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Small Capacity Solar-Powered Desalination Units: Analysis to Inform Decision Making

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Abstract: *The photovoltaic powered reverse-osmosis system is one of the new technologies for producing fresh water from either brackish or seawater, especially small units for remote areas. The present paper is directed to study the performance and economics of a small scale brackish water desalination unit, using four types of power supply systems. These are: system-1: PV modules, batteries, and inverter, system2: PV modules, batteries, inverter and diesel generator, system-3: diesel generator, and system4: Local national grid electricity. The results showed that electrical energy costs are 0.46, 0.25, 0.1 \$/KWh, for system-1, system-3, and system-4 respectively. In addition, regarding economic and environmental benefits, the results proved that system-1 can compete with system-2, whenever the price of PV module is reduced down to 1\$/W_p or less. Also, the unit cost of fresh water is found to be 3.12, 2.23, 1.787, and 1.382 \$/m^3 for system-1, system-2, system-3, and system-4 respectively.*
Keywords: *Brackish Water, Reverse Osmosis, Photo Voltaic, Desalination, Economics*

I. Introduction

Desalination systems with capacity up to 60 m^3/day are considered as Small capacity. Reverse osmosis (RO) is a desalination system uses a membrane. Advantages of RO are low energy requirements, modularity, compactness, easy installation, and simplicity in operation [1–8]. Consequently producing cheap fresh water is possible.

Solar photovoltaic water pumping (SPVWP) has been implemented around the world as an alternative electric energy source for remote Areas in developed countries [9–21]. Canada, Mexico, western US, and Australia are the biggest portion of the SPVWP system users [11].

Simulation and field tests for a photovoltaic - powered water pumping system, employing an induction motor pump, has been developed by Daud, et. al. [18].The system average daily capacity was 50 m^3 at 37 m head. The system was installed on a desert well in Jordan based on the average solar radiation amount =5.5kWh/m^2/day.

A small case study for application of solar powered pump to a deep well in Zambia was analyzed by Romas, J. S. [19]. The case was to supply 10 families with a consumption of 100L/day each. The well depth was 100m. They concluded that, the water cost is 1.07£/m^3 and investment cost is 3019£. The pump power is154W, and solar array of 195W_P is necessary. Also, as indicated to make the pre-sizing process is easier, the following figures are important:

1. The necessary PV power for each m^3/day of water pumping is 195W_P/m^3.
2. The PV power for each watt of pump power installed is 195/154 = 1.27W_P/W_{Load}.
3. The power of water pump needed per m^3 is 154W_{Load} / m^3.

Finally, they mentioned that PV pumping is the best economic solution compared to diesel generators or the extending electric grid.

Other figures for sizing the PV pumping system were reported by Al-awaji et. al. [15]. It was concluded that, based on 600L/h at 50 m head using submersible pump motor of 0.55 KW, the following components are necessary: 16 PV modules, each of 70W_P (1120W_P) with control unit of 1500W, variable voltage and frequency and soft starter of 12.5A DC at120VDC.

From practice, PV pumping system is more economic and reliable than diesel pumping system for areas of average solar intensity higher than 5kW/m^2/day (under the condition of water requirements are lower than 100m^3/day and depths of 15-60 m) [18,19].

Different capacities of solar pumps are available in the market (flow rates up to11m^3/h and head up to 240m) [21]. For example, to lift water from depths exceeding 65m at 5.7l/min, power required is less than 150W. In sunny day (10h of sunrise) it can lift 3400 Liter which is enough for several families. The power source from PV can be connected to the pump motor directly or using either DC/DC inverter or DC/AC inverter.[21].

A summary of Installed BW-RO plants driven by PV power is given in table (1). Also, the main components of PV-BWRO are shown in fig.(2).

The present paper is directed to study the performance and economics of a small scale Brackish water pumping and desalination units, using the following four types of power supply systems as shown in figures (2-a, b, c and d):

- System-1: PV array, batteries, and inverter
- System-2: PV array, batteries, inverter and diesel generator
- System-3: diesel generator
- System-4: Local national grid electricity.

