EXPERIMENTAL INVESTIGATION OF THE PERFORMANCE OF A REVERSE OSMOSIS DESALINATION UNIT OPERATING UNDER FULL AND PART LOAD CONDITIONS

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Abstract

Reverse Osmosis (RO) desalination constitutes a successful technology for covering the potable water needs of islands and coastal regions. RO units can be combined with Renewable energy technologies. Photovoltaic and Wind generators produce the energy consumed by the Desalination Unit. Conventional small scale RO units are not often combined with energy recovery devices; however, these devices can decrease drastically the energy consumption of the RO unit. Furthermore, in the literature there are references which prove that the operation of a desalination unit in part-load conditions can result in lower specific energy consumption compared to a full-load operation.

In the present paper, an experimental evaluation of an existing RO desalination unit, installed in the Laboratory of Agricultural Engineering of AUA, is realized in part-load operation. The experimental operation of the RO Unit in part-load conditions is achieved via variable operation parameters such as the speed of the motor – pump assembly, the pressure and the feed water supply. In order for this to be achieved, the motor of the unit was equipped with a frequency converter to control its rotational speed.

During the evaluation of the measurements results, an optimum operational window (25 – 45 Hz and 40 – 50 bar respectively) was drawn regarding the operation of the RO desalination unit in part-load conditions. More specifically, in this pressure range the average value of fresh water production was 60 L/h with an acceptable fresh water electrical conductivity (< 600 μS/cm), and with a specific energy consumption bellow 6.5 kW/m^3.

In general, it is proven that in remote areas, where the needs of electrical energy and potable water are satisfied with polygeneration microgrids, a RO desalination unit could operate with low specific energy consumption periodically under a suitable planning and management program in full-load and in part-load conditions.

Keywords: *Desalination, Reverse Osmosis, variable operating conditions.*

1. Introduction

Many areas in the world suffer from natural fresh water shortages. The increasing population together with the expansion of industrial and agricultural activities has led to the excessive exploitation of available water resources and the contamination of fresh water resources. Conventional water resources (rivers and groundwater) are presently limited and are being increasingly depleted at an alarming rate in many places [1]. Consequently the seawater desalination process occurs as a solution to this problem, providing high quality potable water. Desalination systems combined with Renewable Energy Sources (RES) are environmentally friendly and can help developed and developing countries of the world.

Conventional desalination methods consume large amounts of electrical energy and they have to be installed in places that face energy supply difficulties. This happens especially on islands and in remote areas [2]. Reverse Osmosis (RO) desalination systems, which are powered by photovoltaics and wind turbines, are thought to be a viable solution for the water production in these remote areas. The main advantages of RO are low energy consumption and minimal maintenance requirements. This approach can also be used in cases of brackish water [3].

Therefore, RES and more specifically photovoltaics, which have a low cost and simultaneously a negligible environmental impact, have been considered as a solution to the problem. The integration of renewable energy technologies with desalination is technically feasible and increasingly applied all over the world.

Renewable energy powered microgrids, are small scale power supply networks that they are designed to provide energy to decentralized areas. They can work either as autonomous systems or interconnected to the grid. A polygeneration microgrid is more reliable because it can operate at lower power levels if there is a failure of one power source instead of shutting down completely [4]. An energy management system of the microgrids used in order for the devices to be able to operate in part load conditions which allow better overall management of the available energy [5].

The major objective of this paper is to investigate experimentally a RO desalination unit which operates in part load conditions in order to be integrated in a polygeneration microgrid topology [4]. Using a frequency converter it is possible to control the rotational speed of the feed water motor pump assembly of the unit. In this way we can investigate the effect of several unit parameters (feed/concentrate flow rate, feed/concentrate electrical conductivity, membrane inlet and outlet pressure and the specific energy consumption) in different frequencies of the motor. The experimental results of the RO desalination unit can be used for the software development of the energy management system which controls the desalination unit's operation in this topology [5].

2. Description of the experimental setup

The Reverse Osmosis (RO) desalination unit was equipped with a DC motor which is used for the experimental investigation of reference [6]. The DC motor was replaced by an AC motor which is equipped with a frequency converter for the control of the motor’s rotational speed. A data logger system was designed and implemented and was responsible for the evaluation of the desalination unit operation in part load. The configuration of the system is presented in Figure 1. The system works in a closed water loop circuit to avoid continuous solution preparation (Figure 2)

