# SIMULATION OF AN HYBRID POWER SYSTEM TO PRODUCE WATER AND ELECTRICITY FOR REMOTE COMMUNITIES IN TUNISIA

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**ABSTRACT**
OPEN-GAIN project's aim is to supply fresh water and electricity to rural remote communities not connected to the public grid, using the renewable energies and the reverse osmosis desalination technique. In this paper, the system used is described and several scenarios were investigated in the simulation to compare the PV only and Wind only systems with the hybrid system. The simulations were carried out using HOMER tool provided by NREL (National Renewable Energy Laboratory). The results show that the combination of PV and WT power generators, with batteries, allows obtaining a better renewable energy fraction of 95%.

Keywords: renewable energies, hybrid system, water desalination, open gain

## 1. INTRODUCTION

Fresh water and electrical energy are the two elements that absolutely must be available to guarantee a better quality of life. Unfortunately, a significant number of the world population lives in extremely arid or semi-arid areas. Those areas have usually an important solar radiation causing a lack of water, and their connection to the public grid of electricity is subject of heavy technical and financial constraints. The OPEN-GAIN project (OPtimal ENgineering design for dependable water and power Generation in remote Areas using renewable energies and INtelligent automation) (www.open-gain.org) deals with these facts and its global objective is to develop a new model-based optimal system design approach to economically improve the overall performance, dependability, reliability and availability of co-generating water-electricity plants powered by renewable energy for remote arid areas using a high level of automation to meet specific cost requirements and to disseminate the new technology MENA wide (Middle East and Northern Africa).

The OPEN-GAIN technological challenge consists on supplying fresh water using reverse osmosis as a desalination technique of brackish water, and to feed the Reverse Osmosis plant with electricity via renewable energies sources, backed up by a conventional one (diesel generator), the whole designed plant is installed in the site of Borj Cedria in Tunisia in CRTEn (Centre de Recherche et des Technologies de l'Energie).

## 2. DATA REQUIREMENTS FOR THE SYSTEM DESIGN

To identify the adequate solution of fresh water supply from water desalination with autonomous powered RO plant in the site of Borj Cedria, several studies were realized in order to obtain the required database essential for the components design(Ulrike Seibert & al, 2004). The collected data concerns the following parameters:

Water:

- Collection and assessment of data on water resources, availability, and type of water (lake, river, rain, ground water, sea water, brackish water…)
- Density of rural homes not connected to water pipelines
- Analysis of fresh water demand and capacity needed for domestic use, agriculture use…

Energy:

- Collection, and assessment of data on energy resources and availability
- Density of rural homes not connected to the grid
- Type of alternative energy available in the site
- Analysis of energy demand and capacity needed for domestic use and others (Reverse Osmosis plant)

In Tunisia, a typical rural site contains about 480 inhabitants. The average water consumption is around

60 liters per day per person, when is it around 100 liters per day per person in the urban areas, these data are necessary to estimate the water production needed for the concerned remote area and to know consequently the electrical power required for the reverse osmosis unit. In the case of OPEN-GAIN project, the typical water user profile lead to the design of $24m^3$ per day RO plant, which needs $5kW/m^3$ as power supply. The estimation of power demand should include electrification of both RO plant and households. According to national electricity authority, one household in rural areas in Tunisia have a daily power consumption of 1.9kWh in winter and 3.03kWh in summer, the annual average consumption is estimated to 966kWh.

A database of the specific weather data of CRTEn's site was collected, as the whole prototype is going to be installed there. In CRTEn, a meteorological station is installed to collect regular values of the following parameters:

- Wind speed, and direction
- Solar radiation and temperature

For 2009, the wind speed varied from 4.33m/s to 6.54 m/s, which means that the target site is rather windy all over the year. The average speed is 5.45m/s. Concerning the solar radiation, the worst value was registered in January: $0.108kW/m^2$, and the best one was in July: $0.3kW/m^2$.

## 3. THE OPEN-GAIN'S HYBRID SYSTEM

The data described in the previous part allowed the estimation of the required installed power of the renewable energies components: the Photovoltaic generator (PV) and the Wind Turbine (WT). In the case of OPEN-GAIN project, the total installed power of each component is 15kW.

The optimal design is when the renewable energy sources provide a quantity of power equal to the power required by the loads (RO plant and households) in a same period of time (day, year or month). This sort of equilibrium point can't always be reached, especially in a continuous way, that's why a diesel generator of 20kVA was foreseen, to compensate an eventual lack of energy. A storage system of 12 batteries, 12V, 210 Ah each, was also foreseen to stock potential energy excess.

