

The Canary Islands: A world laboratory for RET-desalination

The Canarian Archipelago is made up by seven islands: Lanzarote, Fuerteventura, Gran Canaria, Tenerife, La Palma, La Gomera and El Hierro. It is located in parallel 28, 60 miles off the African coast and 750 miles away from Cádiz.

DATA OF INTEREST:

Population	1.7 million people
Tourists per year	10 million people
Area	7.447 km ²
Coastline	1.531 km

No connection through submarine cable
Each island generates its own electricity.
No conventional energy resources

These characteristics, together with the strong role played by the tourist industry on the regional GDP and the growing necessity of water production resulting from it, regulate the supply and hinder the application of some energy policies and water programs. Today, water desalination in the Canary Islands goes beyond some techniques for water treatment. Desalination technology has represented a survival factor for many communities in the islands in the last 30 years; in fact, the very survival of the islands is not conceived without desalination. This way, desalination is closely attached to the human and financial activities in the Archipelago.

It is difficult to imagine how life in the Canary Islands would have been today without the extensive application of different desalination techniques. In the past, those islands that had almost no ground water resources were supplied with water by means of tank vessels from the Navy. It is probably true to say that neither the population, nor the tourist sector and even the farming industry would have gone so far today without desalination technologies. The first desalination plant in the Canary Islands was installed in 1964 in the island of

Increased pressure on water resources caused by population and tourist growth obliged the Canary Islands to look for new formulas of water supply. The most paradigmatic case can be seen on the island of Lanzarote where more than 80% of water consumption comes from desalinating plants.

The Canary Islands should therefore approach the search for an immediate solution where desalination is based on Renewable Energy Sources.

Lanzarote and had a capacity of 2.300 m³/d. Today, the desalination capacity is approximately 315.000 m³/d, representing almost a 2% of the world desalination capacity but the population represents only the 0.028% of the world population. This production capacity is diversified in all kinds of processes and plants of every size and capacity. These figures are really remarkable if we keep in mind the low population and extension of the islands, and show to which extent the water supply in the Canary Islands is based on desalination.

This water coming from desalination plants supplies about 1 million people and almost all tourists visiting the islands. In the case of Lanzarote, the island that most strongly depends on desalination, 97% of the used water comes from desalination plants and use nearly 40% of its energy to produce water.

But this solution to water shortage has a major disadvantage: it is strongly dependent on energy and, therefore, on the amount and price of it.

Because of this situation, the Canary Islands have started a last struggle: the industrial production of drinking water from seawater using local and renewable energy resources, mainly wind and solar energy, without disregarding other middle term possibilities. Many of these technologies, because of their applicability to other areas on Earth with

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similar features, can be a positive contribution, on the part of Canary Islands, to several local and industrial developments.

Desalination with Renewable Energies

Stand Alone Systems

Sea water desalination with an autonomous wind energy system (SDAWES Project)

The system is made up by two synchronous windturbines, connected in parallel and isolated from the electrical grid, with 230 kW of nominal power each one. These windturbines supply the necessary power for the operation of the different desalination plants associated to the project: 8 Reverse Osmosis desalination plants (with a total capacity of 200 m³/d) a vapour compression plant (with a capacity of 50 m³/d) and an electrodialysis plant (with a capacity of 192 m³/d). As far as we know, this is the first time that a stand alone wind farm (isolated from the electrical grid) is connected to a desalination plant.

Objectives

The main objective of the project is to identify the best desalination systems for connection to a medium power off-grid wind farm. This objective is developed according to the following points:

- Design of a wind farm to be operated isolated from the grid
- Determination of the behaviour of each desalination system (RO, VVC, EDR) working under intermittent and variable load operation
- Design, installation and working of a RO system with several units, making possible the connection and disconnection of each unit as function of the instantaneous power.
- Determination of the life of the membranes working under intermittent operation
- Determination of the water production quality in function of the variations of the wind
- Assessment of the advantages and disadvantages of each desalination system working in the isolated system: determination of the optimal design of each plant.
- Adaptation of the VC and the EDR plants to work connected to an off grid wind farm: definition of the working conditions and limits.
- Design, installation and assessment of a control system to make possible the automatic working of the system.