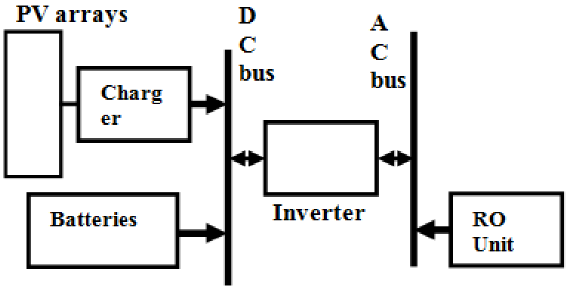

Fig.(1-a). *Block diagram forSystem-1.*

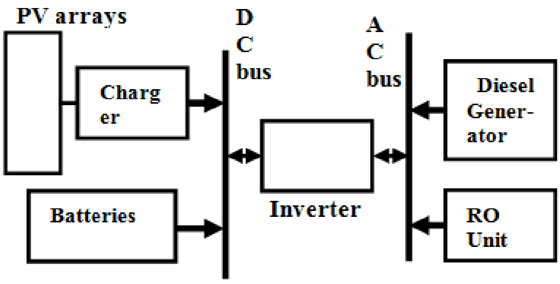

Fig.(1-b). *Block diagram forSystem-2.*

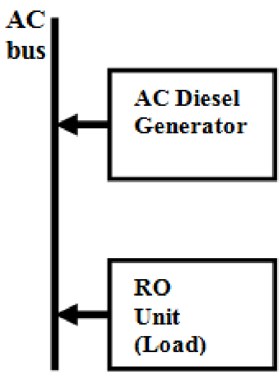

Fig.(1-c). *Block diagram for System-3.*

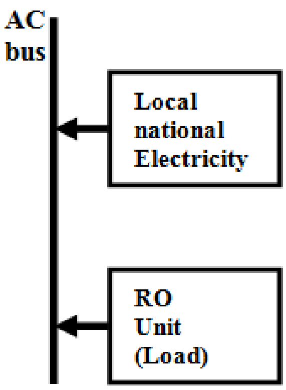

Fig.(1-d). *Block diagram for System-4.*

Also, the study compares between the different four systems for use in pumping and desalination of brackish water. For economical analysis, the present worth method is used. In this method, lifetime, cost items, and interest rate for each proposed system are considered. These cost items are: capital cost (CAPEX), operation and maintenance (O& M cost, Labor cost (OPEX) cost, Replacement cost, Installation cost, energy. The calculations are done using a simple calculation program (Microsoft Excel).

Table2.*The BWRO plant design data[33].*

Max. Feed water Temperature, °C	42
Feed water pressure, Psi	20:80
Operating pressure, Psi	180:250
H_2 sulfide	Must be removed
Turbidity	Should be removed
Max. Iron content, ppm	0.05
Feed water TDS, ppm	0:2000
PH range	3:11
Max. Silica, ppm	25ppm @ 60% recovery
Membrane size and quantity	4X40 inch, Q=2
Permeate flow, GPD	15000
Feed pump power	2.5 hp (motor)
High pressure pump power	5.5 hp.
Motor power at TDS=1000ppm, hp	3

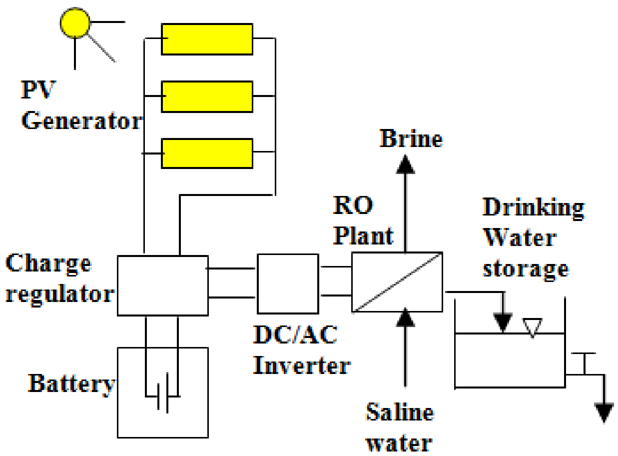

Fig.2.*Schematic of PV-BWRO system[24].*

Table1.*Installed small-scale Brackish water RO plants driven by PV power[23,24,25,28].*

