Design And Simulation Of Photovoltaic Energy System To Drive RO Desalination Plant

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Abstract

Energy and water are the primary factors that affects the social and economic health of the modern world. Many places that suffer from fresh water shortage are now days increasingly depending on desalination. As an outcome of this fact desalination market has greatly expanded in recent times and it will continue in the coming years. Combining renewable energy resources with desalination and water purification is a very interesting option. This is because the areas of fresh water shortages usually have lots of renewable energy sources, which makes their operation easy and cost effective there. The main characteristic of renewable energies is that they are friendly to the environment. Production of potable water using desalination methods that is driven by renewable energy systems is an efficient solution to the water scarcity at remote areas.

1. Introduction

Today two of the most important topics that are being discussed are water and energy. Scarcity of water is an emerging problem. A water crisis is a situation in which the available potable, unpolluted water within a region is less than that region's demand. Although three –fourth part of the earth is covered by water, the fresh water available is only 3%[9]. Thirty percent of all fresh water is underground, most of it in deep, hard-to-reach aquifers[4]. Rapid industrial growth and the worldwide population explosion have resulted in a large rise of demand for fresh water. Added to this the problem of pollution of rivers and lakes by industrial wastes is also increasing. In order to overcome the problem of water scarcity, desalination is a good option.

To desalinize means removal of salt from saline or sea water or removing impurities from brackish water. According to World Health Organization (WHO), the permissible limit of salinity in water is 500 parts per million (ppm)[4]. Excess water salinity causes many problems like unpleasant taste, stomach problems. Water desalination can be done by different methods. They can be divided into two processes names as thermal and membrane processes. But here arises next problem, energy for the operation of this plants. We usually use conventional sources of energy like fossil fuels to run the plant. But the usage of fossil fuels have a lot of environmental impacts and also at the same time the fossil fuel sources are depleting at a very fast rate. As a solution for this problem we can use renewable energy sources to run the plant.

Production of potable water using desalination methods which is driven by renewable energy is considered to be a good solution for water problem. Remote areas always lack potable water and also at the same time conventional energy sources like heat and electricity grid. Considering the problems created by usage of conventional energy sources for power production for desalination, renewable energy (RE) is a clean, non-polluting alternative.

Reverse Osmosis membrane technique is the one of the most commonly used technique for desalination. Among the renewable energy sources solar energy is the most promising source. If we use the solar energy to run the desalination plant, then it will be good option.This paper discuss about a sea water RO desalination plant and an isolated photovoltaic system (PV) producing the power required for the desalination process. In order to increase the efficiency of PV panel here a tracking system is also employed.

2. Desalination

As we discussed above the lack of potable water is a big problem in parched regions of the world. Clean drinking water is one of the most important international health issues today. In some cases the areas which are lack of fresh water have abundant source of salt water. In such cases desalination can be good option to provide fresh water. Desalination is basically the process of removal of salts from brackish or sea water. Salt water is fed into the process, and the outcome is one output stream of pure water and the other one is wastewater with a high salt concentration[6].

3. Desalination Techniques

Commercial desalination processes based on thermal energy are

- Multi-stage flash (MSF) distillation
- Multiple effect boiling (MEB)
- Vapor compression (VC)

Another method of desalination is based on membranes. These are

- Reverse osmosis (RO)
- Electro-dialysis (ED).[5]

In the thermal processes, the distillation of seawater can be achieved by utilizing a thermal energy source[8]. The thermal energy may be obtained from different sources like fossil-fuel source, nuclear energy or from a non-conventional solar energy source or geothermal energy[7]. MSF and MEB processes consist of different set of stages at successively decreasing temperature and pressure[8].

