# DESIGN AND SIZING OF SMALL – SCALE PHOTOVOLTAIC (PV) CELLS POWERED REVERSE OSMOSIS (RO) DESALINATION SYSTEM FOR WATER SUPPLY IN REMOTE LOCATIONS

**Hasan Shakir Majdi**
**info@mustaqbal-college.com**

**ABSTRACT:-**

This paper present the design and sizing of a small-scale solar photovoltaic powered reverse osmosis purification system that provides drinking water to domestic or small group in a remote area in Babil Governorate in south Iraq. The aim of this study is to estimate an optimum PV system to power the RO that produces 20 l/h (0.35 $M^3$ /day ) at constant daily load profile. The system designed based on brackish waters at a (Total dissolve solid (TDS) value of 1500-2000 mg/L) from well in mention area, The PV and solar source simulated by TRANSYS16 Software to evaluate various PV-RO system. The results indicated requires energy of approximately 216.5 Wp with about 38 hours battery storage that can operate the RO unit continually after the sunset . The RO systems powered by PV panels have many advantages, such as lowest operation cost , simple operation , environmentally friendly , easy installation and maintenance, high reliability and suitability for brackish water.

**KEYWORDS : photovoltaic, purification system, reverse osmotic, power system, small- scale solar ,desalination.**

عنوان البحث :تحديد المحددات التصميمية لمنظومات تحلية الماء بالتناضح العكسي الصغيرة الحجم العاملة بالخلايا الضوئية لتجهيز الماء في المواقع البعيدة .

حسن شاكر مجدي

الخلاصة :

تم في البحث مناقشة المحددات التصميمة لوحدة تصفية ماء صغيرة الحجم تعتمد على الطاقة الشمسية و باستخدام تقنية التناضح العكسي للتصفية المياه لتجهيز ماء الشرب لمجموعة صغيرة من السكان في احدى القرى جنوب محافظة بابل العراق . ان الغرض من الدراسة لتحديد المعاملات المثالية لانتاج الماء الصالح للشرب بطاقة انتجية بمقدار ( 035 ) متر مكعب في اليوم او 20 لتر في الساعة من محطة تنقية ماء البئر باستخدام الطاقة الشمسية و في حمل ثابت . لقد تم اعتماد موديل TRANSYS Software لحساب الطاقة المتولدة من الخلايا الضوئية و مقدار اشعة الشمس اللازم لتشغيل منظومة التناضح العكسي التي تحتوي على خلايا التناضح العكسي و الاغشية و التبادل الايوني. تتكون المنظومة من مصفي / وحدة التناضح العكسي / سطوح الخلايا الضوئية (pv) وبطاريات خزن الطاقة .إن تنقية الماء المالح في معدل عكورة (2100-1500 mg/L) TDS يتطلب طاقة بحدود (216.5 W) مع طاقة خزن (38) ساعة للبطاريات التي يمكن تشغيل منظومة التناضح العكسي بصورة مستمرة بعد غياب الشمس ، منظومات التناضح العكسي العاملة بالخلايا الضوئية ذات مزايا متعددة تشمل الصيانة وسهولة النصب والتركيب والتشغيل .

**Design and Sizing of Small – Scale Photovoltaic (PV) Cells**　　　　　　**Dr. Hasan Sh. Majdi**
**powered Reverse Osmosis (RO) Desalination system for**
**Water Supply in Remote Locations**

**ABBREVIATIONS :**
PV= photovoltaic
RO = Reverse -osmosis
TDS= Total Dissolved Salts
PPM= part per million
TH= Total Hardness
TUR= Water Turbidity
EC = Electrical conductivity
TSS= Total soluble salt
Q = permeate flow
$\Delta_P$ = driving pressure
$\Delta_\pi$ = wetted surface area
A = permeability coefficient
$N_A$ = salt flux
B= salt diffusion coefficient
C $f_c$ = feed concentration
$C_P$ = permeate concentration
CH= compensated Hardness
E= Energy (kwh)
Ap = Total solar panel Area ($m^2$)
r= solar panel yield (%)
H= Annual average solar radiation on litted panel
PR= performance ratio
R= yield of solar panel
EL= The Theoretical daily energy required
$\mu$ = battery losses
PSSH= peak sunshine hour
$W_P$ = Watt Photovoltaic
$W_h$ = Watt hour

