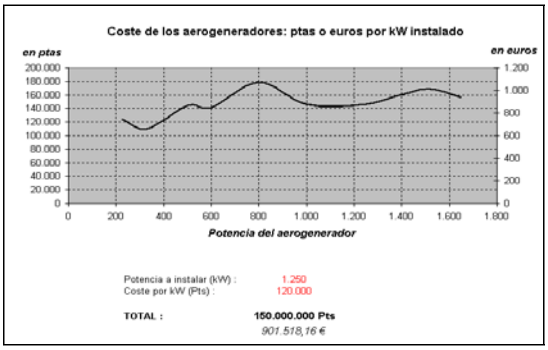

Fig. 7. Wind generator costs Vs power

F. Hydroelectric generation

With flow and height as input data, the only part that the user has to determine it's the type of turbine wished, Francis or Pelton, based on the work point of the machine and its personal preferences. From there, the program determines the cost of the hydroelectric system.

The other elements of the hydroelectric system, are calculated from the cost of the turbines, considering that a big part of the civil construction and necessary builds already is in the pumping station.

5. Application of the program to a real case

A. Characteristics of the installation

The planned pumping station will be formed by a pumping building located besides the "Acequia de la Violada" (a drain), a pump pipe and a dam situated in a high place, where water will be spread to all the irrigation lands.

The installation general map can be seen on Fig. 8. The dam will be build taking advantage of the land topography, in order to minimize the cost of earth displacement. Physical data are:

- Total length of pipe: 2.025 m
- Pumping Height: 83 m

The placement was carried by means of a former study of the feasibility for renewable energies integration in Aragón.

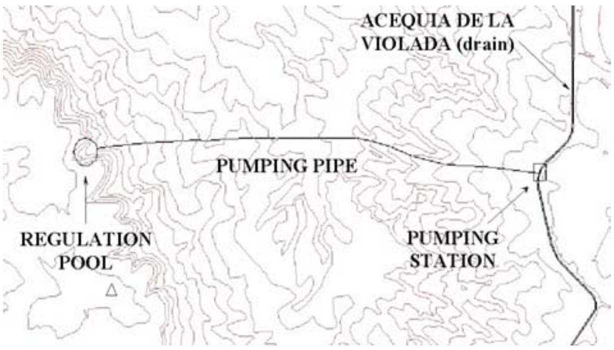

Fig. 8. General map for the pumping station

The watering needs of the zone are two, the traditional crops and the energetic crops. The energetic crop is thistle (Cyanara Cardunculus), and corresponds to the needs of a 12 MW biomass energy plant. Demand for traditional (right) and energetic (left) crops can be observed in Fig. 9. In this way, we can obtain an almost constant demand.

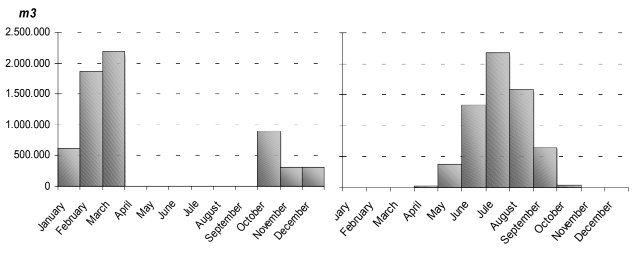

Fig. 9. Watering demands

B. The sizing of the optimal pumping station

Optimization of dam size, pipe width and pumping power has been done with the computer science tools HIIER and CIBER, designed by the research team in this project.

The computer tool calculates installation costs and operational costs for different combinations of pumping power and dam size; this is done considering pumping only in low power demand hours, and dam size big enough to face daily water demand. Using this approach, it's achieved a station with **minimal investment** and with **minimal operational costs**. Finally, yield account is been done in a 15 years time basis, which is shorter than installation service life, and we obtain the installation with minimal annual costs.

The basic principles of the system are:

- Pumping preferably in low-cost hours (in Spain they are called "valley hours"), in order to decrease operational costs (they are reduce to a minimum). Nevertheless, this condition can be compromised by irrigation demand: if this is high enough, it must be pumped through the rest of the non-valley hours.
- While there be hours of low cost power, system will store the maximum amount of water, so it can face water demand and reduce high cost power.
- For every case is analyzed if increments in pump power or dam size worth increase of investment installation service life.

The results found can be observed in TABLE I.

TABLE I.- Sizing for pumping station

	Minimal operation cost	Optimal installation	Minimal investment
Power required:	2.411 kW	**1.071 kW**	904 kW
Dam size:	70.179 m^3	**42.857 m^3**	30.000 m^3
Pipe width:	1.581 mm	**1.184 mm**	1.114 mm
Height annual cost:	180.316 €	**213.326 €**	247.520 €
Investment:	2.754.756 €	**1.487.675 €**	1.375.959 €

In order to design with commercial values, and seeing previous ranges, the chosen configuration was:

Power installed:	1.075 kW
Dam size:	43.000 m^3
Pipe width:	1.184 mm

Consumption results are shown in TABLE II:

TABLE II.- Hourly distribution of consumption

	Work hours	kWh
Low-cost	2.635	2.832.257
Medium-cost	692	743.626
High-cost	33	35.580

C. Integrating renewable energies in pumping stations

In this point the differences between a pumping station fed only by power utility, and an installation backed-up by renewable energies are analyzed. It is also analyzed if the necessary investments for this are profitable.