Basic method of approach

A general view of the installation can be seen in figure 1.

The elements of the complete system are the following:

Wind Farm

It is composed by two 230 kW wind turbines, a 1,500 rpm flywheel coupled to a 100 kVA synchronous machine, an isolation transformer and a UPS of 7.5 kW.

Desalination Plants

There are ten plants installed:



Fig 1: General view of the installations. (1) Pumping Station. (2) Product water tank. (3) Brackish water tanks. (4) Desalination dome. (5) Flywheel building. (6) Wind Turbines. (7) Feed water pipe circuit

- Eight reverse osmosis (RO) units (25 m³/d each), with a specific consumption of 7.2 kWh/m³
- One vacuum vapour compression (VVC) plant unit (50m³/day), working at 0.2 bar with a specific consumption of 16 kWh/m³, and a variable speed compressor (8400-12000 rpm).
- One unit of electro dialysis reversible (EDR) with a production of 190 m³/d, with a specific consumption of 3.3 kWh/m³, and a variable production: 35%-100% (obtained by the variable feed flow and the variable stack voltage).

Water Circuits

In the pumping station there are two seawater pumping groups one for the RO plants (2 x 13 kW), and the other for the VVC (2 x 9 kW). The water is taken from a well of 35 mts. deep, located at 100 mts. from the coast; this configuration avoids the introduction of marine life, and the consequent fouling.

There are four pipe circuits:

- Two feed water pipes: one for RO plants, and other for the VC plant
- A product pipe, from the desalination area to the 200 m³ product tank
- A brine pipe, from the desalination dome to a specific brine well.

As there is no natural brackish water source, the EDR plant is connected in a closed circuit. An artificial brackish water was prepared by mixing distilled water and seawater; this water is stored in two tanks. These tanks feed the plant, and the outputs of the plant (desalted water and brine) are introduced in the tanks again.

Working of the system

When the start-up signal is given, the system measures the wind speed and decides if there is enough wind to start up the isolated system (minimum average of 6 m/s during 5 minutes or similar). Under these conditions, one of the wind turbines starts to accelerate the flywheel until it reaches 48 Hz, then the synchronous machine is activated to generate a three phase grid of 400 V which is detected as a reference by the wind turbine (WT). Then the WT introduces energy to the only connected load: the flywheel, until it reaches the upper speed limit of 52 Hz.

From that moment the normal loads can be connected; the WT will change the blade angle to adapt the supplied power to the consumed power. If the wind speed decreases, the control system will detect the reduction of the frequency and request a reduction in the consumption by disconnecting plants or modifying the working point until reaching the nominal frequency (52 Hz); if the wind is very weak, all the loads will be stopped.

The system has two control modes: from the wind farm (in case of excess of wind) and from the loads control (in case of shortage of wind).

As a general assessment at this point of the project (more than four years since the beginning) it can be said that as a original R&D, several unexpected difficulties have appeared, which have forced the partners to create original solutions. It has meant, on the one hand, a cost in time and in money; and on the other hand, a very interesting learning experience.



Fig 2: Flywheel and synchronous machine.

Major findings

The preliminary major findings are the following:

Checking the stability of the system

The stability is possible due to the double control: from the wind, by changing the blade angle in case of excess of wind; and from the control system, by reducing the power consumption in case of lack of wind.