## 1. INTRODUCTION :

Most Iraqi villages suffer from water scarcity , pollution , and water contamination. Although more challenges in rural areas, erratic of power supply , availability of power varies from 4 to 8 hours a day and even the available power supply with voltage fluctuations and sudden power cuts. Availability of plentiful of solar sources in south Iraq and implementation of desalination and water purification technologies will help in a big way in providing safe drinking water. In regards to sustainable water technologies , development and implementation must make economic and social sense to the stakeholder . Technology implementation that provides safe and affordable drinking water [C. Ray and R. Jain,2011]..  The RO- PV technology had been used commercially in Iraqi remote location , suitable for brackish water sustenance of the quality and quantity of the product .[ AMPAC USA, 2010]
Many research interested in studies feasibilities of application RO plants, powered by PV-systems of small to medium capacity (0.1 to 75 m3/day), had been built in different locations of the world [A. Chermandi, R. Messalem,2009] . António J. et al 2000.[ A. Joycea, David Loureiroa,2001] , described autonomous mathematical model for small RO compact units

with typical daily productions of the order of 100–500 L and functioning with pressures as low as 5 bar. running on PV modules from 50–100 Wp . [ Murray T and David I. (2002)] described efficient cost-effective battery less photovoltaic-powered seawater reverse-osmosis desalination system  (TDS 40000 PPM) for water from sea in UK. Research program  focused on improving the feasibility of PVRO  had been studied by [Amy M. Biltona et al.2011] focused their  research on development of smart control algorithms to increase PVRO  system efficiency and improve feasibility. .[ Kh.A.  et al] Optimized of renewable power system for small scale seawater reverse osmosis desalination unit in Mrair-Gabis Village, Libya. [S.S.Phuse and  R.S.Shelke  ,2012 ] proposed  water purification system for remote areas focused on providing a pure drinking water at low cost with high reliability to the rural families. It involves the research, design and manufacture of water purification system using renewable energy. Studied of  optimization and life-cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER software  conducted   by[ Ali Al-Karaghouli and L.L. Kazmerski ,2010]. Stand-Alone river water purification system powered by solar photovoltaic panels in Haiti presented by[  Rami C Sleiman and Ziyad M  2014]  they described design of the application of a river water purification system using green technology, presented by solar photovoltaic (PV) panels, as well as the design of a water pumping system powered also by solar energy. [ D.P Clarke et al 2011] investigated modeling to analyses the performance of small-scale stand-alone (energy) systems incorporating Reverse Osmosis (RO), providing up to 15litres/day potable water in  Western Australia. Designed and  cost-effective sea water reverse  osmosis developed by [ Asmerom M. Gilau and Mitchell] . [ Ali Al-Karaghouli and L.L. Kazmerski 2010] described A medium-capacity (2000 m3/day) reverse-osmosis (RO) desalination plant was  proposed to be installed in Umm Qasr city, south of Basra, Iraq, it performance and economics were analyzed using HOMER software created by the National Renewable Energy Laboratory (NREL) and DEEP-3.2 software created by the International Atomic Energy Agency (IAEA). Umm Qasr is a port city located on the Gulf shore and has no fresh water resources. HOMER analysis shows that a hybrid system consisting of a photovoltaic array, batteries, inverter, and auxiliary generator is the best option compared with systems using either solar energy devices or diesel generator alone . PV-RO systems encounter an important technical challenge due to the intermittent and variable nature of solar radiation, whereas RO units are generally designed to run continuously and at constant flow. Therefore, batteries are needed to address this challenge, even though this arrangement results in a high cost of water production, reduced system energy efficiency, and increased system complexity. These batteries are charged during sunshine hours and allow the RO unit to run continuously at constant flow and pressure. [ Fawzi B. et al  2012] presented a small PV-driven reverse osmosis desalination plant in a village in the northern part of Jordan with a capacity of 0.5 m3/day. [  Herold and Neskakis 2001] presented a small PV-driven reverse osmosis desalination plant on the island of Gran Canaria with an average daily drinking water production of 0.8 - 3 m3/d. RO systems are very flexible in feed water quantity and quality, as well as in the site location and the start-up and shut-off of the system . Factors such as the daily per-capita consumption, total population, as well as hours of operation of the unit per day are critical factors for the sizing of the RO unit [William S. Duff , David A. Hodgson,2005] . Water characterization is the first step in designing an RO system. [ El-Manharawy et al. 2001] discussed in detail water characterization and guidelines for RO system design. [Ali Al-Karaghouli and L. L. Kazmerski ,2010] analyzed and predicated economic of a small  brackish water (TDS   4000

**Design and Sizing of Small – Scale Photovoltaic (PV) Cells**        **Dr. Hasan Sh. Majdi**
**powered Reverse Osmosis (RO) Desalination system for**
**Water Supply in Remote Locations**

ppm) with capacity 5 m$^3$ / day , operated photovoltaic , proposed installed in remote area of the Bablyon Governorate in Middle Iraq, their analysis showed the lowest cost achieved from using RO/PV solar system 3.98 \$ / m$^3$ .

