

ANALYSIS OF THE USE OF WIND POWERED REVERSE OSMOSIS SEA WATER DESALINATION PLANTS IN THE NORTHEAST REGION, BRAZIL

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ABSTRACT - This paper presents a seasonal complementarity between wind and hydro climatological regimes in Northeast Brazil, especially in Ceará State. Wind resources, in 10 % of the Ceará's coast can supply the electrical demand of the State throughout the year and in the dry season, with the use of wind energy converter powered reverse osmosis (WEC-RO) seawater desalination plants, can supply the drinking water demand. The state-of-the-art shows that WEC-RO plants are a technically promising option in water-scarce regions with plenty of wind.

Keywords: Wind energy; reverse osmosis; seawater desalination.

1. INTRODUCTION

According to a report from UNESCO, by the middle of this century, at worst 7 billion people in sixty countries will be water-scarce, at best 2 billion people in forty-eight countries. This expectation makes necessary for humanity to look for new alternative ways of ensuring a dependably supply of drinking water. The significance of this problem is increasing in the underdeveloped countries as well as in industrialised regions (UNESCO, 2003).

An example of an area affected by this problem is the Northeast Region of Brazil. In this region the mean annual rainfall precipitation is about 700 mm, but ranges from as little as 250 mm to over 1000 mm. Because of the warm weather, the annual evaporation potential is around 1700 to 2000 mm, which greatly exceeds the annual precipitation. For water policy purposes, the distribution of rainfall throughout the year is more important than the average. The main problem lies in the fact that most rainfall (some 85% or more of the precipitation) occurs within the short rainy season (January-May), and very little more falls during the rest of the year. In addition to the intra-seasonal fluctuation, rainfall is variable among years. Often sequences of years exhibit rainfall well below average, leading to the characterization of the region as the drought polygon (FUNCEME, 2002).

Desalination of seawater and brackish water is one of the alternatives for ensuring a dependably supply of drinking water. In recent years the process of reverse osmosis has become increasingly important compared with other desalination processes. Some of the reasons for this trend are the low specific energy consumption of this process and the considerable progress made in membrane technology (Maurel, 1990).

Use of wind energy converter is a technically promising option in regions with plenty of wind. The recent technology in RO membrane with improved tolerance to pressure fluctuations made wind-powered reverse-osmosis system the most attractive system in the short-term since the technology is well developed and relatively cheap (García-Rodríguez et al., 2001).

2. EXPERIENCE GATHERED WORLDWIDE WITH WEC POWERED RO PLANTS

SPAIN, 2003 (Carta et al., 2003)

The main goals of the project were the testing of the technical feasibility of a wind farm with no battery bank and diesel support generator sets, as well as an analysis of the problems that could appear in the proposed loads control.

A Wind energy converter powered reverse osmosis (WEC-RO) plant appears like a promising solution for stand alone and large scale seawater desalination. The main components of the plant installed on the island of Gran Canaria in the Canarian Archipelago are:

- a wind farm (two E-30 wind turbines with 230 kW each);
- a flywheel with inertia of 677.5 kg.m² to serve as a grid frequency and voltage reference;
- rectifiers and power inverters;
- a synchronous motor (100 kW) mechanically coupled to the flywheel;
- an asynchronous motor (22 kW) connected via a power transmission belt (1:1.17) to supply the necessary torque for its start-up;
- a central control subsystem (CCS) with two industrial PC type computers and six programmable logic controllers (PLC);
- an uninterruptured power system (UPS) unit with 10 kW to supply the CCS;
- group of eight RO plants, each of them has a motorized solenoid valve which enables a gradual increase of membrane pressure during the start-up periods
- sensors for product and brine flows, pressures, pH and conductivity.

The system start-up process consists of two main stages: the creation of a electrical grid and the later connection of the various loads in a particular given order. The order in the connection-disconnection of the RO modules has two different operating strategies:

- base strategy: the first RO plant to be connected will be the last to be disconnected;
- ring strategy: the order in which the plants are disconnected is identical in which they are connected.