OPEN-GAIN is a cooperation of several participants; the figure below shows a block diagram of the physical decomposition of the plant and the localization of the work packages (Adrian Gambier & al, 2009):

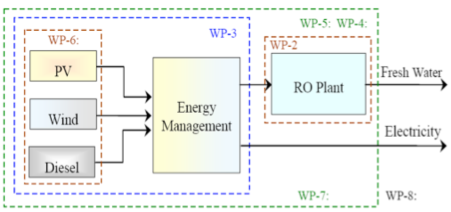


Figure 1: Physical Decomposition Of The Plant And Localization Of The Work Packages

CRTEn, as a leader of the WP-7, is responsible of the complete integration of all other work packages and the final ensemble of the whole prototype. The first activities were the selection of the site and the construction of the data base of the weather characteristics and user profile. The design of the renewable sources and the diesel engine and the batteries and the convertors, as well as the RO plant, was a result of a fruitful cooperation between all the participants. CRTEn received all the components and brought each one safely to the place where it should be installed.

CRTEn team is responsible of the PV generator installation, so, according to electrical requirements, the total installed PV power were divided in 3 rows of 5kW each. Each row is composed of 3 strings in parallel, and each string contains 9 panels in series, delivering 15.3A as a maximum current. The PV panels were divided in 3 rows to obtain a three phase system.

The PV generator, which can deliver 15.3A as a maximum current, was installed and tested to confirm its electrical specifications. The tests were performed in a typical sunny day of January to establish the curve of the current I as a function of the voltage V (I(V) characteristic) of the PV modules:

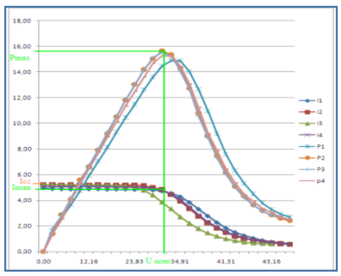

Figure 2: Test Of The PV Modules In The CRTEn's Site

According to the standard test conditions, ($1000W/m^2$ of solar radiation), the maximum power of the module is $P_{max}$=185W. During the tests performed in CRTEn, and as the solar radiation was lower than the standard value, the maximum power obtained was $P_{max}$=155W.

The PV generator, as well as the rest of the components (Wind turbine, diesel generator and batteries), are connected to the loads (RO Plant and electrification) via inverters and electrical boxes to adapt the energy and to insure the necessary protections.

The first set of inverters allows converting the direct current delivered by the PV generator into alternative current to be injected in the AC bus. The alternative current delivered by the wind turbine crosses first a rectifier to obtain direct current and then, an inverter converts it into alternative current and injects it in the AC bus. The batteries and the diesel generator are connected to bidirectional invertors that manage the charge and discharge cycles of the batteries and start/off cycles of the diesel engine. The inverters will be connected to a web box that will allow the Ethernet connection to a monitoring system.

## 4. INVESTIGATION AND OPTIMIZATION OF THE HYBRID SYSTEM

A feasibility study of such a hybrid system was carried out using the software HOMER which is a sizing and optimization tool provided by NREL (National Renewable Energy Laboratory) (www.nrel.gov).
For the given site, with water and power demand specified, we simulate the behavior of the hybrid system under various scenarios of running with the aim of satisfying the demand using mainly the renewable sources.

As main entries, we have to specify the meteorological characteristics of the site of Borj Cedria, of the load and of the power sources. The installed power of the diesel generator must be sufficient to feed the load in the worst meteorological conditions and the capacity of the battery system must be able to store a potential energy excess and insure the system's autonomy. Obviously, the diesel engine must intervene as a last resort in order to minimize the fuel consumption and the $CO_2$ emissions. The unmet energy demand is fully satisfied first by the excess energy stored in the batteries and then by the energy supplied from diesel generator.

### 4.1 PV generator alone

The simulation of a system with only PV as renewable energy, without battery storage system, gives a renewable fraction of only 0.4. The 15kW of installed PV power are insufficient to feed the load, this leads the diesel engine to work at 60%, in terms of yearly production (kWh/yr).