This paper discusses design and sizing of small scale (domestic scale ) RO water purification system, using PV power panel to purified brackish water of well at village located in south Babil governorate Iraq. The analysis of local solar radiation during year , days and PV load have been performed by application of TRANSYS16 Software. The source water showed very high hardness , high total dissolved salts (TDS), highly contamination and very high salinity , these challenges required much more treatment processes technology than other water sources, and much more energy power supply. The purification process accordingly required softener to reduce hardness and increase RO membranes life , Ro system to reduce TDS and UV lamp to disinfection . Therefore , in this research focused on load profiles, sizing of the stand-alone PV power load to the RO system that could overcome mentioned challenged .

## 2 . MATERIALS AND METHOD :

### 2.1 System components

The components of proposed PV/RO system are summarized as pre-treatment stages (3 stages 10 Micron , Activated Carbon and 5 Micron Filter), softener and RO filters. The flow diagram of the PV-RO system is shown in Figure 1.

### 2.2 Specification of Raw water: (Table -1)

| | |
|---|---|
| TDS (PPM) | 1500 – 2000 |
| TH (PPM) (Total hardness) | 900 – 1100 |
| No$_3$ (mg/L or PPM) | 70 – 80 |
| Po$_4$ (mg/L or PPM) | 0.06 – 0.05 |
| So$_4$ (mg/L or PPM) | 300 – 400 |
| TUR (NTU) (Turbidity) | 12 – 15 |
| TSS (PPM) | 200 – 300 |
| Mg$^+$ (PPM) | 60 – 80 |
| Ca$^+$ (PPM) | 300 – 400 |
| Ec (Ms / cm) ( Micro simins) (Electrical conductivity) | 3000 – 4000 |

## 2.3 Outlet (drinking) water specification  (Table-2)

| | | |
|---|---|---|
| TDS    (PPM) | | 40-50 |
| - | TH     (PPM) (Total hardness) | 40-60 |
| - | $Na^+$     (mg/L or PPM) | 8-14 |
| - | $CL^-$    (mg/L or PPM) | 14-25 |
| - | $Ca^{++}$ (mg/L or PPM) | 20-30 |
| - | TUR    (NTU) (Turbidity) | 0.5-1.0 |

## 3.   SYSTEM DESIGN PARAMETERS :

### 3.1 RO system design

The design of specific RO- system is defined by its feed pressure ( or permeate flow, if the feed pressure is specific ) and it is salt passage. In the simplest terms, the permeate flow Q through an RO membrane is directly proportional to the wetted surface area by the net driving pressure $(\Delta P - \Delta \pi)$. The proportionality constant is the membrane permeability coefficient or A- value. The familiar water permeation equation has the form

$$Q = (A)(S)(\Delta P - \Delta \pi) \tag{1}$$

The salt passage is by diffusion; hence the salt flux NA is proportional to the salt concentration difference between both sides of the membrane. The proportionally constant is the salt diffusion coefficient or B- value .

$$N_A = B(C_{fc} - C_p) \tag{2}$$

**Where :**

Cfc= feed – concentrate average concentration.

Cp= permate concentration.

**RO Unit operation condition   :** The desired operation condition    RO  system capacity 20 liter/hr (0.35 m3 /hr), Inlet pressure (2.8 -5.5 bar ) and  temperature 15-40 C ). The technical data

**Permeate (l/h ) = 15-**55
**Recovery     % = 25-**33

**Salt Rejection = 90-**93 %

**Feed Pressure**  = 2.7-5.5 bar

**Design and Sizing of Small – Scale Photovoltaic (PV) Cells**       **Dr. Hasan Sh. Majdi**
**powered Reverse Osmosis (RO) Desalination system for**
**Water Supply in Remote Locations**

**3.2 Hardness calculation**: Define if softener needed as in term defined below :

| Term. | Ppm |
|-------|-----|
| Soft. | 17.0 or less |
| Slightly Hard. | 17.1.  To 60 |
| Moderate Hard. | 60. To 120 |
| Hard. | 120 to 180 |
| Very hard. | 180 over |

**Compensated Hardness**

When sizing water conditioning equipment the hardness should be based on compensated hardness take into consideration minerals and other factors that will reduce the softening capacity of softener .these items cannot picked up in standard hardness test. the formula therefore **.,** According to **.,** Compensated Hardness =  Hardness test * F

    F factor between 1.1 to 1.5 based on term of hardness test
As the hardness around (900-1000) the raw water regards  very hard and essential to used softener, to reduce faulting in RO elements .