Location	Feed Water ppm	Capacity m^3/day	PV kW_{Peak}	Batteries kWh	SPC, kWh/m^3	Cost$/$m^3$	Year
Sadous, Riyadh, Saudi Arabia	5800	15	10.08	264	None		1995
Magan, Israel	4000	3	3.5+0.6wind	36	None	11.6	1997
Elhamrawien, Egypt	3500	53	19.84+0.64control	208	0.89	None	1996
Heelafar, Rehab, Oman	1000	5	32.5	9.6	None	6.25	1995
Haifa, Israel	5000	3	3.5plus0.6wind	36	None	None	2001
White cliffs, Australia	3500	0.5	0.34	None	2.8	None	2003
Solar flow, Australia	5000	0.4	0.12	None	1.86	10-12	2001
Hassi-Khebi,Algeria	3200	0.95m^3/h	2.59	None	None	10	None
INETI, Lisboa, Portugal	5000	0.1-0.5	0.05-0.15	None	None	None	2000
Concepciondel Oro, Mexico	3000	0.71m^3/day	2.5	none	6.9		1982
Thar desert, India	5000	1m^3/day	0.45		1kWh/kg salt		1986
Perth, Australia	BW	0.4-0.7m^3/h	1.2	None	4-5.8		1989

Gillen Bore, Australia	1600	1.2	4.16	None			1996
Wano Road, Australia	BW		6				
Kasir Ghilen, Tunis	5700	50				7.25	2006
Coite-Pedreias, Brazel	BW	0.25	1.1	9.6	3-4.7	14.9	
Mesquite, Nevada	3500	1.5	0.4		1.38	3.6	2003
North of Jawa, Indonesia	BW	12m³/day	25.5				2008
Eritrea	BW	3m³/day	2.4				2004
Ksar Ghilène, Tunis	3500	42m³/day,2.1m³/h	10	72(600AhX120 VDC)			2006
Gaza, Palestine	4200	1-5	5.4(9x600W)		1.4	6-7	2006
	4000	5m³/day	3	11.7	1.44	3.98	2010
University of Almeria, Almeria, Spain	BW	2.5m³/h	23.5				

II. RO System Selection

Based on the water analysis, the right RO system can be selected. Then system components can be defined (pre-filtration, the type, number, and configuration of membranes, pumps and motors). Table (2) shows the specifications of the BW-RO unit which is considered under the study[33].

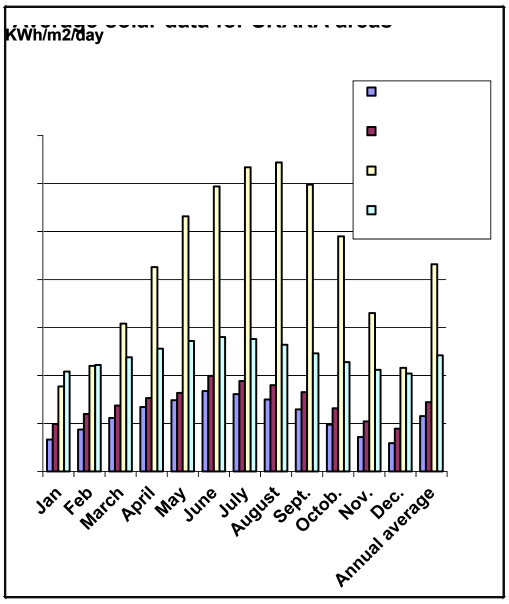

Figure3. *Average monthly solar data [1].*

III. Solar Input Data for Sizing the System Components

The monthly Average solar radiation was obtained and plotted in figure (3) [1]. From this figure, the average solar radiation for horizontal and tilted plane is 5.77, 7.22 kWh/m²/day and tilted respectively. In addition, the annual average day light hours are 12 h. Also, from this figure, the lowest value is obtained in Dec. (4.45kW/m²/day).

IV. Analysis

To study the performance and economics of the studied four systems, the following mathematical modeling of each component is given below. While, the economic analysis is given in Appendix(A).

IV.1.Sizing Photovoltaic Components

- *PV array*

The PV generator is used to get direct current (DC) electric power from solar radiation received on its surface. Then, the DC power is converted to AC power to supply the motor using the inverter. A battery bank is used as a storage system. To get the inverter input voltage from PV arrays, it is connected in series. While to generate enough power necessary to run the system (including losses), a number of PV rows are connected in parallel.