Types of integration to be analyzed are:
1. Pumping with wind support.
2. Pumping with wind support and wind generation.
3. Pumping with hydroelectric generation.
4. Pumping with total integration.

D. Pumping with wind support

Will be considered, to install 5 x 250 kW power, the same that pumping power, in order to reduce station energy consumption. 250 kW wind generators because they have a better profit of slow winds.
In this analysis has been considered wind hourly distribution, obtained of a meteorological study with Wasp 7.0 program.
The reduction of the annual energy consumption from the utility can be observed in table 3 and Fig. 10. Monthly comparison between simple pumping and pumping with wind support.

TABLE III.- Hourly consumption with wind support

	Pumping with wind backing		
	Worked hours	kWh consumption	% savings
Low-cost	1.098	1.180.215	58,3
Medium-cost	379	407.187	45,2
High-cost	0	0	100

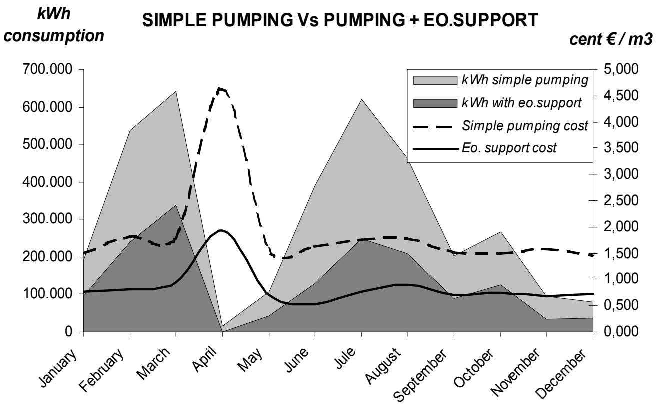

Fig. 10. Monthly comparison between simple pumping and pumping with wind support

Results for Payback, NPV and IRR, calculated on the new investment in wind backing, considering as incomes the savings originated by its deployment, in 15 years are:

- Investment: 901.518 €
- PB: 7,9 years
- NPV: 584.231 €
- IRR: 11,25 %

E. Pumping with wind support and wind generation

Installation is the same as the one in wind backing, but here it is used all energy produced by windmills. When power from windmills exceeds the necessary power for pumping, or it isn't necessary pumping, energy production will be sold to the electric grid, utilizing better the produced electric energy and making a more profitable investment.

The hourly shares for pumping consumption and wind generation are showed in TABLE IV. Energy savings are clearly shown in Fig. 11

TABLE IV.- Pumping consumption and wind generation

	Consumption		Generation	
	Hours	KWh	Hours	KWh
Low	1.098	1.180.215	776	970.407
Medium	379	407.187	398	496.900
High	0	0	283	353.775

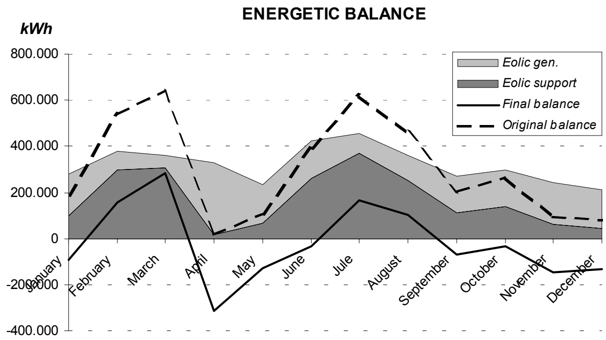

Fig. 11.- Monthly energy balance with wind sup + gen

In the energy balance for the whole system, can be observed that energy shares by wind backing or wind generation are higher than energy demand, so the system has a positive annual energy balance, which is a very favorable which shows that the system has energy exceeds, so it is a very worthy energy integration system.

Nevertheless, the system is not a stand-alone one, because energy generated sometimes is not enough to use it for pumping and some other times it cannot be profited, because is not needed pumping. Because all of these reasons, system must stay connected to the electricity grid.

Yield account is:

- Investment = 901.518 €
- PB = 3,95 years
- VAN = 2.049.639 €
- TIR = 33,31 %

F. Pumping with hydroelectric generation

The main characteristics of the hydroelectric station are:

- Flow: 1,01 m^3 /s
- Pump height: 79,78 m
- Total power: 790 kW
- Turbine efficiency: 89 %
- Generator-transformer group efficiency: 90 %
- Generator leads power: 632 kW

The cost increment of the installation for the hydroelectric exploitation is only 416.952 € because the pumping building will be also used for the turbine. The only new components added will be the bypass, the turbine, the generator and all the protection and control needed elements.

