SIZING METHOD OF A PHOTOVOLTAIC POWERED ELECTRODIALYSIS PLANT

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Abstract

This paper presents a sizing method of a photovoltaic (PV) powered electrodialysis desalination plant with batteries. The method is based on aspects of three distinct sizing methods and is applied for the Brazilian Northeast region climatic conditions. The sizing program use as operational basis the platform Excel 2000® and Visual Basic® interfaces, trade mark by Microsoft, with the objective of facilitating the diffusion and the use of sizing concepts of PV stand-alone systems. For these reasons, the mentioned program is a tool to aid in the area of brackish water desalination and alternative sources, especially solar energy.

Keywords: photovoltaic, sizing, electrodialysis

1. Introduction

In the Northeast Region of Brazil a great volume of water exists in the underground, enough to alleviate the water supply crisis of this area. However, due to the fact that 51% of the total area of Northeast (about 788,358 km^2) is located on crystalline rocks, water from deep wells often has high salt concentration (brackish water) preventing direct usage as drinking water. But, due to the lack of options, some rural populations in the area are forced to consume this water, which has a salt content greater than the limit recommended of 500 mg/L by the World Health Organisation (e.g. SBPC, 1995).

It is therefore necessary to find suitable solutions and methods for desalinating the brackish water to make it suitable for human consumption. Electrodialysis is a procedure for this purpose. Its advantages are compact plant design and high water yield in relation to the energy consumption.

The use of PV arrays to power electrodialysis plants for brackish water desalination makes sense in arid and semiarid regions. In such regions there is often an inadequate water and energy supply infrastructure together with good levels of solar radiation, as is the case of the Brazilian Northeast region. As a positive aspect, the electrodialysis plants need no inverter for the direct current given by the PV arrays.

2. Electrodialysis (ED)

Electrodialysis is a membrane separation process that utilizes d-c current application to move and separate dissolved minerals in water. Cations and anions are displaced by an electric field through selective membranes leaving drinking water. The separation of minerals occur in individual membrane units called cells, which consist of a cation selective membrane and an anion selective membrane. The complete assembly of cells is called membrane stack. The figure A1 shows a representation of the electrodialysis separation cell.

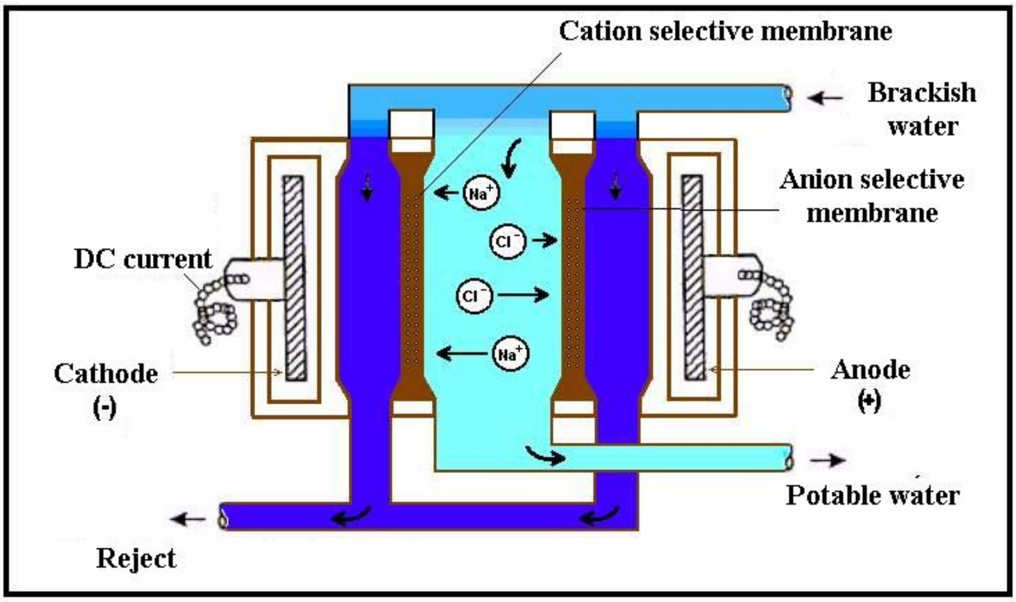

Figure A1: Electrodialysis separation cell

3. PV-ED Sizing Program

The sizing program consists of four components: electrodialysis consumption, full sun hours and PV array inclination, storage sizing and PV array sizing in the blue fields. The program presents the results in simple and direct bold field in the same screen. The figure A2 shows the PV-ED sizing program screen:

3.1 Description of the electrodialysis consumption

For the PV sizing it is necessary to know the characteristics of the electrodialysis load with the introduction of the specific energy consumption (kWh/m^3) and drinking water production per day (m^3/day).

The description of the electrodialysis consumption takes into account:

- the brackish water salt content (mg/L) and the specific energy consumption.

An experimental PV powered electrodialysis desalination plant was developed in Spencer Valley in the USA and performance data were collected. The system was turned on and the membrane stacks voltages were adjusted to obtain a product water quality of 340 mg/L. The collected values as voltages, currents, pressures and flow rates were used to calculate the overall power consumption. The obtained data were limited to a feed water quality of 2200 mg/L (e.g. Lichtward et al., 1996), but the results presents a linear function and it is considered up to 5000 mg/L.

The equation A1 $Sco = 0.55 + \dfrac{Tds}{2300}$ represents a curve-fitting of these linear function that gives a relation between the specific energy consumption (Sco) and the brackish water salt content (Tds);

- The system nominal voltage (V);

- The Ampere-hour consumption (Ah/day): it shows the average consumption of the load per day. It is obtained by the product of the specific energy consumption (kWh/m^3) and the drinking water production per day (m^3), divided by the system nominal voltage;

Electrodialysis Consumption	Unit	Value		Range
Brackish water salt content	mg/L	2000	MENU	500 to 5000
Drinking water production per day	m^3/day	0.75		
Specific energy consumption	kWh/m^3	1,42		
Energy consumption per day	kWh	1.06		
System nominal voltage	V	24		
Ampere-hour Consumption	**Ah/dia**	44.4		
Full sun hours and PV array inclination	**Unit**	**Value**		**Range**
Full sun hours	h/day	5.0		2 a 6
Local latitude	degrees	4		
PV array inclination angle	degrees	**15**		
Storage sizing	**Unit**	**Value**		**Range**
Batteries efficiency factor		0.8		75% to 95%
Corrected consumption Ampere-hour	**Ah/day**	**55.5**		
Autonomy days	days	1.0		0 to 5
Maximum depth of discharge		0.5		0.1 to 0.5
Necessary capacity for the batteries	**Ah**	**28**		
Capacity of the selected battery	Ah	50		
Number of batteries in parallel		**1**		
Battery nominal voltage	V	12		
Number of batteries in series		**2**		
Total number of batteries		**2**		
PV array sizing	**Unit**	**Value**		**Range**
Correction factor of the PV module		0.7		0.5 to 0.9
Current of the project	**A**	**11.1**		
Corrected current of the project	**A**	**15.8**		
Nominal current of the PV module	A	3.15		
Number of PV modules in parallel		**5**		
Necessary voltage to load the batteries	**V**	**24**		
Module voltage for the highest temperature	V	15.0		
Number of modules in series		**2**		
Total number of PV modules		**12**		

Figure A2: PV-ED sizing program screen

3.2 Description of full sun hours and PV array inclination

In that subsystem is described the meteorological condition and the local latitude:

- The average number of full sun hours (h/day) is a form of expressing the accumulated value of the solar energy along the day. It is defined as the number of hours that the solar radiation should stay constant and equal to 1000 W/m^2 so that is equivalent to the accumulated energy in kWh/m^2 per day.
- The installed PV array should be in the same angle of the local latitude, so it can maximize the produced annual energy. For the Northeast Region of Brazil is considered the minimum PV array angle of 15 degrees.