Assuming the inverter efficiency (η_{inv} = 90%), the battery efficiency (η_b=85%) and the PV array thermal losses in the local environment about15% (F_{th} = 0.85), the PV array Peak power equation is given[27];

PV array Peak power=

(1)

where: PSSH is the average peak sun shine hours., E_L is the load energy in kWh/day.

- *Batteries capacity:-*

The battery bank is selected to operate the system for one day. The power of battery bank is calculated as follows[22]:

(2)

Where DOD is a battery maximum depth of discharge (50%).

Considering that 24V is the voltage output from the battery, the required battery bank capacity in

Ampere hour(Ah) = Battery capacity×1000/24 (3)

- *The inverter*

To convert from DC power to AC power, the inverter is used. The inverter is sized based on the peak power of the PV array, and its input and output voltages must be suitable for the operation of the battery and ROunit.

- *Batteries charger*

Charge controller acts as interface between PV array and the batteries. Considering the controller efficiency, the charger output is:

(4)

Where, P_{PVR} : is the output power of the charger,

P_{PVout}: is the PV output power, and

η_{PVR}: is efficiency of the controller.

The rating of charge controller is chosen according to the battery voltage and the output power from PVarray.

IV.2. Calculations of Pumping Power Consumption

The ideal hydraulic power to drive a pump depends on the mass flow rate, the liquid density and the differential height – either it is the static lift from one height to another, or the friction head loss component of the system- can be calculated as follows[10]:

P_h=Qρgh/(3.6×10^6) (5)

Where

P_h=Hydraulic power(kW)

Q=Flow capacity(m^3/h)

ρ=Density of fluid(kg/m^3)

g=Gravity(9.81m/s^2)

h=Differential head(m)

The shaft power is the power transferred from the motor to the shaft of the pump, which depends on the efficiency of the pump and can be calculated as:

Ps=Ph/η (6)

Where, η is the overall pump efficiency, which is taken equal to 0.6 during the present study.

Hence, the specific power consumption can be expressed as:

(7)

where,is the total electric power consumed by feed and high pressure pumps, kandis the permeate flow rate at outlet from RO membranes unit,m^3/h.

IV.3. Stage Recovery Calculations for RO Passes (R%)

Recoveryistheratioofpermeatetomembranefeedflows,typicallyexpressedasapercentage.

(8)

Where,is the permeate flow rate at out let from RO membranes unit, m^3/h, andis the feed flow rate at inlet to RO membranes unit, m^3/h.

IV.4.Diesel Generator

An approximation for fuel consumption relation with rated power of the diesel generator and the actual power provided by this diesel generator is given below[40].

$F=0.246 * P_{Gout} + 0.08415 * P_{Gr}$ (9)

Where F: is fuel consumption (Liter/h),

P_{Gout}: is the actual operating output power(kW),

P_{Gr}: is the rated electric power of diesel generator(kW),

0.246: is an empirical factor and it is in (liters/kWh), and
0.08415: is also an empirical factor and it is in (liters/kWh).

IV.5. RO Product Cost Calculations

The RO cost data includes the following [28]:

- Direct capital cost (DCC) in US$
- Membrane purchase cost(@60%DC)
- Membrane annual replacement cost(@10% of Membrane purchase cost.
- Plant capacity (m) = m^3/day
- Electric cost (c) = $/$m^3$
- Specific consumption of electric power(w)=kWh/m^3
- Specific cost of operating labor*(L)*=$/$m^3$
- Specific chemicals cost (k) = $/$m^3$

The calculations proceed as follows:

1. The amortization factor, a:
   $/year
2. The annual fixed charges, A1:
   A1=(a)(C)
3. The annual electric power cost, A2:
   A2=(c)(w)(f)(m)(365)$/year
4. The annual chemicals cost, A3:
   A3= (k) (f) (m) (365) = $/year
5. The annual membrane replacement cost, A4:
   A4 = $/year
6. The annual labor cost, A5:
   A5= *(i) (f)* (m) (365) = $/year
7. The total annual cost, At:
   At =A1+A2+A3+A4+A5 $/year
8. The unit product cost per m^3, A_s:
   As= At / ((f) (m) (365)) = $/$m^3$ (10)

V. Assumptions

The following values which are applicable for the present application are used as input data for studying the proposed four systems [55, 56, and 57]:

PV system components

The sizes of the PV system components (arrays, batteries and inverter) are estimated using the peak sun hour method and solar energy availability for the specified site. The average daily solar radiation of 5.77 kWh/m^2/day was used [13].