**3.3 Calculation the annual solar energy output of photovoltaic system.**

The global formula to estimate the electricity generated in output of photovoltaic system is :-
$$E = A*r*H*PR \qquad (3)$$
$E$ = Energy (kwh)
$A$ = Total solar panel Area (m2)
$r$= solar panel yield (%) .
$H$ = Annual average solar radiation on litted  panels (shading not included).
$PR$ =  performance ratio, coefficient for losses ( range between 0.5 and 0.9, default value = 975).
$R$ = is the yield of the solar panel given by the ration : electrical power (in kwp) of one solar panel divided by the area of one panel.
$PR$ : performance ration is very important value to evaluate the quality of photovoltaic installation because it gives the performance of the installation independently for the sizing of this system .
Inverter losses (10%).
Temperature losses (8%).
Dc cables losses (3%).
Ac cables losses (3%).
Other losses (5%).

**Design and Sizing of Small – Scale Photovoltaic (PV) Cells**       **Dr. Hasan Sh. Majdi**
**powered Reverse Osmosis (RO) Desalination system for**
**Water Supply in Remote Locations**

**3.4 Modeling by TRNSYS**

 Foundation inputs for the modeling work include location-specific parameter such as solar-resources, ambient temperature, feed water composition, depth and temperature.  A TRNSYS software library contains many components to be used for the simulation of various energy systems . Several different PV generator types are available in TRNSYS 16: type 94 series, type 180 series and type194 series. In this research, Type 194 issued as PV panel model in simulations involving electrical storage batteries, direct load coupling, and utility grid connections.  The model determines the current and power of the array at a specified voltage. Standalone PV systems component models have been selected and connected in TRNSYS 16 simulation studio as shown in Figure 2. The TRNSYS model was tested using the Baghdad city weather data from which input file was created. Most weather stations provide hourly data as the smallest time series. So in the TRNSYS simulation, the simulation time step is set to hourly simulation.

**3.4.1  Solar Resource**

The solar resource is used for the site of the  Babil Governorate in south Iraq.

**3.4.2 Data for Simulation**

Standalone PV systems component models have been selected and connected in TRNSYS 16 simulation. The solar radiation, ambient temperature, and angle of incidence are essential data to the simulation of the energy generated from the PV systems. Figure 3 showed the daily variation of solar radiation during the summer on the tiled surface at a given location. Figure 4 daily variations of solar radiation on tilted surface . Figure 5 shows the monthly average electrical production by the PV modules. It can seen that the stable weather conditions together with long sunshine hours in summer contribute to the highest electrical generated.

**4.   SIZING OF PV/ RO SYSTEM :**
**5.     Sizing** RO load : To ensure the size of PV/RO system is not over the design and it work efficiently, two factors should be considered: 1) the size of the  RO-load (in this case the size of the pump), and (2) seasonal variability in solar insulation. Therefore, in the following sections determines how the RO loads and the size of PV array meeting the daily load requirements all year. The total load and energy requirements determined , daily energy requirements of loads are expressed in terms of current and average operating time. The total daily energy requirements for the RO unit, softener unit and the auxiliaries (sensors, data acquisition system etc.) have been determined as follows:
**RO Load :** Due to the pressures and flow rates involved in the reverse osmosis system, two high pressure pumps are used. The total power of the two pumps during the operation hours per day  calculated and showed in Table (4)

**4.2 Sizing of PV array :**
The size of a PV system is defining the number of PV modules that needed to generate the energy required to run the RO system. The basic components of a PV system are PV arrays, solar charger regulator, battery, and inverter. Sizing of the stand-alone PV system first involves estimation of the energy consumption of the RO system and the solar radiation at the location of operation. To satisfy the design requirements,  the PV modules of polycrystalline

**Design and Sizing of Small – Scale Photovoltaic (PV) Cells**        **Dr. Hasan Sh. Majdi**
**powered Reverse Osmosis (RO) Desalination system for**
**Water Supply in Remote Locations**

silicon type of 54Wp as peak power are selected (Isc=3.31A, Voc = 21.7 V, Im=3.11A, Vm=17.4V at standard test conditions STC ( Global irradiance = 1000 w/m2,  temperature 25 C , air mass = 1.5 ). The PV array is an interconnection of PV modules or panels that produces direct-current (DC) electricity in direct proportion to the global solar radiation incident upon it, independent of its temperature and voltage to which it is exposed. The theoretical daily energy requirement for the system is about 1586 Wp/day (EL), including the inverter losses . The battery losses ($\eta b$) is about 15%  and the PV thermal losses ($\eta th$) is about 15% also  The average peak sunshine hour (PSSH) in IRAQ is about 7 h. The peak power of the PV module can be determined as follows :
First, the PV size is determined based the all loads of the RO system.

Peak power of the PV= $EL$ /(PSSH * $\eta th$ * $\eta b$ )

$$1586/(7*0.85*0.85)= 313.5 \ W_P \ \ldots\ldots\ldots\ldots \tag{4}$$

The size of PV module must be such as to produce 313.5 kW with operating voltage more than 24 V, in order to charge the batteries.  Considering that the DC side operating voltage of 24 V, then 2 PV modules in series are required (2*17.4) =34.8 V. These (2 PV modules in series ) have to be organized in sub-arrays of 4 parallel strings (4*3.11 A=12.44 A). The total array peak power is ( 3.11A*17.4V)*(2*4)= 433 Wp.