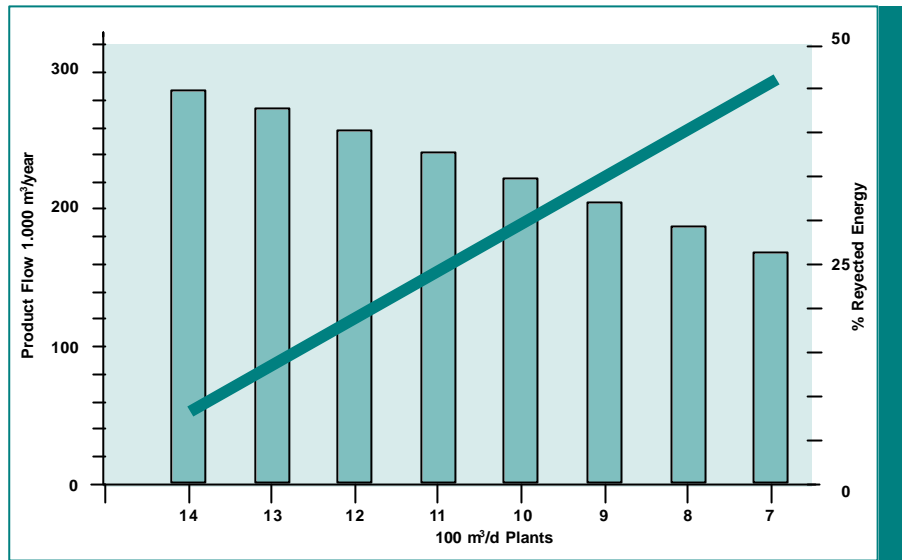
Determination of the pressure control in the RO feed pipe

Depending on the number of the connected RO plants, the flow changes and varies the pressure; several tests were performed to determine the control of the pressure.

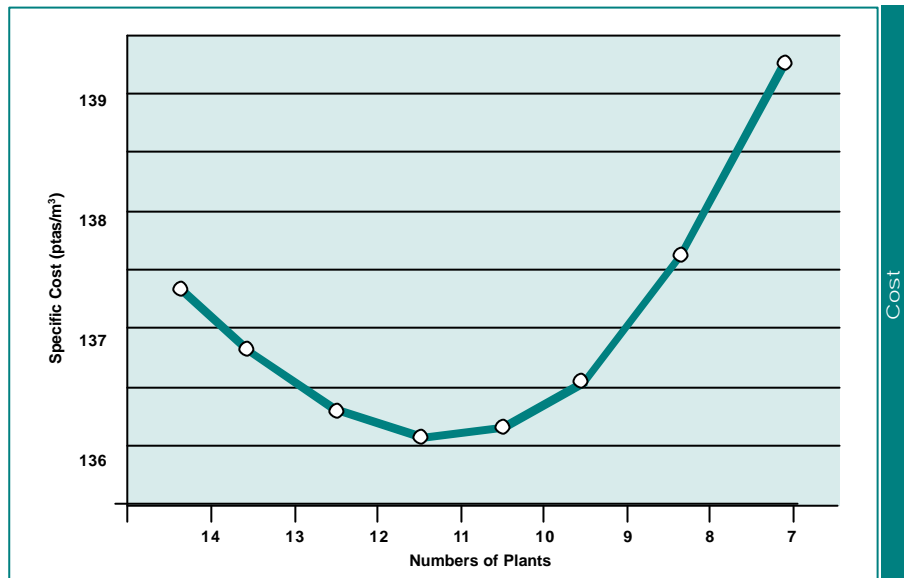
Optimisation of the system (wind farm with RO)

A simulation model has been used to identify the optimal installation of RO plants connected to an off grid wind farm. It has been decided to use only RO plants because it is the most suitable desalination system for seawater with the smallest specific consumption.

The graphic 4 shows the rejected energy and the production of water depending on the number of RO plants installed; the production of water increases with the plants and the rejected energy decreases, because with less loads it is more difficult to adapt the consumption to the available power.



Graphic 1: Rejected energy and water production as function of the plants



Graphic 2: Specific cost as function of installed plants

PESETAS (Ptas)	EUROS (€)
136	0.817
137	0.823
138	0.829
139	0.835

In the graphic 5 it can be seen the specific investment cost in relation with the number of plants, showing that there is an optimal number of plants to get a minimum cost. As a preliminary economical analysis, a simulation software has been programmed to know which is the optimal installation of desalination plants (only RO) connected to an off grid wind farm. The results showed it would be possible to produce water with a competitive cost (about 0.8 euros/m³).

The starting up and operation of two medium power wind turbines working in parallel within an isolated system has been an original achievement of this project.

Determination of the optimal desalination system powered by wind energy

It is one of the main objectives of the project. For the moment, preliminary aspects have been concluded about the advantages and disadvantages of each desalination system. (See Table 1).