- PV array: Poly-crystalline - P_{peak} = 250W, V_{peak} = 30V, I_{peak} = 8.33 A, V_{OC} = 36V, I_{SC}=10A.
- The efficiency factors of losses in battery and inverter are estimated to be 0.8 and 0.85, respectively.
- Investment cost (I.C) of PV arrays is5$/$W_P$.
- Installation cost PV arrays is16% of its I.C.
- Operation and maintenance cost of PV is 3% of its IC, annually.
- Life time of PVarraysis20years.
- Batteries Investment cost(I.C) is 250 $/kWh.
- Battery O&M cost is 3% of its I.C, annually.
- Battery replacement cost=I.C
- Battery lifetime is10years.
- Inverter
- I.C of Inverter is 500$/$KW_P$.
- I.C of charger is 400$/$KW_P$.

Diesel Generators cost data[31,32]:

- Investment cost(I.C), \$/KW:500
- Installation cost is 6% of its I.C.
- Specific fuel consumption of 0.41 Liter/kWh
- Lifetime is 3 years
- Annual usage: 8322h (95% availability)
- Annual maintenance and operating cost: 500\$/kW
- Top overall maintenance cost is15% of I.C., annually.
- Salvage value is 1000\$(revenue at end of lifetime).
- Local Fuel cost is 0.3SR/Liter=0.081\$/Liter.
- Amount of CO_2 produced=2.4:2.8 kgCO_2/ Liter fuel.

VI. Economic Analysis [37,38]

The present calculations are based on the present worth values of capital, maintenance, repair and energy. The repair and replacement costs include the costs of replacing solar batteries every five years. Equipment prices were obtained from suppliers. The expected lifetime of PV panels is 20years. The interest rate and the inflation rate is considered as 10 and 4% respectively .An exchange rate of 3.7 was used to convert the costs in local currency to US\$. More details for economic analysis are given in Appendix(A).

VII. Solution Technique

All calculations were performed using the above mentioned equations and assumptions. Technical and economic results are obtained using Microsoft Excel program.

VIII. Results and Discussions

VIII.1. Electricity Generated Using PV System

Based on solar radiation data shown in fig.(4) and assuming the PV array conversion efficiency of 15%, The estimated average electricity can be obtained as plotted in fig.(4).

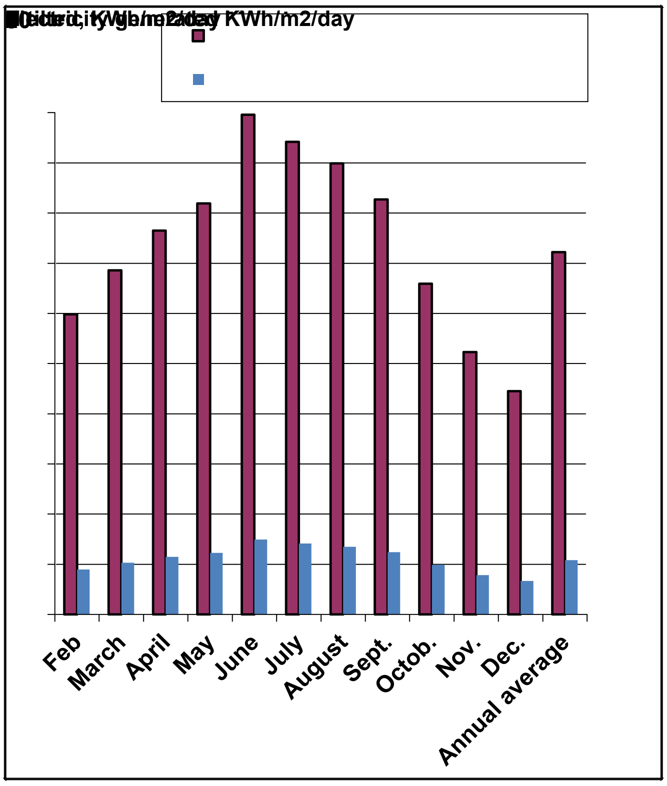

Figure4. *Estimated average monthly electricity production at 15% conversion efficiency of PV system.*

VIII.2. The Load Demand for Pumping and Desalination System

a. For pumping the underground Brackish water from the well, the calculated power consumption is 2kW against flow of 4m^3/h at 100m head.
b. For the selected BWRO desalination unit, to produce permeate flow of 2.5m^3/h at max TDS of 2000ppm,

the total power required is 10kW (peak load).