3.3 Description of the storage sizing

That stage corresponds to the energy storage sizing used by the stand-alone system in the periods in that the PV array generation is not enough to supply the load.
In the storage sizing the following concepts are approached:

- The batteries efficiency factor: the value considers the load efficiency and discharge of the batteries. It is obtained from the manufacturer, when not possible the program suggests 0.95;
- The corrected consumption Ampere-hour (Ah/day): it represents the relationship of the consumption Ampere-hour and the efficiency factor of the battery;
- Autonomy days: the number of days when there is no PV generation, but there is system operation based on the storage energy. That value is indicated by the program user;
- Maximum depth of discharge: it represents the maximum discharge allowed for the battery;
- Necessary capacity for the batteries: represents the division of the corrected consumption Ampere-hour by the maximum depth of discharge, multiplied by the autonomy days;
- Capacity of the selected battery (Ah);
- Number of batteries in parallel: it is obtained by the division of the necessary capacity for the battery by the capacity of the selected battery;
- Nominal voltage of the battery (V);
- Number of batteries in series: it is obtained by the division of the nominal voltage of the system by the nominal voltage of the battery;
- Total number of batteries: it is given by the program by the product of the amount of batteries in series and the amount of batteries in parallel.

3.4 Description of the PV array sizing

This program stage describes the component of the stand-lone system to supply the electrodialysis unity and to load the bank of batteries. For the PV array sizing the following values are considered:

- Correction factor of the PV module: it represents the adjustment factor of the module current for field conditions as dust accumulation in the module surface, losses among the modules badly connected, high temperature and degradation along the time. This value is considered usually equal to 0.7 for amorphous silicon and 0.9 for crystalline silicon;
- Current of the project (A): it is obtained by the division of the corrected consumption ampere-hour and the number of full sun hours;
- Corrected current of the project (A): it represents the minimum current generated by the necessary PV array to supply the daily average electrodialysis load. It is obtained

by the division of the current of the project and the correction factor of the PV module;
- Nominal current of the PV module (A): it represents the nominal current of the module given by the manufacturer for the standard conditions;
- Number of PV modules in parallel: it is the necessary number of PV modules connected in parallel to supply the corrected current of the project;
- Necessary voltage to load the batteries (V): it is obtained by the product of the nominal voltage of the battery and the number of batteries in series;
- Module voltage for the highest temperature (V): it represents the value given by the manufacturer for the voltage of the module corresponding to the expected highest operation temperature;
- Number of modules in series: it is obtained by the division of the necessary voltage to load the batteries and the module voltage for the highest temperature;
- Total number of PV modules: it is obtained by the product of the number of modules in parallel and the number of modules in series.

3.5 Application of the program

As application of the program was analyzed the case of the village of Coité-Pedreiras, 150 families, located in the state of Ceará. Considering a daily drinking water consumption of 5 liters per family, the total daily consumption is of 750 liters. The other electrodialysis consumption input data are:

- salt content of the brackish water equal to 2000 mg/L;
- nominal voltage of the system (V) equal to 24 V;

The full sun hours and PV array inclination data are:

- average number of full sun hours equal to 5 h/day;
- local latitude equal to 4º;

The storage sizing input data are:

- efficiency factor of the batteries equal to 0,8;
- autonomy days equal to 1;
- maximum depth of discharge equal to 0,5;
- capacity of the selected battery equal to 50 Ah;
- Battery nominal voltage equal to 12 V;

The PV array sizing input data are:

- correction factor of the PV module equal to 0.7;
- nominal current of the PV module equal to 3.15 A (PV module power equal to 55 W_p, product of 3.15 A and 17,4 V);
- module voltage for the highest temperature equal to 15V.

The results of the PV-ED sizing program are shown in the bold fields of the Figure 2. In this case there is the need of 2 batteries with capacity of 50 Ah, voltage of 12 V and also 12 PV modules of 55 Wp for the production of 0.75 m^3 of drinking water per day.

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