In order to reduce the energy consumption, only the energy required for two high pressure pumps and booster pump are considered with 8 hours and the auxiliaries load with 24 hours of operation. The desired peak power of the PV module is about (918.524)/(6*0.85*0.85) =212 Wp, the average peak sunshine of 6 h is employed to be on the safe side. The PV array of the system consists of 2 PV modules in series and  have to be organized in sub-arrays of 2 parallel strange, therefore the total array peak power of the system is (3.11* 17.4 )*(2*2)=216.5Wp , which covers the amount of energy required .

### 4.3 Solar Charge Controller:

The charge controller is a regulator which limits the rate of current that goes to and from the battery pack. Charge controllers are essential to prevent overcharging or completely draining a battery. The size of the solar charge regulator is determined in table 5;

### 4.4. Batteries storage:

The battery of the PV-RO system is design to act as energy storage to run the system whenever insufficient solar irradiation is available (cloudy days and nights).The maximum depth of discharge (MDOD) is 80%, and therefore, the required maximum battery capacity per day is calculated as follows:

Battery capacity (Wh)= EL /(MDOD*$\eta_b$ ) = (918.524)/(0.8*0.85)= **1350.8 Wh**.

- Two batteries of 1560 Wh (120 Ah*12V) connected in series are selected , producing 3120 Wh (130 Ah*24V) in total. To calculate the number of hours for the battery storage that can operate the RO unit continually:
- Number of hours(day)=(battery capacity (Wh)*MDOD*$\eta_b$ )/ EL ( Wh/day)
Number of hours (day)=(3120 *0.8*0.85)/(1350.8) = 1.58 day = 38 h

## 5 -  RESULTS AND DISCUSSION :

The size of a standalone PV system and its performance has been simulated by TRNSYS software. TRNSYS software is used to investigate the dynamic behavior of a solar photovoltaic during the day when solar radiation is available. The energy output was modeled using a computer program called TRNSYS with the "integrated" solar radiation and ambient temperature .

The RO units designed to operate 8 h/day. The energy required which is supplied by a PV array and battery storage is used to power the RO unit during the low solar intensity periods. The generated energy from the PV array varied in accordance with variations in the environmental conditions (insolation and ambient temperature). These variations affected the amount of daily produced water.

The average daily generated energy ($E_{gen}$) is calculated during different months and can be determined as follows:

$$E_{gen}=P_{peak} \text{ PSSH } \eta_b\eta_{th} \tag{5}$$

where, the ($P_{peak}$) is peak power of the PV array .

Table 5 shows the power output and PV current and voltage during the month's changes. It can be seen that the solar irradiation and the ambient temperature had a significant influence on the performance of the PV system. The current increase significantly as the irradiation increases. This is due to that the high energy absorbed by the PV modules at high irradiation.

   **Using** the above equation and the data modeled using TRNSYS software, a comparison has been made between the average daily generated energy during months and that required by the loads to operate the system for 8 h per day as shown in Figure 6. It can be seen that the energy generated during summer months exceeds that required by the system (excluded the intake pump) by up to 50 %. The variation in the energy generated from month to month depending mainly on the sky if sunny or cloudy. The simulated monthly output energy ranges from 715 Wh/d in Dec to 1380 Wh/d in Jun and July. The small energy generated in Dec is mainly due to the lowest monthly solar radiation received.

Generally, the energy output decreases with decreasing the solar radiation. For a given tilt angle, the annual output energy for the PV panels installed on a horizontal tiled surface are between 755 to 1380 Wh/d  which enough to covered  the RO system.

## 6.  CONCLUSIONS :

In this study, models were successfully developed in order to evaluate PV/ RO  purification system performance. Simulations using , TRNSYS 16   were performed under various environmental conditions in order to determine the optimal energy  load configuration, and required power supply for different scenarios. The simulated monthly energy showed that the energy generated by PV panel for period March- October (1000-1380 Wh/d ) higher than request energy required by the system , with further care required during months Nov –Feb . The  operation condition pressure  results showed that for this system , the operation condition with temperature in the range (2.8-5.5 bar ), the flow rate for RO  (20-50 ) l/ hr .   The sizing