The WEC-RO system has a drinking water production capacity of 25 m³ per day with an average specific electrical consumption of 6.9 kWh per m³. Each RO module was designed for operation with a recovery ratio (relation between product water flow and feed water flow) of 33 %, a feed pressure of 62 bar and a feed water temperature of 25°C. The average daily drinking water flow and concentration are affected by frequency variations of the electrical grid. The configuration of the prototype, the creation process of the isolated electrical grid and its operating strategy permit its extrapolation to large scale wind powered water desalination without the back up support of fossil fuel energy sources.

SPAIN AND GREECE, 1997 (Grottke et al., 1999)

Two modular WEC-RO pilot plants were installed:

- Island of Syros, Greece: E-40 wind converter (500 kW), with a RO unit with 8 membranes, drinking water production between 60 and 900 m³/day. The WEC and the RO unit are installed at two different sites, about 1.5 km distant, and linked via a medium voltage grid line. The WEC machine has a synchronous ring generator and a grid management system

which allows for output frequency and voltage control and self-adaptation of the WEC to weak electric grids. The energy is buffered in the storage system before it is fed into the RO unit and the electric grid. The RO unit contains 8 identical RO membranes. Since the maximum power consumption of the RO unit is only 200 kW where as the nominal power of the WEC is 500 kW, a large fraction of the generated electricity is fed into the island's electric grid. The RO unit is installed in five 40' containers. The main container houses the purification plant and the rinsing system, as well as the main electrical connection and the main control. Each of the two RO containers houses four RO membranes. The tank container is identical to its counterpart in the plant on Tenerife. The collection container houses the connection pipes to the island's water distribution system and to the RO and tank containers as well as two pumps: a pre-pressure pump supplies the RO containers with sea water and another pump feeds the produced drinking water into the water distribution system.

- Tenerife, Spain: E-12 wind converter (30 kW), with a single RO membrane, drinking water production between 60 and 110 m³/day. When using an electric motor as a load such in the case of a RO plant, the management system output has a variable frequency and voltage. The pilot plant does not include an energy storage. The RO unit is installed in two 40' and one 20' containers. The 40' main container houses the RO membrane, the purification plant for the incoming seawater, the rinsing system and a pump for feeding the produced drinking water into the island's water distributions system. The rinsing system is required because the RO modules must be flushed with drinking water after each switch-off, in order to prevent the membranes from getting blocked. The main container houses also the connection for the electricity supply of the RO unit and the main control. The 40' tank container houses two 14m³ tanks, one for pre-filtered sea water and one for the produced drinking water. The sea water tank serves as a buffer for the seawater and hence as an energy buffer, while the drinking water tank serves primarily as a storage for the rinsing system. The 20' collection container houses the connection pipes from the main and from the tank container. It houses also the dosing stations for the sea water and for the purification system.

SPAIN, 1996 (Ehmann et al., 1996)

A WEC-RO plant was installed in the Canarian Archipelago. The main goal of the project was to find the best plant configuration for stand-alone operation. The plant operates with no batteries but with diesel support generator sets. In this strategy, the system needs to work with variable pressure and must stay in the operational limits. The power is supplied by a E-30 WEC (200 kW) with pitch angle control system. In the brine flow was installed a Pelton turbine to energy recovery.

GERMANY (Petersen and Fries, 1985)

A WEC-RO plant was erected at Hallig Süderoog's Island in the North Sea, Germany. The 14 kVA WEC is a two blades synchronous generator. The seawater is pumped to a well. From this flow through a Filter with a low-pressure pump. Then the feed flow is pumped with a high-pressure (60 bar) pump against two RO membranes.

The system has a drinking water production capacity of 0.2 m³ per hour with an average specific electrical consumption of 19 kWh per m³. From a water salt concentration equivalent to 27.000 ppm, a drinking water quality of 334 ppm is obtained.

FRANCE, 1982 (McBride et al., 1987)

A WEC-RO plant was carried out by CEA - Cadarache Research Center in association with Aerowatt Company for seawater desalination on the island of Planier, near Marseille. The RO unit with a production capacity of 0.5 m³/h is supplied by a 4kW WEC without batteries. The plant employed a Pelton turbine for energy recovery, retrieving 1.2 kW from the outgoing

brine flow. The major problem reported was the frequent start up and shut down cycles particularly when the wind speed was in the cut in speed region. When operating at a wind speed higher than 7 m/s was observed a specific energy consumption of 7.8 kW/m³ with an averaged recovery ratio of 25%.