4. Need Of Renewable Energy

Renewable energy is the energy that comes from different natural sources like sunlight, wind, rain, tides, biomass etc. The greatest advantage is that they can be naturally replenished. Presently we are mainly depending upon conventional sources like fossil fuels to full fill our energy requirements. But these sources are not renewable. The fossil fuel sources are depleting very quickly. As a consequence of the usage of fossil fuels, harm full emissions are being discharged to environment which causes greater harm to the stability of the nature. So the usage of renewable energy resources will help us to overcome these problems. Thus in this paper we select a renewable source(solar photovoltaic) to run the desalination plant

5. Photovoltaic Energy System

Today one of the most commonly used renewable source is solar photovoltaic energy. Photovoltaic cells convert sunlight into electric energy. Usually photovoltaic cells are made of crystalline silicon. A PV cell consists of two or more thin layers of semi-conducting material, mostly, silicon. As a result of exposure of silicon to light electrical charges are generated and this can be conducted away by metal contacts as direct current (DC). A single cell can produce only a small electric current, so large number of cells are connected together and enclosed in a cover, usually glass to form a module or a panel.

The PV panel is the principle building block of a PV system and any number of panels can be connected together to give the desired electrical output. This is one of the considerable advantages of the PV system, in which we can add any number of panels according to the requirement. Even though the cost to produce of electricity from solar panel is high, current trend shows that it starts decreasing[2].

6. Description Of PV-RO System

The block diagram of PV-RO system is as shown in figure 1

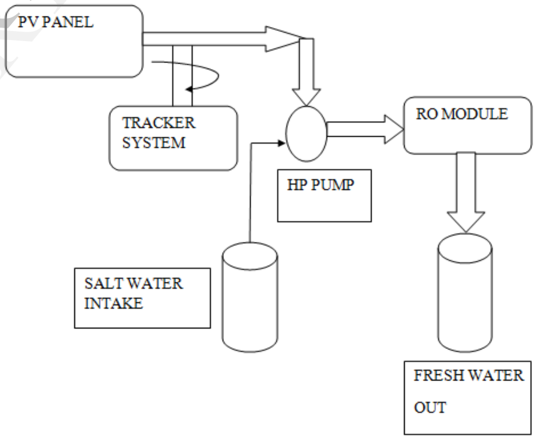

Figure1 block diagram of PV-RO system

In this paper we discuss the simulation of a PV powered RO desalination system. In a reverse osmosis process the water that is to be treated has to be passed through a series of RO module which filters away the salt content or impurities. This feed water must be passed through the RO membranes at very high pressure. The high pressure will make the feed water to pass through the membranes at a very high pressure. Here the power for this HP pump will be provided by the solar modules . A tracker system is also employed to increase the efficiency of solar module. In this paper the modelling of a 10W solar panel and its tracking along with the simulation of desalination of borewell water is presented.

7. Modelling Of Solar Panel

The basic equations which we used here for modelling PV panel is as given below. They are based on equations given in reference [11].

The photovoltaic current is given by

$$I_{PH}=[I_{SC}+K_I(T_C-T_{REF})]*G \quad (1)$$

Reverse saturation current is given by

$$I_{RS}=I_{SC}/exp(q*V_{OC}/k*T_{REF}*A)-1 \quad (2)$$

Saturation current is given by

$$I_S=I_{RS}*(T_C/T_{REF})^3*exp[q*E_g/k*a(1/T_{REF}-1/T_C)] \quad (3)$$

Output current is given by

$$I=N_P*I_{PH}-N_{P*}I_S[exp(q*V/N_{s*}k*T_C*A)-1] \quad (4)$$

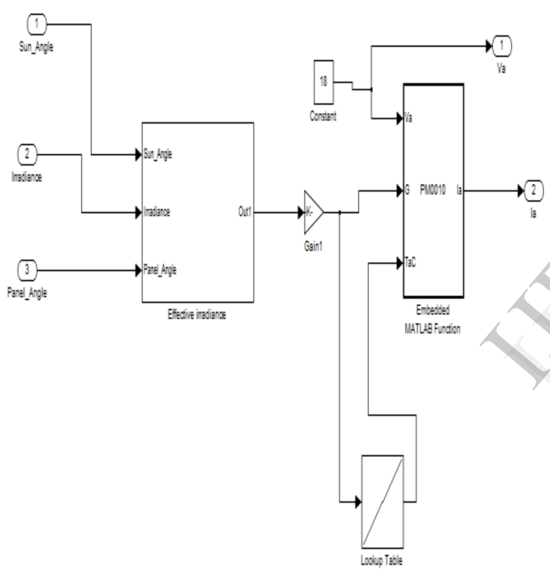

Figure 2 simulation of static panel

8. Solar Tracking

The power generated in a solar panel will depends on the amount of irradiance received by it. A solar tracker is a device that orients various payloads toward the sun. An ideal tracker would allow the PV cells to accurately point toward the sun, compensating for both changes in the altitude angle of the sun (throughout the day), latitudinal offset of the sun (during seasonal changes) and changes in azimuth angle[3]. In this paper the solar tracker model consists of an LDR model, microcontroller model and a servo motor model.