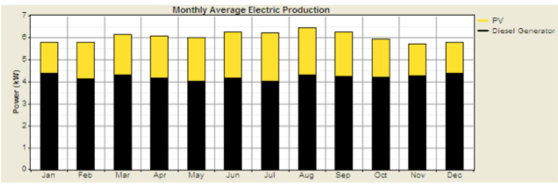


Figure 3: Monthly Average Electric Production Of The System PV + Diesel Generator Without Batteries

### 4.2 WT Generator alone

The simulation with only the Wind turbine as renewable source, and without battery storage system, gives a renewable fraction of 0.56. The diesel generator works at 44% in this case.

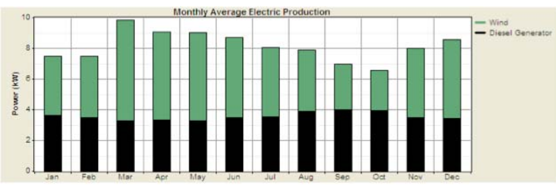


Figure 4: Monthly Average Electric Production Of The System Wind + Diesel Generator Without Batteries

This difference between the PV only and Wind only systems, without batteries, is due to the weather resources: the site of Borj Cedria is windy all over the year, while there is a difference in the solar radiation between months of winter and summer. In addition, the wind potential can be available along the 24 hours of a day, when the solar radiation is available only during few hours around midday.

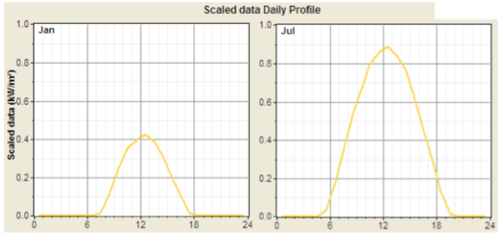


Figure 5: Example Of Solar Radiation Distribution Along A Day Of Winter And A Day Of Summer

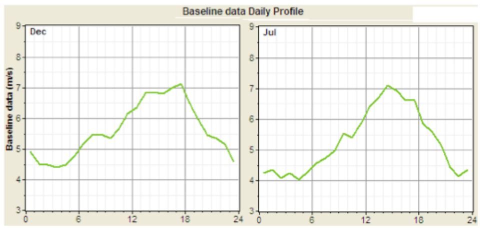


Figure 6: Example Of Wind Potential Distribution Along A Day Of Winter And A Day Of Summer

### 4.3 Combination WT and PV Generators

We simulate first the combination of the two renewable sources to obtain a hybrid system, without storage. The results give a renewable fraction of 0.73.

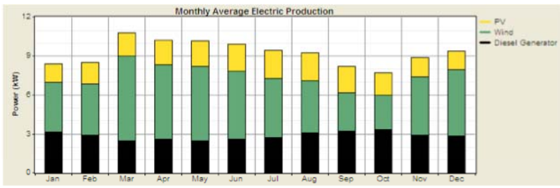


Figure 7: Monthly Average Electric Production Of The System Wind + PV + Diesel Generator Without Batteries

When we add to the previous hybrid system, a battery storage system, the renewable fraction is enhanced to 0.95 (95%). The diesel engine works for only 5%.

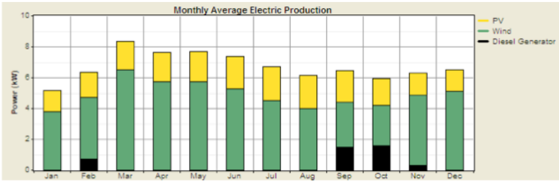


Figure 8: Monthly Average Electric Production Of The System Wind + PV + Diesel Generator + Batteries

## 5. CONCLUSION AND PERSPECTIVES

We presented a simulation of a hybrid energy system devoted to satisfy the needs in water and electricity of a rural community using the software HOMER. First results show that a combination of PV and WT power generators allows the renewable energy fraction to reach 95%.

At the present time, activities in progress are the finalization of subsystems installation and then the global wiring of the components. After the prototype assemblage, it will be started-up subsystem by subsystem by using an iterative procedure to solve malfunctions once a failure is detected before the next subsystem is started up until the correct operation is finally verified (www.open-gain.org). Finally, last activities of other work packages may be concluded. Once the model has been tuned to the real plant, the control system will be adjusted to the real model and finally implemented in real time. The control system first have to be tested and evaluated by simulation on the adjusted model and at last, the overall hybrid control system including all control levels has to be assembled and implemented in real-time. Here, it is necessary to choose proper hardware and software for real-time applications and the algorithms have to be tuned for real application conditions.

It is expected in the end of the project period that the integrated system engineering design works properly and that it will be able to be transferred for industrial development (Adrian Gambier & al, 2009).

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