3. WIND ENERGY POTENTIAL IN THE NORTHEAST REGION, BRAZIL

The last hydroelectric power plants in the Brazilian Northeast region were built in the last decade and there is a tendency to use natural gas power plants to supply the future energy demand. In the renewable energy field this region has a great wind energy potential. This is true mainly in the State of Ceará, that is leader in the use of wind energy in Brazil, with a installed capacity of 16.2 MW in wind parks whereas Brazil has nowadays the capacity of 20 MW.

According to the wind energy resource atlas of State of Ceará, the statistical distribution in the dry season (July – December) averaged for 5 towers, 40 – 50 m anemometer height, installed in very low roughness sites in the coastal area of Ceará shows that wind speeds lower than 4 m/s occur for an average of ca. 2 hours per month (0.27 %); for more than 90 % of the time, wind speeds are between 7 m/s and 13 m/s, which corresponds to the maximum aerodynamic efficiency of existing wind turbines. For this semester a shape factor of 5.85 is found. Considering the technological trend towards Megawatt-sized wind turbines, corresponding to hub heights of 70 m or higher, the annual potential wind energy production in Ceará is estimated at 233.7 TWh/year (to compare, the Brazilian electrical power consumption in 2002 was 290.5 TWh). The State of Ceará occupies less than 1.8% of the Brazilian territorial area (SEINFRA, 2001).

4. THE COMPLEMENTARITY BETWEEN THE WIND POTENTIAL AND THE RAINFALL DISTRIBUTION

Independent studies conducted by CHESF - Power generation and transmission utility in Northeast Brazil (CHESF and COELCE, 1996), show the potential wind power electricity production in a percentage of 10 % of the area along the Ceará's coast (573 km coast line x 5 km width) for the construction of wind parks. That means an area of 286.5 km². The adopted number of wind turbines per square kilometer is ca. 21. That leads to a number of turbines equal to 6045. The average turbine spacing is 5D x 7D. The array efficiency considered is 90%.

The hourly average wind speeds at 10, 20 or 30m height data were recorded at ten stations sited at most 5km from the sea. The temperature and the air density measurements are obtained by the weather stations close to each anemometer tower. The daily wind speed and speed frequency distribution for the period 1991-1995 are utilized for estimation of the energy production. The program used is the ALWIN software and is developed by the DEWI (Deutsches Windenergie-Institute), Wilhelmshaven and Ammonit GmbH, Berlin. ALWIN is made available free-of-charge by the Ammonit GmbH World Wide Web. The potential wind power electricity production presented at Figure 1 was calculated based on representative samples of state-of-the-art wind turbines in the class of 500 kW (50 m height); that means a total wind parks capacity of 3,022.5 MW. Considering adjustments due to local pressure and temperature and reductions due to losses the annual renewable energy delivered is 9,548.6 GWh. This value corresponds to circa 11 % of the expected energy to be produced by wind parks in Europe in 2010; based on the energy delivered the model calculates a capacity factor of 33.3 %.

Figure 2 shows the monthly rainfall distribution averaged for the period 1974-2002 in Ceará State. It can be seen two distinct seasons: the rainy season, here considered from January to May, and the dry season from June to December. The potential wind power electricity production in the rainy season, circa 478.3 GWh per month, is enough to supply the electrical energy demand of the Ceará, which was 459.2 GWh per month in 2002. In this season the use of cisterns can supply the drinking water demand, considering that the rainfall precipitation is greater than 156 mm. However, in the dry season, when precipitation is lower than 19 mm, the drinking water demand can be supplied by WEC-RO units. The state-of-the-art shows that this system consume 6.9 kWh/m³ (Carta et al., 2003); the electrical energy production, approx. 1,022.4 GWh per month in this season, can supply the electrical energy demand of the Ceará, the approximately 9 m³/s of the Ceará's drinking water demand (CAGECE, 2003), witch corresponding to an energy consumption of about 160.96 GWh/month. The surplus electrical energy in the dry season, approx. 402.2 GWh/month, can give a contribution to the Brazilian electric system, since it is predominantly a hydraulic one (Amarante et al., 1999).