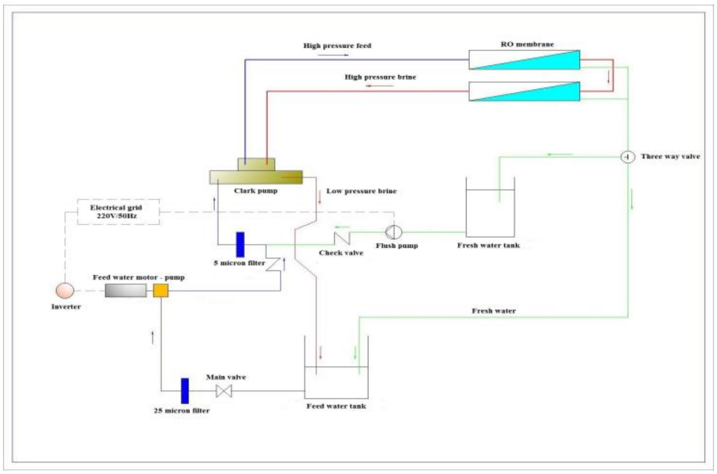

Figure 1: Schematic diagram of the desalination system

2.1 Feed water tank

The feed water tank is a black polyethylene tank with a capacity 1 m^3 [7]. The Electrical conductivity of the NaCl solution, which is prepared by the de-chlorinated tap water, was adjusted to 50 mS/cm, simulating the seawater.

Figure 2: Reverse Osmosis Desalination Unit

2.2 Feed water pump assembly

The feed water motor pump assembly consists of an AC motor and a water rotary vane pump which drives the feed water from the mixing tank to the system through the pretreatment system and also provides the positive pressure required at the inlet of Clark pump. The technical specifications of the motor pump assembly are shown in Table 1.

Table 1: Technical characteristics of the feed water motor pump assembly

Feed water pump	
Pump type	Rotary
Model	Fluid - o – tech PO700
Maximum pressure	16 bar
Rated flow rate at 1450 rpm	0.8 m^3/h
Motor specifications	
Motor type	CEG 80b – 4
Rated Power	0.75 kW
Voltage	Single phase, 220 V

2.3 Pretreatment system

To increase the efficiency and life – time of reverse osmosis systems, effective pretreatment of the feed water is required. The pretreatment system of the RO desalination unit is described in detail in [7].

2.4 Clark Pump

The Clark pump replaces the high pressure pump in a conventional reverse osmosis desalination unit. The Clark pump is a piston pump which increases the seawater pressure in an appropriate value to enter the membranes. The feed water motor pump assembly pressurizes the NaCl solution, from the main mixing tank to one of the two cylinders of the Clark pump. The high pressure brine enters the second Clark pump cylinder and exchanges its hydraulic energy with the medium feed water pressure; the result of these actions is the intensification of the feed water pressure to the required membrane pressure (around 50 bar). The technical characteristics of the Clark pump are shown below in Table 2.

Table 2: Technical specifications of the Clark pump

Type	Eco systems Clark pump
Model	E - 25/590
Rated feed flow rate	760 L/h
Product water flow rate	90 L/h
Rated operating pressure	50 bar
Rated operating feed pressure	12 bar

2.5 *Membranes*

The RO desalination unit consists of two 25 – 40 spiral wound seawater Filmtec membrane elements connected in series in order to increase the recovery rate of desalinated water. The Membrane is the “heart” of the desalination unit and separates the feed water stream into two output streams: low-salinity product water and high pressure brine. The RO membrane technical characteristics are shown in Table 3.

Table 3: RO membrane specifications

Housing	Code line
Membrane type	Filmtec SW 30-2540
Maximum operating pressure	69 bar
Maximum operating temperature	45 ^{0}C
Maximum feed flow rate	1.4 m^3/h
Product water flow rate	83 L/h
Salt rejection	99.2%
Single element recovery	8%

Reference: Dow Chemical Company [8]

2.6 *Fresh water tank*

The flushing tank, constructed of a white polyethylene sheet, has a capacity of 100 L. The product water, produced by the desalination unit, is used for the wash out of the Clark pump and the membranes modules.

2.7 *Flush pump*

The flush pump is a centrifugal pump, which drives the fresh water from the flushing tank to the desalination system, for the washout of the system. The technical characteristics of the motor pump assembly are shown in Table 4.

Table 4: Technical characteristics of the flush pump motor assembly

Flush Pump	
Pump type	Centrifugal
Model	ECOJET 120
Maximum suction lift	7.6 m
Maximum flow rate	3.6
Maximum pressure	5 bar
Motor specifications	
Motor type	Totally enclosed fan cooled
Rated Power	1 Kw
Voltage	Single phase, 220 V

2.8 *Frequency converter*

The frequency converter is a low voltage analog converter, responsible for the variable speeding conditions of the feed water pump. The AC driver is connected in parallel with the feed water motor pump assembly in order for the required frequency level to be achieved. The technical specifications of the frequency converter are shown in Table 5.