8.1 LDR

One of he simplest optical sensor is a photo resistor(Light Dependent Resistor) which may be a cadmium sulfide (CdS) type or a gallium arsenide (GaAs) type. The photocell is a passive component whose resistance is inversely proportional to the amount of light intensity directed toward it[3]. In this simulation model the two LDR's will produce two voltages, LDR top voltage and LDR bottom voltage. They will be given as input to the microcontroller model.

8.2 Servo Motor

A Servo is a small device that has an output shaft and this shaft can be positioned to specific angular positions by sending certain programmed signals. As long as the coded signal is fed to servo it will maintain the angular position of the shaft. With the change in signal the angular position will also change[3].

In this simulation the motor model will receive the PWM signal output of the microcontroller model and it will use that value to produce a corresponding panel angle. This panel angle will be given back to panel model each time.

8.3 Microcontroller

A microcontroller can be considered as a small computer on a single integrated circuit which contains a processor core, memory, and programmable input/output peripherals. Microcontrollers are mainly used in automatically controlled products and devices. The usage of microcontroller reduces the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices.

In this paper a microcontroller model is used. In the simulation of tracker system it is designed in such a way that the LDR block produce output voltage corresponding to the change in the irradiation. These two voltages and the current panel position has been given to the microcontroller model as inputs. It will in turn produce a PWM signal as a function these three inputs and this signal will be given as the input to the motor model.

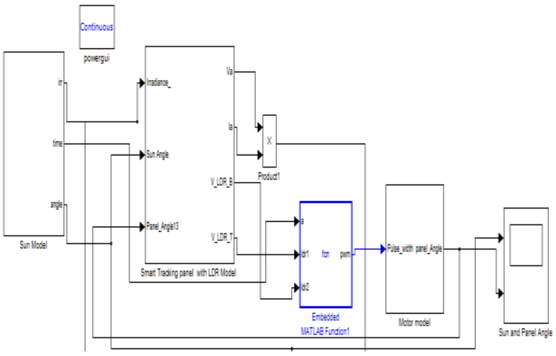

Figure 3 simulation of tracking of solar panel

9. Reverse Osmosis

Among desalination technologies, reverse osmosis (RO) is one of the most reliable technologies. Reverse osmosis is a pressure-driven process that depends on the properties of semi-permeable membranes to separate water from a salt dominated feed. The amount of freshwater that can be recovered from the feed is limited by membrane fouling and scaling. Overall water recovery rates are 45–50% for seawater RO systems, and they can be as high as 90% in brackish water desalination systems[1]. The RO process is effective for removing total dissolved solids (TDS) concentrations of up to 45,000 mg/L. This can be applied to the desalination of both both brackish water and seawater[8].

A reverse osmosis process consists of four major steps: (1) pre-treatment, (2) pressurization, (3) membrane separation, and (4) post-treatment stabilization.

In order to carry out the simulation of RO system we need to know the properties of water in which we are going to purify. The simulation of RO system is done using IMS design. The chemical parameters of borewell water that we obtained is given below in table 1.1

The simulation of RO system is done using IMS design software. The values of chemical parameters of bore water is entered here along with the number of level of filtering that we require(ie.1 or 2). The level of flow, pressure and total dissolved contents at different stages is shown in table 2.