TABLE V.- Basic results of the pumping installation with hydroelectric generation

	Pumping	Pump + hydro generation	
		Consumed	Generated
KWh/year consumed/ generated	3.611.463	4.702.323	*-666.574*
Annual pumping cost	212.141 €	224.015 €	

Concluding, the turbine process associated with pumping is not economically profitable mainly due to three facts:

1. The process performance is rather low, 61 % of performance implies a cost of 1.63 kWh per obtained kWh.
2. The tariff type: The non-exclusive use of water for irrigation forces to change tariff class, arising energy price, so that, it's needed to pay an excess of 11.151 €/year due to the tariff change
3. The actual selling price for this kind of energy (hydroelectric generation) is not profitable. The energy selling price would be higher than 6,48 cent € in order to be profitable.

The lack of profitability of this process does not entail that in the future it could be economically favourable. In [6] it is shown how this kind of installations will be viable after 2005.

G. Pumping with wind total integration

This case is a combination of all of the precedent ones. The wind power system will always be contributing energy to the process provided that the necessary wind conditions are fulfilled. The produced energy will be used in the pumping process or will be injected directly to the power network, depending on the particular needs. The hydroelectric generation will use the excess of pumped water.

The total investment needed in order to set up all the backings is 1.218.470 €.

The consumption distribution of this new situation can be observed in Fig. 12.

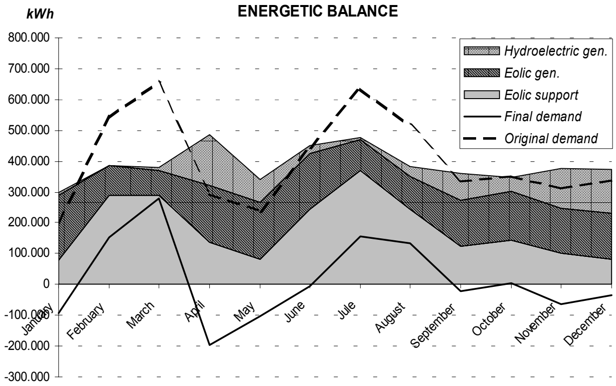

Fig. 12. Monthly energy balance in total integration case

Calculated results of PB, NPV and IRR, taking into account the new investments in the wind backing and the savings due to its next 15 years operation are:

- PB: 6,28 years
- NPV: 1.406.718 €
- IRR: 16 %

H. Summary results

Fig. 13 shows cost per pumped water m^3 for irrigation. Solid line shows mean costs for pumped m^3 in present installations in the same zone, which is around 2,4 y 2,8 cent € /m3. It can be observed one of the great advantages of this study is reaching optimal cost for irrigation, because the price per pumped m^3 is lowered in a vast amount for every case. The best option in €/m^3 pumped way is pumping with wind support and wind generation or total integration.

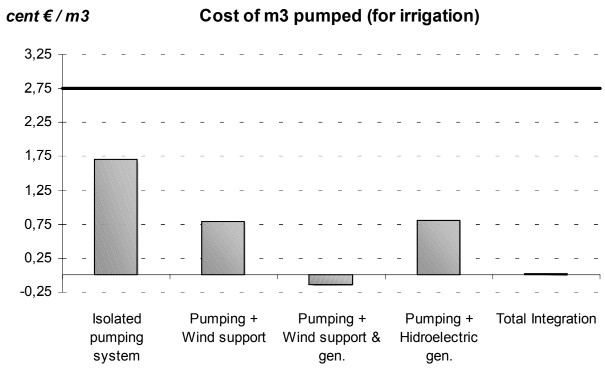

Fig. 13. Cost for pumped water m^3

Fig. 14 shows system energy balance for each one of the different options. When wind support and wind generation or total integration is used, an annual zero is reached.

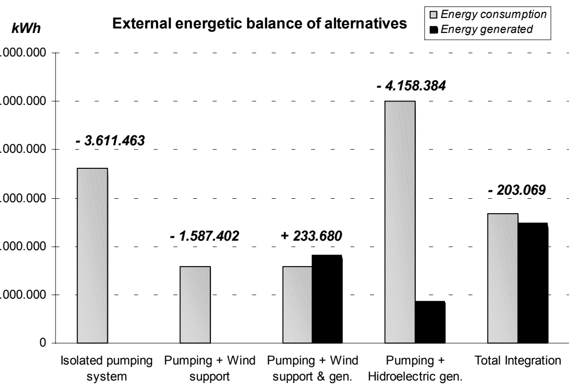

Fig. 14. Energy balance

Nevertheless, such an installation cannot perform alone, because in consume peaks it cannot get all the power demanded from it, and because owed to its own random nature, there are any situations in which energy production cannot be assured. In order to solvent this problem, this installations might be deployed besides biomass plants [7], so as with similar installations nearby, in order to establish a small autonomous generation system isolated from the electricity grid.

6. Conclusions and main contributions

- Development of two computer science programs, that allow the analysis of the integration of RES in any type of pumping station for irrigation, calculating technical and economic aspects
- Has been able to define the costs of investment based on parameters or variables such as installed power, size of the dam, geographical situation …
- Has defined an optimization algorithm that allows finding between all possible solutions, one that values the relation investment cost/operation cost, to find the optimal point of economic yield.
- Have opened different lines of investigation for the search of better techniques of optimization.

Acknowledgment

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