Table 5: Technical specification of the frequency converter

Type	HYUNDAI 015SF
Model	N50-015SF
Applicable motor capacity	1.5 kW
Rated output current	7 A
Rated output voltage	3-phase, 220~230 V
Maximum output frequency	400 Hz

3 Experimental investigation

The aim of the experimental investigation was to be monitor and evaluate the operation of the RO desalination unit in part load conditions. Thus, several parameters was measured and recorded such as feed/concentrate flow rate, feed/concentrate electrical conductivity, membrane inlet and outlet pressure and the active power consumption of the feed water motor pump assembly in different frequencies of the motor. At the beginning of the system operation the inverter operated in full load at the frequency of 60 Hz and was decreased gradually by 5 Hz until the frequency of 10 Hz.

3.1 *Feed water and membrane inlet/outlet pressure*

The regression analysis of the experimental data showed a nearly linear relationship between the frequency of the feed water motor and the membrane inlet pressure, the brine pressure (membrane outlet) and the feed pressure with a correlation coefficient value of nearly 99% (Figure 3). As it can be seen in Figure 3, the feed water pressure, combined with the brine pressure, raises the membrane inlet pressure due to the Clark pump.

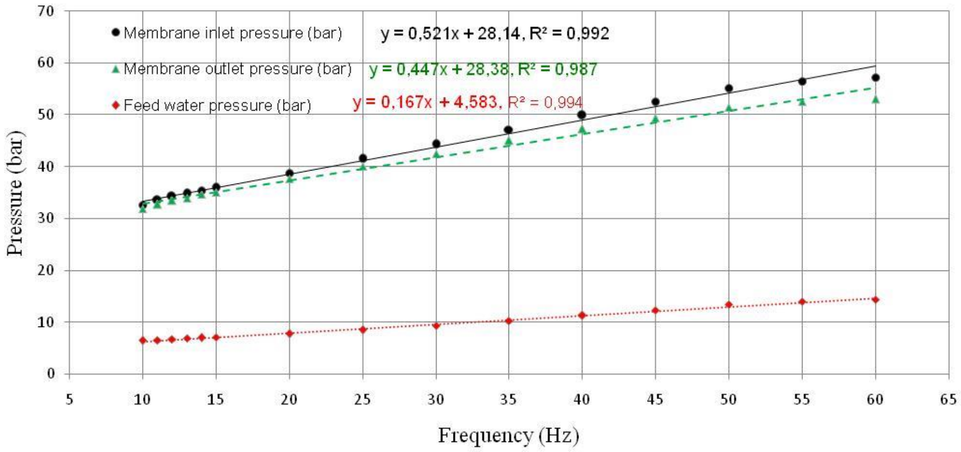

Figure 3: Pressures of the system

3.2 *Fresh water production*

As can be shown in Figure 4, the product water production starts at 10 Hz and continues with a linear relationship till the frequency of 50 Hz. When the frequency is increased the membrane inlet pressure is raised, thus the product water is increased.

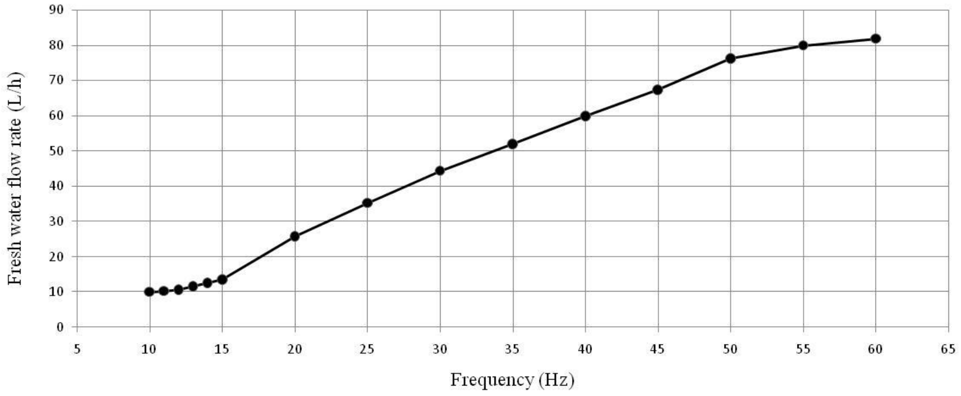

Figure 4: Fresh water production

3.3 *Fresh water quality*

The increased membrane inlet pressure increases the rejection of salts and therefore reduces the electrical conductivity of the desalinated water. Thus, the fresh water quality, shown in Figure 5, is lower than 600 μS/cm at 30 Hz and it drops even more as the frequency of the feed water motor is increased.