**Design and Sizing of Small – Scale Photovoltaic (PV) Cells**      **Dr. Hasan Sh. Majdi**
 **powered Reverse Osmosis (RO) Desalination system for**
**Water Supply in Remote Locations**

of PV consist of 2 PV modules in series and sub-arrays of  2 parallel strange ( 216 Wp ) which cover the amount of energy required.
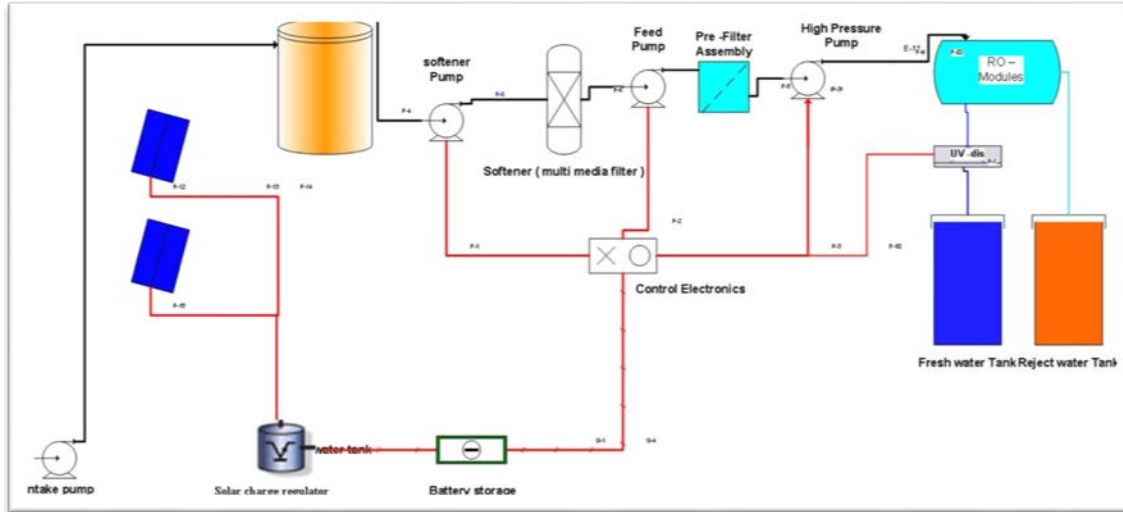


**Figure 1:   Process flow diagram of the PV-RO system**

Table -3 :Operation Condition  Flow rate (l/hr ) as Function of pressure and Temperature

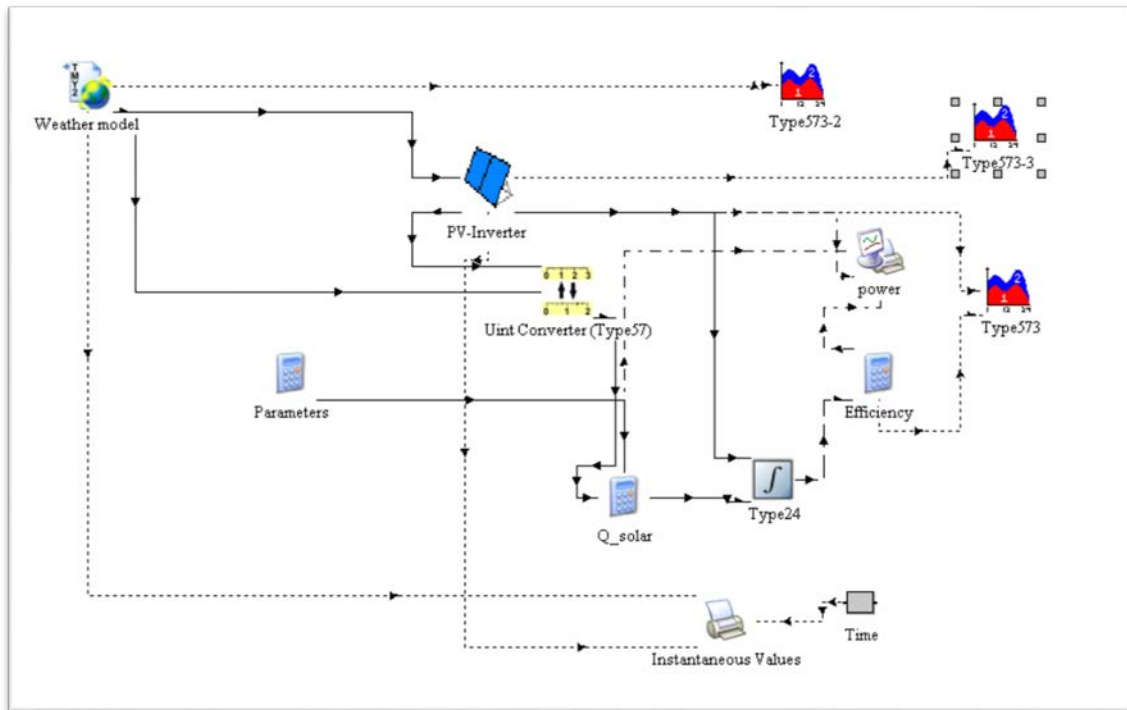| Temp. C | Pressure  (bar ) | | | | |
|---------|------|------|------|------|------|
|         | 5.5  | 4.8  | 4.1  | 3.4  | 2.8  |
| 30      | 48   | 40   | 35   | 28   | 22   |
| 20      | 38   | 33   | 28   | 22   | 18   |
| 15      | 31   | 27   | 24   | 18   | 14   |
| 10      | 29   | 26   | 21   | 17   | 12   |