Fig 3 View of the Reverse Osmosis units

Possible breakthroughs

Some breakthroughs has been the followings:

Operation of an off grid wind farm

Relation of the main advantages and disadvantages of each desalination system in isolated system operation.

Determination of the modifications in the desalination systems in order to improve the working in an isolated wind grid

The suppliers of the VVC and EDR plants prepared a specific design to include the possibility of a variable power consumption in order to achieve a better connection to the off grid wind farm; however, a more complete analysis should be done.

The installed RO system does not include any modification, hence there are important possibilities to improve the system in future projects, for instance the substitution of several small plants by only one big plant with a variable flow high pressure pump.

Major obstacles

Many difficulties and obstacles have appeared along more than four years of working in the project. From a technical point of view the main problems have been the following:

Control program debugging

It has been necessary to modify several times the original software to solve all the control problems that have appeared during the tests.

Malfunctions in electronic instruments

There are many electronic instruments installed to take the signals (more than 130) which will be recorded in the acquisition data PC. Due to different reasons (wrong connections, low quality of the equipment, difficulties in the calibration) several failures have happened

High harmonic distortion

The EDR plant operates in DC, therefore it includes converters AC / DC. There are more converters in that unit (pumps) and in the VC unit (compressor). These elements have been causing harmonic distortion and excessive reactive power consumption (power factor less than 0.5 in EDR unit).

Application area

The project can be installed in any part of the world with a medium wind speed. Nevertheless, due to the state-of-the-art

Desalination system	Advantages	Disadvantages
RO	Fast starting-up and stop	- Discontinuous power consumption - Difficult pressure control in the feed water circuit
VVC	Variable continuous power consumption	- Slow starting-up - Scaling if discontinuous operation
EDR	Variable continuous power consumption Fast starting-up and stop	- Only for brackish water - Harmonic distortion (due to the conversion AC/DC)

Table 1 :Main advantages and disadvantages of desalination systems in stand alone operation

technology used by the system, it seems more appropriate to install it in places with a medium-high technological development

Partners & Funding

The project has been cofinanced with the European Commission through the JOULE Program; the ITC is the co-ordinator of the project. The other partners of the project are: the University of Las Palmas of Gran Canaria (ULPGC); ENERCON; the research centre Instituto de Energías Renovables of Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (IER-CIEMAT), and the Centre of Renewable Energy Systems Technology (CREST), and National Engineering Laboratory (NEL)

Windgenerator with mechanical coupling to a desalination plant

(AERODESA I Project)

Low-tech windgenerator with a rated power of 15 kW, specially designed to be coupled to a seawater R.O. desalination plant (with a capacity of 10 m³/d) with a mechanical coupling system and seawater as a control fluid.

The unit has been designed for both ordinary and low maintenance conditions, which is essential in isolated areas or developing countries.

Technical Description

The rotor is made up by three 4.5 meter long blades, built with fibber-glass in polyester in the traditional way. The blades have been

built in Gran Canaria (Canary Islands).

The driving gear consists of a main low rotation shaft in the windturbine nacelle, a first multiplication for bevel gear, a vertical prop shaft made of different units elastically attached, and, finally, a multiplication for the desalination pump.

The desalination module is made up by four osmotic membranes, set in series, with a low recovery rate, according to the operation requirements of the system. The control system, supported by a pressure accumulator, uses seawater as a control fluid.

The desalination plant works under variable regimen, according to the technical limits established by the membrane's manufacturer (from 45 to 70 bars). This variable regimen is regulated by the seawater valves system, that act as a control system.

Application area

The project can be installed in any part of the world with a medium wind speed. Nevertheless, the unit has been designed for both ordinary and low maintenance conditions, which is essential in isolated areas or developing countries, so that these kind of areas seem to be its natural market



Fig 4: Blades: built in Gran Canaria (Canary Islands)



Fig 5: Windgenerator -mechanical coupling-

Some interesting data

- Relation surface/water production: 59 m²/m³-d (m³ means 1 m³ of desalted water per day)*
- Water cost m³ (prototype): 629 ptas/m³= 3.78 €/m³
- Water cost m³ (fabrication cost): 314 ptas/ m³ = 1.89 €/m³

Funding

The project has been financed by the Government of the Canary Islands. The project has been carried out by ITC.