VIII.3. Sizing Results for System Components

- ***PV Generator***
  1. Assuming the system will operate 7hrs daily, the pumping load energy (E_L) = 7×2 =14kWh/day. Similarly, for BWRO unit= 7×10 =70 kWh/day.
  2. Peak power of PV array=E_L/7×0.85×0.85×0.9. Hence the PV array peak power =3.2 and 15.3 kW for pumping and desalination respectively.
  3. If PV arrays of the mono-crystalline silicon type are selected each of 250 W peak power, then:

a. Number of modules in each parallel string =3200/250=13 and 15300/250=62 modules are required for pumping and desalination respectively.
b. Number of modules in each series string (according to the required battery voltage) =1 , as $V_{PVmodule}$ at max. power point =30V.
c. Hence the total number of PV modules =a×b=(14+62)×1=76.

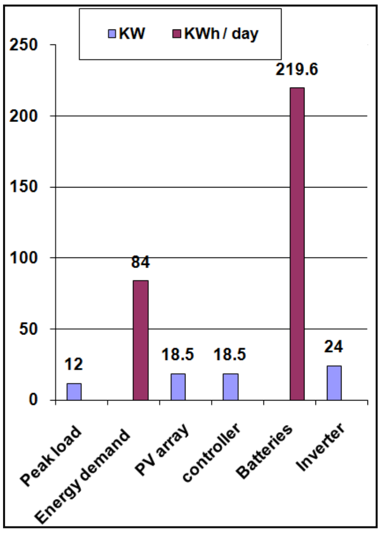

Fig.5. *Sizing results for components of Solar PV system.*

Noting that, it is preferable to make the PV array voltage higher than battery voltage and to use a max. power point charge controller. In this case, the number of solar panels in each string = 2 to get 60V. Then the total number of modules is doubled.

- ***Batteries sizing results:***
  1. Batteries capacity for pumping =14KWh/0.5×0.85×0.9=37kWh, similarly for desalination =183kWh.
  2. Considering that 24V voltage output is required from the battery bank, the required AH is 1542 and 7625AH for pumping and desalination respectively.

By selecting 12v@1766AH battery, then a batteries bank of 2 battery (2×12=24V) is required for pumping, and additional 5×2=10 batteries for desalination.

  3. The suitable battery charge controller for this system is selected to be able to handle the short circuit current of the PV array. Thus, it is selected with the specification of 60V and 24V at input and output respectively,18.5kW.
  4. The selected inverter has the specifications of 24V/220Vsingle phase,18kW.

A summary of sizing results is shown in fig.(5).

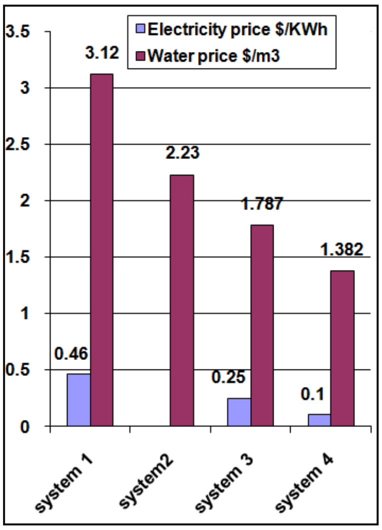

Fig.6. *Electricity and Water prices for the studied four systems (note: electricity price for system-2 is not included in the figure as it is hybrid).*

VIII.4. Energy Cost

As depicted in fig.(6), the electrical energy costs are 0.46, 0.25, 0.1$/kWh, for PV system (system-1), Diesel generator (system-3), and local national grid (system-4) respectively. As shown, electricity price from national grid is the lowest one, because of promotion from the government. Also, the price from Diesel generator is lower than PV system, due to the lower local price of fuel.

Now considering the fact that the future of PV system is promising, consequently, the price is expected to be decreased more and more. So, the prices from system-1 was re-calculated and plotted at different prices of PV arrays, as shown in fig.(7).