**Figure 2: Solar Power System modeling in TRNSYS 16.**
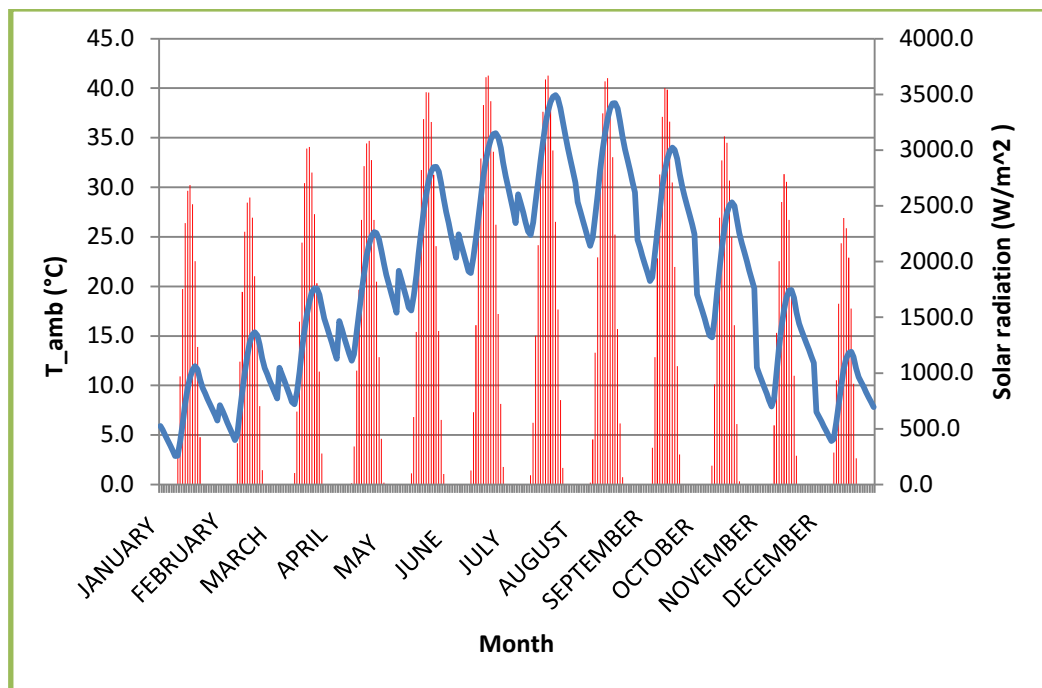


**Figure 3 : Monthly solar radiation on tilted surface**.

**Design and Sizing of Small – Scale Photovoltaic (PV) Cells**
**powered Reverse Osmosis (RO) Desalination system for**
**Water Supply in Remote Locations**