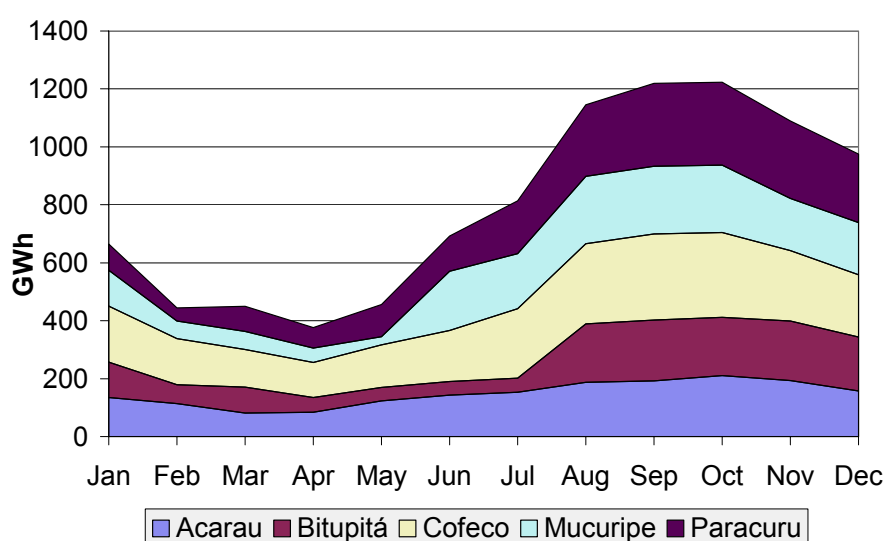


Figure 1: Potential wind power electricity production in 10% of the Ceará coast (CHESF and COELCE, 1996)

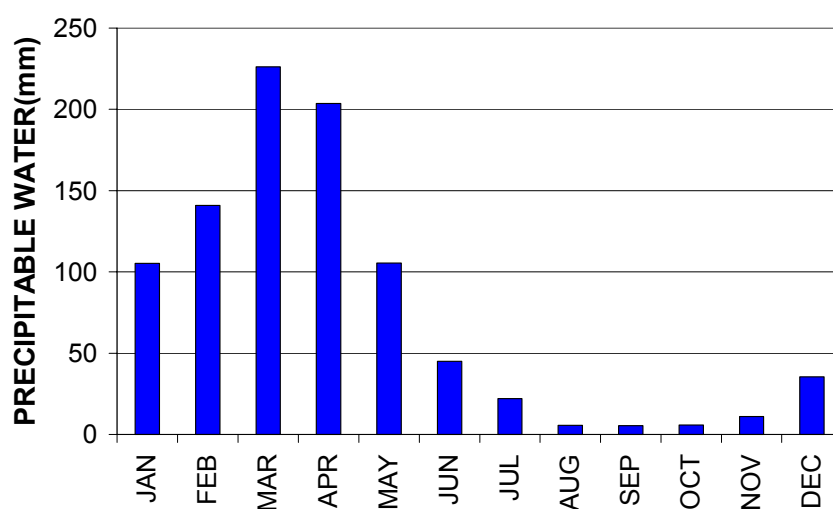


Figure 2: Monthly rainfall distribution averaged for the period 1974-2002 in Ceará State (FUNCEME, 2002)

5. CONCLUSION

Wind and rainfall distribution have an important seasonal complementarity in Northeast region, especially in Ceará. In this state the wind resources can supply the electrical demand throughout the year and in the dry season can supply the drinking water demand by the use of reverse osmosis plants. In this way, the state-of-the-art shows that WEC-RO is a technically promising option in water-scarce regions with plenty of wind. This seasonal complementarity is also important to balance the dominant hydroelectric generation in Brazil; the potential synergy between wind and hydro climatological regimes may lead to a stable energy supply based on renewable resources in Brazil, especially in the Northeast region.

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