Table 1 chemical parameters of bore water and its value

IONS	PERMEATE(mg/l)
Ca	1.406
Mg	.843
Na	8.573
K	1.912
NH4	0.076
Ba	0.009
HCO3	9.75
SO4	.837
Cl	7.413
F	1.166
NO3	7.791
B	0
SIO2	.64
CO2	3.29
TDS	40.6
pH	6.65

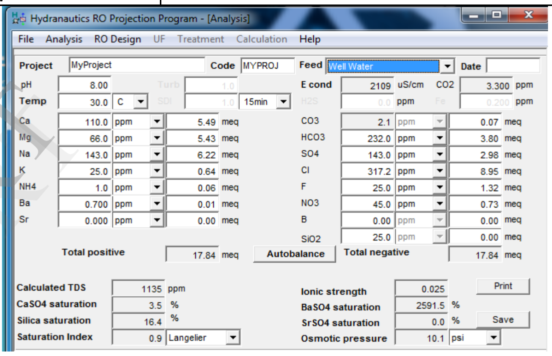

Figure 4 simulation of RO system

	1	2	3	4	5	6	7	8
Flow (m^3/hr)	2.3	2.3	2.2	2.2	2	0.1	0.2	0.4
Pressure(bar)	0	2.7	2.4	8.4	8.1	0	0	0
TDS (ppm)	1135	1135	1184	1184	1330	53.9	31.7	29.3

Table 2 Different levels of flow, pressure and TDS at various points

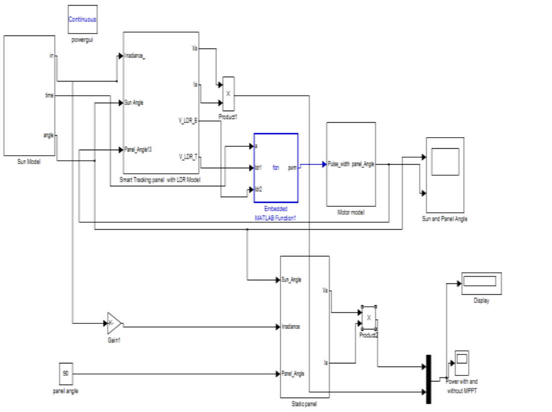

Figure 5 overall simulation of tracking system

10. Simulation Results

Here a 10W solar panel is simulated along with the tracker system to produce required power to run a reverse osmosis plant. As observed from the plots, the solar tracker is able to follow the sun angle. From the plot, we can see that the smart tracking panel produces a higher output current compared to the static PV panel.

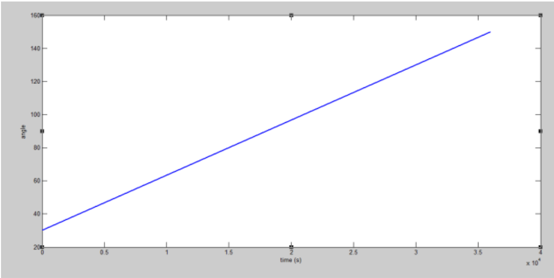

Figure 6. sun angle

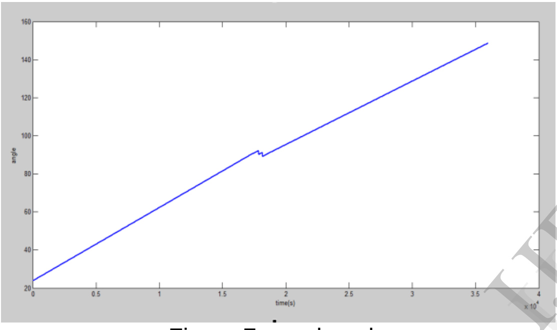

Figure 7 panel angle

From the results of RO simulation we can see that the total dissolved content of the input feed water (here bore well water) is decreasing from stage to stage. Hence purifying the input feed water.

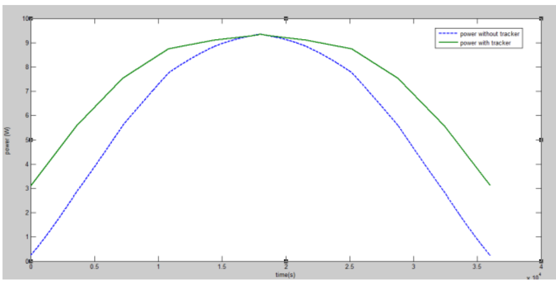

Figure 8 power with and without tracker

RO program licensed to:
Calculation created by:

Project name:	MyProject		Permeate flow:	0.25	m3/hr
HP Pump flow:	1.7	m3/hr	Raw water flow:	1.7	m3/hr
Feed pressure:	1.5	bar	Permeate recovery:	15.0	%
Feedwater Temperature:	30.0	C(86F)			
Feed water pH:	8.00		Element age:	3.0	years
Chem dose, ppm (100%):	0.0	H2SO4	Flux decline % per year:	7.0	
			Fouling Factor	0.80	
			Salt passage increase, %/yr:	10.0	
Average flux rate:	10.0	lm2hr	Feed type:	Well Water	

Stage	Perm. Flow m3/hr	Flow/Vessel Feed m3/hr	Flow/Vessel Conc m3/hr	Flux l/m2-hr	Beta	Conc.&Throt. Pressures bar	Conc.&Throt. Pressures bar	Booster Pressure bar	Element Type	Elem. No.	Array
1-1	0.0	1.7	1.6	2.9	1.02	1.3	0.0		SanRO-HS2-4	2	1x2
1-2	0.2	1.6	1.4	24.0	1.19	7.0	0.0	6.0	SanRO-HS2-4	1	1x1

	Raw water		Feed water		Permeate		Concentrate	
Ion	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Ca	110.0	5.5	110.0	5.5	1.406	0.1	129.2	6.4
Mg	66.0	5.4	66.0	5.4	0.843	0.1	77.5	6.4
Na	143.0	6.2	143.0	6.2	8.753	0.4	166.7	7.2
K	25.0	0.6	25.0	0.6	1.912	0.0	29.1	0.7
NH4	1.0	0.1	1.0	0.1	0.076	0.0	1.2	0.1
Ba	0.700	0.0	0.700	0.0	0.009	0.0	0.8	0.0
Sr	0.000	0.0	0.000	0.0	0.000	0.0	0.0	0.0
CO3	2.1	0.1	2.1	0.1	0.000	0.0	2.5	0.1
HCO3	232.0	3.8	232.0	3.8	9.750	0.2	271.2	4.4
SO4	143.0	3.0	143.0	3.0	0.837	0.0	168.1	3.5
Cl	317.2	8.9	317.2	8.9	7.413	0.2	371.9	10.5
F	25.0	1.3	25.0	1.3	1.166	0.1	29.2	1.5
NO3	45.0	0.7	45.0	0.7	7.791	0.1	51.6	0.8
B	0.00		0.00		0.000		0.00	
SiO2	25.0		25.0		0.64		29.30	
CO2	3.29		3.29		3.29		3.29	
TDS	1135.0		1135.0		40.6		1328.2	
pH	8.00		8.00		6.65		8.06	

	Raw water	Feed water	Concentrate
CaSO4 / Ksp * 100:	4%	4%	4%
SrSO4 / Ksp * 100:	0%	0%	0%
BaSO4 / Ksp * 100:	2591%	2591%	3121%
SiO2 saturation:	16%	16%	19%
Langelier Saturation Index	0.91	0.91	1.11
Stiff & Davis Saturation Index	0.96	0.96	1.14
Ionic strength	0.03	0.03	0.03
Osmotic pressure	0.7 bar	0.7 bar	0.8 bar

Table 3 result of RO system

11. Conclusion

Many areas worldwide that suffer from severe water scarcities are increasingly dependent on desalination as a highly reliable, non-conventional source of freshwater[10]. The need for fresh water will lead to wars in future. Also at the same time energy crisis also emerges as a major problem. For water crisis desalination is a good option. . Despite a steady reduction in the energy consumption of pressure-driven membrane processes in recent decades, energy consumption is still a major cost component of RO desalination plants, accounting for 40–45% of total costs[5]. Though desalination is a good option its energy requirement is huge.

Thus combining renewable energy resources with desalination technique is a good solution for water and energy crisis. If the huge energy requirement for desalination can be fulfilled by renewable energy resources like solar photovoltaic we can reduce the problems due to the usage of fossil fuels. The usage of solar photovoltaic energy to run a desalination plant with reverse osmosis technology will be good solution for of fresh water crisis and also at the same time for energy crisis too. Simulation results are also shown here.

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