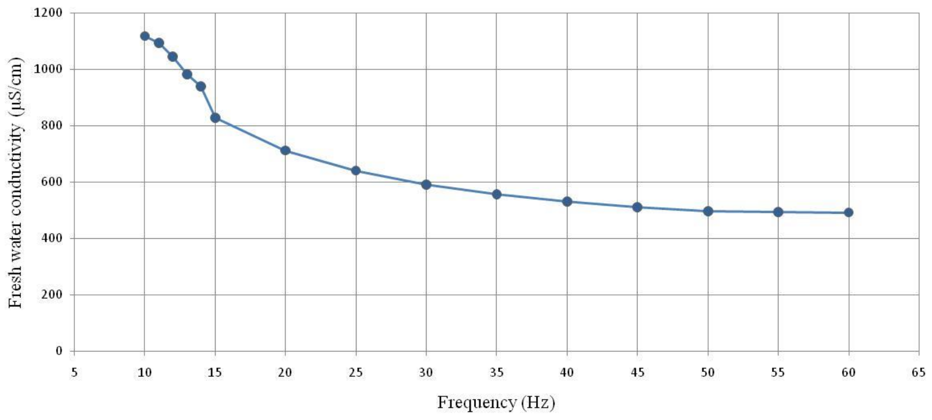

Figure 5: Fresh water quality

3.4 Specific Energy consumption

The specific energy consumption was calculated with equation 1.

$$S_{EC} = \frac{E_m}{Q_p} \qquad (1)$$

Where S_{EC} is the specific energy consumption (kWh/m^3), E_m is the energy consumed by the feed water motor (kWh) and Q_p is the fresh water production (m^3).

In Figure 6 the results from specific energy consumption are presented, calculated for variable operating conditions. It can be noticed in Figure 6 that there is an optimum operational range (approximately 25 – 45 Hz and 40 – 50 bar respectively) in which the RO desalination unit could be operated in part load with minimum specific energy consumption. In this operational window the energy consumption of the motor is low while the fresh water production is relatively high.

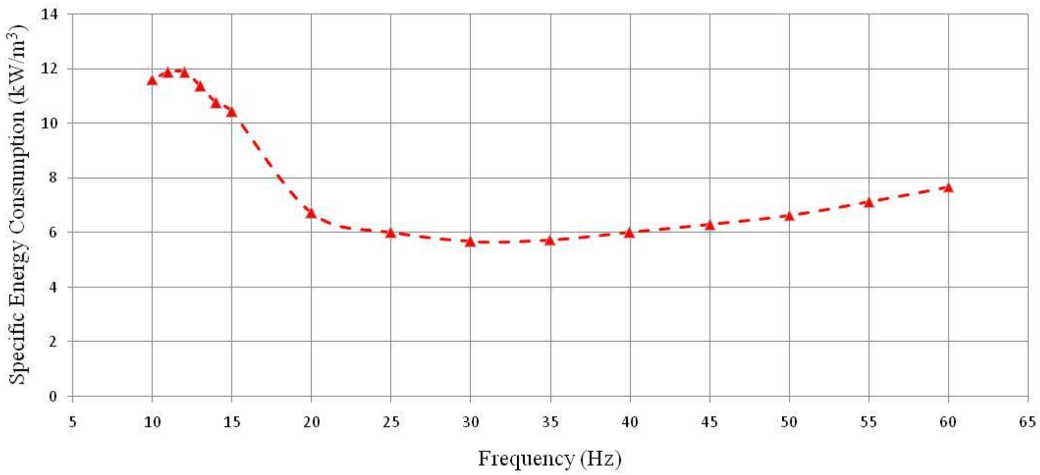

Figure 6: Specific energy consumption

4. Conclusions

The conclusions arising from this work could be evaluated with regard to the fresh water quality and the operating efficiency of an RO desalination unit for its integration in a polygeneration microgrid.

- RO Desalination systems driven by Renewable energy systems such as a polygeneration microgrid topology are suitable in isolated areas characterized by lack of potable water and lack of an electricity grid.
- During the operation of the desalination unit in part load conditions, an optimum operational window is identified (approximately 25 – 45 Hz and 40 – 50 bar respectively) in which the specific energy consumption is low with an acceptable quality of fresh water (< 600 μS/cm).
- In remote areas, where the needs of electrical energy and potable water are satisfied with polygeneration microgrids, a RO desalination unit could operate periodically under a suitable planning and management program in full-load and in part-load conditions.

5. Symbols

S_{EC} : Specific energy consumption (kWh/m^3)

E_m : Energy consumed by the feed water motor (kWh)

Q_p : Fresh water production (m^3)

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