Windgenerator with hydraulic coupling to a desalination plant

(AERODESA II PROJECT)

Windgenerator with a rated power of 15 kW, specially designed to be coupled to a seawater R.O. desalination plant of two modules (with a rated capacity of 15 m³/d) with an oil-hydraulic mechanical coupling system, thus allowing a high automation of the system.

Technical Description

It is a horizontal axis wind turbine with a passive downwind orientation system and two hinged blades. It has also an overspeed brake system and a hydraulic power transmission system by means of a set

turbine and a displacement oil pump. The oil-hydraulic system, which act as a control system, allows the desalination plant to work under nominal conditions.

Application area

The project can be installed in any part of the world with a medium wind speed. Nevertheless, the unit has been designed for both ordinary and low maintenance conditions, which is essential in isolated areas or developing countries, so that these kind of areas seem to be its natural market

Some interesting data

- Relation surface/water production: 55 m²/m³-d (m³ means 1 m³ of desalted water per day)*
- Water cost m³ (prototype): 4.2 €/m³
- Water cost m³ (fabrication cost): 2.03 €/m³

Funding

The project has been financed by the Government of the Canary Islands. The project has been carried out by ITC.

Windturbine electrical coupled to a desalination plant

(AEROGEDESA PROJECT)

Electrical coupling from a 15 kW commercial windturbine to a Reverse Osmosis desalination plant (with a desalination capacity of 18 m³/d), operating under a constant regime and managing the storage and available wind energy use through a battery bank. The battery bank guarantees that the washing system is filled with seawater, thus guaranteeing a longer working life of the membranes. The whole system is fully automated.

Technical Description

Wind turbine with a rated power of 15 kW, a three-phase self exciting induction generator for a static condenser battery, a charger and a three-phase sine wave inverter, both micro-processed. It also has a battery



Fig 6: Windgenerator- hydraulic coupling



Fig 7: Oil-hydraulic system



Fig 8: View of the Windgenerator

storage with an autonomy of 20 minutes. A Reverse Osmosis desalination plant of 18 m³/d adapted to a frequent start/stop configuration is coupled to the system. It is an electric coupling from a commercial wind turbine of 15 kW to a Reverse Osmosis desalination plant, operating on a constant basis and managing the storage and use of the available wind energy through a battery bank. The whole system is fully automated.

The control and data acquisition systems are made up by a Programmable Logic Controller (PLC) receiving all the signs from the sensors in the plant and making decisions in relation to the start/stop configuration in the installation. It will also monitor the safety devices by using two microprocessors exclusively used to control and manage the available energy in the electric system. The Reverse Osmosis desalination plant has a brine washing system for stop configurations, so that the plant service life and reliability is maintained. The battery bank (with an autonomy of 20 minutes) will guarantee that the washing system is always full with desalted water.

Application area

The project can be installed in any part of the world with an average wind speed and no grid connection because of economic reasons.

Some interesting data

- Relation surface/water production: 41.26 m²/m³-d (m³ means 1 m³ of desalted water per day)*
- Water cost m³ (prototype): 3.11 €/m³
- Water cost m³ (fabrication cost): 1.91 €/m³
- Water cost m³ (optimised system with energy recover and bigger desalination plant about 300 m³): 1.12 €/m³

Funding

The project has been financed by the Government of the Canary Islands. . The project has been carried out by ITC.

Desalination plant coupled to a solar photovoltaic field

(DESSOL Project)

The project consists of the design, installation estimation and optimization of a drinking water production system in coastal areas isolated from the electricity grid. It is made up by a Reverse Osmosis desalination plant (rated capacity: 3 m³/d) driven by an isolated photovoltaic array (peak capacity: 4.8 kW).