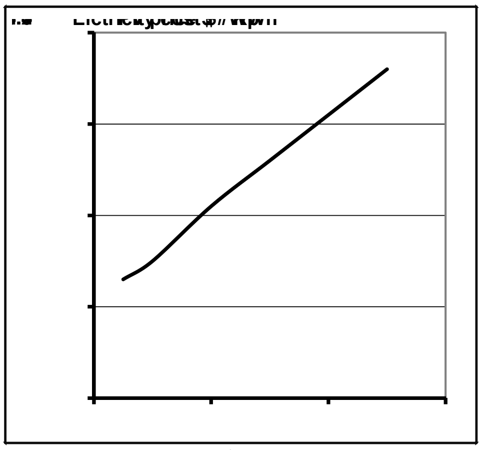

Fig.7. *PV system electricity unit cost($/kWh),at different prices of PV modules.*

It is clear from Fig.(7) that, The PV-system can compete with Diesel generator, whenever the PV array price is reduced down to 1$/$W_P$ or less. This will reflects very good economic and environmental benefits of using the PV system.

VIII.5.Water Production Cost

- For PV unit (System-1), the calculations are based on 7h/day operation, so the BWRO capacity is reduced from50m^3/day down to one-third of this value.
- For hybrid unit (system-2), the BWRO unit will give its full capacity of 50 m^3/day. Where, the PV unit will operate to give one-third of capacity, while the diesel generator will operate to give the other two-third of capacity. Based on this, looking in figure (6), the unit cost of fresh water is 3.12, 2.23, 1.787, and 1.382 $/m^3 for system-1, system-2, system-3, andsystem-4 respectively**.**

Similarly, the product water cost using system-1 was re-calculated and plotted at different prices of PV arrays, as shown in fig.(8).

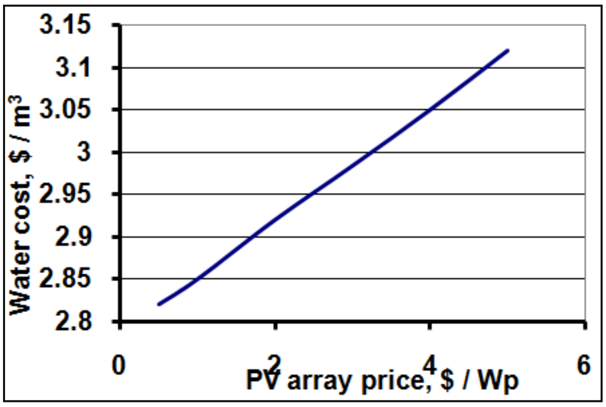

Fig.8.*Water production cost using system-1,at different prices of PV arrays.*

VIII.6. Environmental Benefits of Using PV-Operated BWRO System

The estimated annual reduction in Green house gases (GHG) represented by kg CO_2 is 100% (zero emission) , 32,223, 96,768 using system-1, 2, and 3 respectively. It is clear that a significant reduction is achieved using either of system-1 or system-2.

VX. Reject Water Management

Reject water is by product of RO desalination plant. It has higher salts Concentration than that of feed water. So, this reject Water needs to be disposed properly to avoid contamination and disturbance for the ecosystem. Consequently, disposal of concentrate is one of the important factors to be considered in cost estimation. Recently, environmental regulations for disposal of concentrate have to be followed.
A summary of reject water disposal method is given in Table (3)

Table3.*Methods of reject water disposal in USA out of 137 plants with capacity of 98 m^3/day or more.[4,30].*

Method of disposal	%
Surface water	48
Discharged to waste water treatment plant	23
Land application	13
Deep well injection	10
Evaporation ponds	6

VY. Conclusions

The performance and economics of a small scale Brackish water pumping and desalination units has been estimated to compare between the studied four types of power supply systems. It is concluded that:

1. Electrical energy costs are 0.46, 0.25, 0.1 $/kWh, for PV system (system-1), Diesel generator (system-3) , and local national grid (system-4) respectively. In addition, whenever the PV array price is reduced down to 1$/$W_P$ or less, this reflects good economic and environmental benefits of using the PV system.
2. The unit cost of fresh water is 3.12, 2.23, 1.787, and 1.382 $/$m^3$ for system-1, system-2, system-3, and system-4 respectively.
3. Common methods for RO reject water disposal are mentioned.

Nomenclature

ACT	Total Annual Cost
ART	Total Annual Revenue
a-Si	Amorphous-Silicon
BOS	Balance of System
CI(G)S	Copper Indium (Gallium) Diselenide
COE	Cost of Energy
DC	Direct current
DOD	Depth of Discharge
ELT	Total load Energy
EPBT	Energy Pay Back Time
F	Fuel
ISC	Short Circuit Current
kVAR	Kilo Volt Ampere Reactive
kWh	Kilo Watt Hour
LCC	Life Cycle Cost
MPPT	Maximum Power Point

NOCT	Normal Operating Cell Temperature
NPV	Net Present Value
O&M	Operation and maintenance
ppm	Parts per million(milli gram per liter)
PSH	Peak Sun Hour
PV	Photovoltaic
(PV-RO)	photovoltaic-powered reverse osmosis system
PWF	Present Worth Factor
PWFC	Cumulative Present Worth Factor
PWV	Present Worth Value
SC-Si	Single Crystalline - Silicon
SOC	State of Charge
SOD	Self of Discharge
SPC	Specific power consumption, kWh/m^3
TDS	Total dissolved solids contained in water
VOC	Open Circuit Voltage
W_p	Watt peak
Greek Symbols	
η	efficiency
Subscripts	
b	battery
Gout	Generator actual power
Gr	Generator rated power
inv	inverter
out	output
P	Peak
PV	Photovoltaic
PVR	PV charger
PVout	PV output power
th	thermal

Appendix(A)

Economic analysis of the system life cycle cost (LCC)[60].

A.1. Present worth (PW) analysis

The present worth method converts all cash flows to a single sum equivalent at time zero using *i= MARR* over the planning horizon.(brings all cash flows back to "time zero" and add them up)

Where

i is the annual interest rate %

: is the annual value at year n.

A.2.Costs of System Components

Costs of a system include: components initial costs, components replacement costs, maintenance costs, fuel and operation costs, and salvage revenues. Initial costs include purchasing the following equipment required by the hybrid system:

- ***Costs of PV modules***

The PV module is characterized by its peak watt (W_p) at standard test conditions. Price of PV module depends mainly on its W_p and its type. For high rated power it can be considered about 5 ($/$W_p$) [www.affordable-solar.com].The values of installation costs depend mainly on the location of installation and mounting structures. For domestic applications, it can be considered about 16% of capital costs. PV maintenance costs are often collected in monthly payments for inspection by a maintenance technician. The PV panels are assumed to have life times of more than 20 years (no PV replacement costs during its lifetime).

- ***Costs of batteries***

Any battery is characterized by its nominal voltage and its rated Ah capacity. The 2V cell block batteries are the most common ones in the hybrid systems. Their prices are higher than the prices of conventional ones, butt hey are characterized by their high cycling rate and capability to stand very deep discharge. The cost figures vary in the range (290-250$/kWh) [www.affordable-solar.com].

- ***Costs of diesel generators***

Diesel generator initial costs vary with size, model and design. For the range of power (10KW : 83 KW rated power), the cost can be considered about 500 ($/kW) [www.generatorjoe.net]. The installation cost can be considered about 6% of initial capital cost. Regular maintenance includes:

- Oil change which recommended to take place every 250 hour of operation.
- Oil filter replacement which recommended to take place every 500 hour of operation.
- Air filter replacement which recommended to take place every 3000 hour of operation.
- Fuel filter replacement which recommended to take place every750 hour of operation.
- Top Overhaul maintenance is recommended to take place every 6000 hour of operation.

The diesel generator lifetime is expressed as a function of the operating hours. It varies between roughly 20000 to 30000 hours of run time. The amount of CO2 produced takes values in the range 2.4-2.8 kg CO_2/L diesel fuel.

*A.3.**Life Cycle Periods of Different Components***

In this analysis a typical value of 4% is considered for general inflation rate. Typical values of fuel inflation rate is 5%[34].

The life cycle period of the system is: for the PV system = 20years. The life time of the diesel generator, a typical value of 24000 hour of operation is considered. The lifetime of the battery, a typical value of 10 years is considered as a lifetime of battery where a DOD is assumed to be 80%. The life times of the other components of the hybrid system such as inverter and charge controllers generally take values greater than 20years. Because the cost of each is small comparing to other components.

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