Technical description

The desalination plant has been specifically designed to work isolated from the electrical grid and the system is fully automated. The desalination plant works for a daily period whose duration is determined both by the state of charge of the batteries in the photovoltaic array and the available solar radiation. The system has been designed to



Fig 9: Windturbine -a commercial one-



Fig 10: View of the reverse osmosis plant (18 m³/d)

produce a minimum of 800 l/d under normal conditions of solar radiation in subtropical areas.

Some data of interest

- Surface-production relation: 75m²/m³ (m³ refers to 1m³ of desalted water a day)*

Partners & Funding

The project has been jointly financed with the German association AG-SOLAR. . The project has been carried out by ITC and by REWET (Germany)



Fig 11: View of the photovoltaic field

Desalination plant driven by low temperature solar thermal energy system

(SODESA Project)

The project consists of the design, installation and estimation of a distillation system working under 80°C and severe weather conditions driven by solar collectors (50 m² of total surface). The system has an approximate production of 700 l/d.

Technical description

The project consists of the design, installation and estimation of a distillation system working under 80°C and severe weather conditions (process: "multiple-effect humidification") driven by non-corrosive and technologically ahead thermal solar collectors with selective surface and a high performance (50 m² of total surface). The system, with a hot seawater accumulator to reduce losses due to thermal inertia and allows the system to work 24 hours/d. The system has an approximate production of 700 l/d.



Fig 12: RO desalination plant (3 m³/d)

Partners & Funding

The project has been co-financed with the European Commission through the program JOULE, carried out in collaboration with the Fraunhofer Institute for Solar Energy Systems (the co-ordinator of the project), the ZAE-Bayern Centre for Applied Research and the Agricultural University of Athens.

Some data of interest

- Surface-production relation: $107\text{m}^2/\text{m}^3$ (m^3 refers to 1m^3 of desalted water a day)*

Wind-diesel system for water and electricity supply in the island of Fuerteventura

(PUNTA JANDIA Project)

This project is focused on the basic elements for living in a community, which are the following:

- water
- energy
- improvement of the economic infrastructure of the population

The difficulties of a fishermen's community, without power mains (the electricity grid ends 20 km before the village), have turned, by means of this project, into an increase of the living standards through a full self-supply of:

- drinkable water, through a Reverse Osmosis plant powered by wind energy, with the possibility of water processing.
- energy self-supply through a wind-diesel system isolated from the grid.
- improvement of the economic conditions of the fishermen with an ice generation plant and a cold-storage plant to freeze fish. These plants are also powered by a wind-diesel system.

Detailed description of the project

Location description

Puerto de la Cruz, at the southernmost part of the Jandía Peninsula, on the Island of Fuerteventura (Canary Islands), is a small, isolated fishermen village (with a total lack of energy resources and drinking water). The village is located 20 Km away from the residential and tourist resort of Morro Jable, in the municipality of Pájara, where the electrical grid ends.

Before the project each house had a diesel generator for their own energy consumption. The water was supplied by a truck, therefore the water price was very high because they had to pay for the water price plus the driver

characteristics of the location, including a system of strong and constant winds, it was planned to propose it as a demonstrative example of the application of renewable energies (wind power in this case) to supply isolated communities, with the highest respect to the surrounding environment and independence from external supplies.

Aim of the project

The aim of the project was to provide, electricity, cold and ice to a small isolated fishermen village through wind energy supported by conventional energy.

The project meets two different goals at a general and local level: at a general level, the project aims to demonstrate how a renewable, non-pollutant and independent power source, transformed by means of an advanced technology, can achieve self-supply for a community, within a satisfactory living standard, avoiding negative impacts on the environment. At a local level, the project intends to stop an uncontrolled tourist development of the area -located in a protected natural place- because of its limited energy and water resources.



Fig 14 View of the village



Fig 13: View of the solar thermal field (50 m²)

fees and the truck diesel; so the water price was nearly 3 €/m^3 . This area will hold, according to the local by-laws, a small housing development up to a maximum of 450 summer visitors, 60 permanent inhabitants and 500 occasional visitors per day. But the actual population are 50 inhabitants. Taking into account the

Innovative aspects of the project

Arrangement and renewal the original village (houses, streets and sidewalks), providing it with all the necessary infrastructures (street and home lighting, drinkable water and sewers) with the maximum respect to the original situation (unpaved sand streets and hidden services network).

Outside the village, in an architectonic setting in keeping with the environment, a group of highly technical installations have been developed to meet all the requirements of the village: one windturbine to transform wind energy to electric power,

diesel equipment (when the wind lacks), sea water desalination plant, cold-storage room for fish, ice generation plant, hauling capstan and sewage treatment plant.

Technical data

Installations:

- Planned drinkable water supply: 60 litres/day (with low consumption toilets)
- Power supply (Kwh/person/year): unlimited
- Desalination capacity: 56 m³ per day (higher than necessary, but the desalination plant will only work with wind and never with fuel: all the water will be produced by the wind)
- Water storage tank: 2 x 500 m³.
- Cold-storage room for: 1200 Kg of fish at 0°C
- Ice production: 500 Kg/day
- Peak power demand: 100 KW
- Windturbine: Vestas, V27m 225 KW
- Diesel equipment: 2 x 60 KW
- Control system: flywheel, dump loads and PC with AT Bus.

Benefits of the project

From the environment point of view

This project reduces CO₂ emissions and avoids laying down the electric grid with the subsequent devastation of the environment. In addition to this "free" natural resources, like the wind are used.

These benefits, and many more arising from the project, are some of the results of using natural resources and protecting the environment.



Fig 15: View of the technical installations

From the social point of view

The project contributes directly to improve the working conditions of the community, since it will increase the productive capacity of the fishermen, who no longer depend on the people spending the day in the place for selling the fish. Now, thanks to the ice generation plant and the cold-storage plant, they can store their fish stocks

From the sustainability point of view

The understanding and meaning of the new technological systems will be improved through this project by means of the improvement of the living standards. The aim is to make it clear that sometimes this the only way to keep a sustainable development outside the big cities and large human concentrations and avoid the emigration to these areas.

Application area

This project has been tested to spread it out with improvements and adjustments for

the specific conditions of a particular place and is fitted to any isolated area of the planet with enough wind

Partners & Funding

The project has been cofinanced with the European Commission through the VALOREN Program; Town council of Pájara (Fuerteventura), Fuerteventura Water Association, Industry Council (Government of the Canary Islands) and the Institute of Renewable Energies (IER-CIEMAT). The partners involved were the University of Las Palmas de Gran Canaria (ULPGC) and the Institute of Renewable Energies (IER-CIEMAT). Nowadays ITC is managing the project.



Fig 17: View of the diesel system (2 x 60 KW)

* NOTE: This is a prototype data, this data should be much smaller in an optimised system

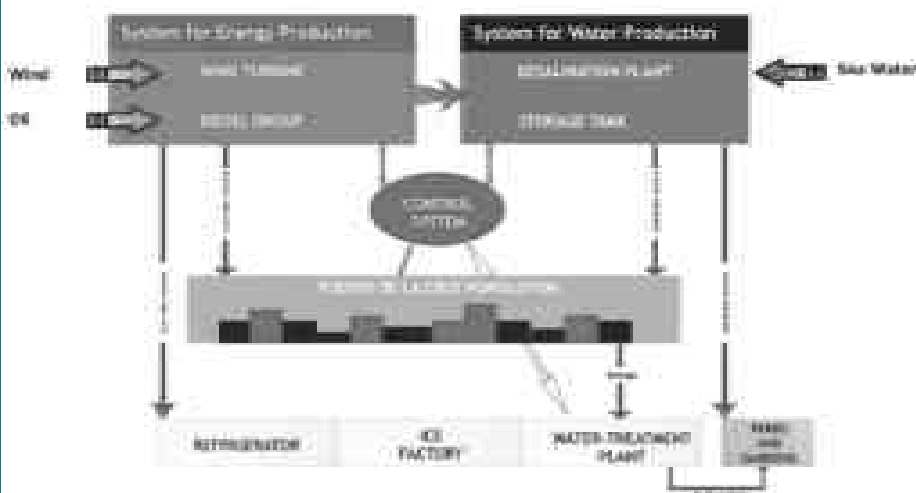


Fig 16: Scheme of the installations

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