**Dr. Hasan Sh. Majdi**
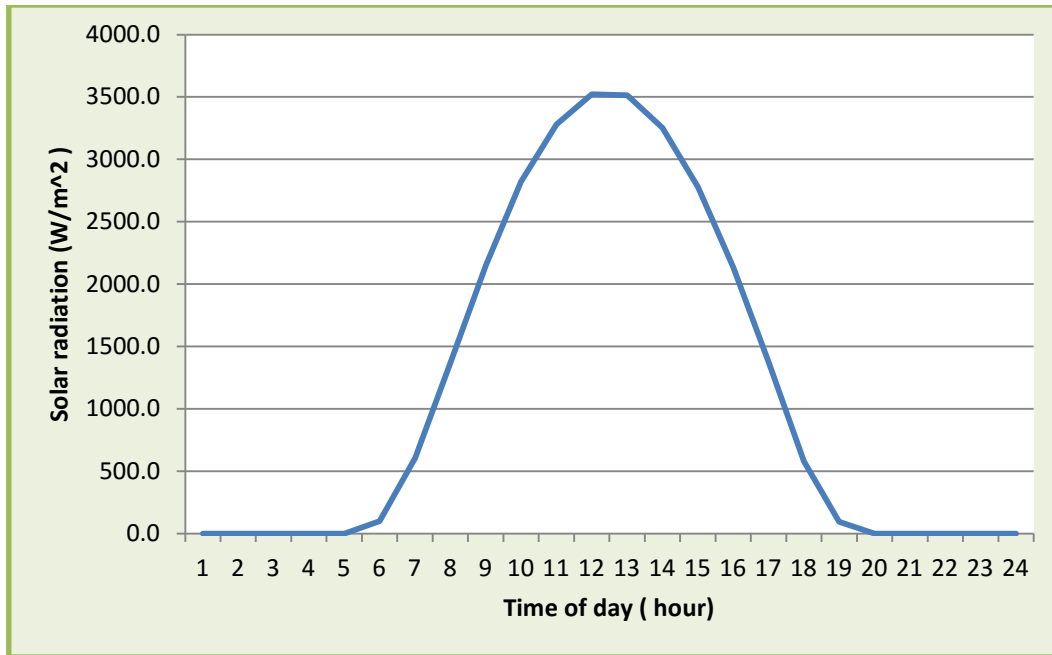
**Figure 4 : Daily variations of solar radiation on tilted surface**
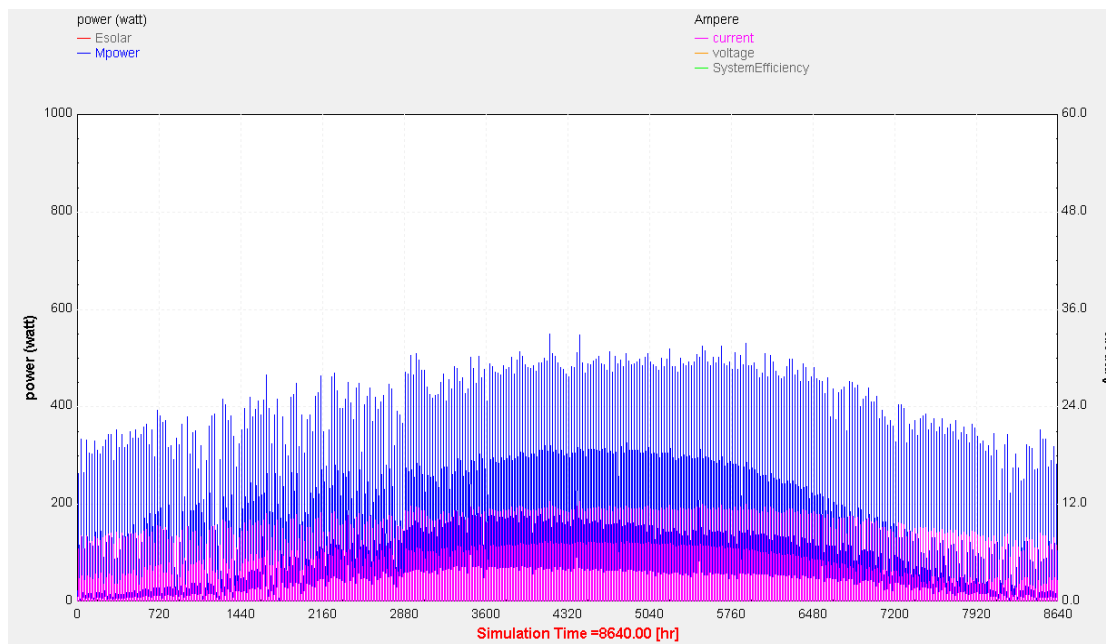


**Figure 5 : Monthly variations of the PV power generated and current output**

**Table (4): Calculated RO system loads**

| 1.  Calculate AC Load | | | | | | 2.  Calculate DC Load | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| AC Load | Watts x | Hours Per Day | Days x Per = Week | Watt Hours | | DC Load | Watts x | Hours Per Day | Days x Per = Week | Watt Hours |
| Intake pump | 66.7 | 8.0 | 1.0 | 533.6 | | High pressure pump (HPP ) | 48 | 8.0 | 1.0 | 384 |
| | | | | | | Low pressure pump (LPP) | 24 | 8.0 | 1.0 | 192 |
| | | | | | | Softener ( BP ) | 7.44 | 8.0 | 1.0 | 59.52 |
| | | | | | | Data acquisition | 5 | 24.0 | 1.0 | 120 |
| | | | | | | Solar charge regulator | 0.38 | 24.0 | 1.0 | 9.12 |
| | | | | | | UV lamp | 0.1 | 8 | 1.0 | 0.8 |
| **AC Weekly Watt Hours** | | | | 533.6 | | **DC Weekly Watt Hours** | | | | 765.44 |
| | | | | x | | | | | | x |
| **AC Inefficiency Factor = 1 +25%** | | | | 1.25 | | **DC Inefficiency Factor = 1 +20%** | | | | 1.20 |
| 25% for mixed systems, 30% for AC only | | | | = | | 20% in most circumstances | | | | = |
| **Total AC Weekly Load** | | | | **667** Watt Hours | | **Total DC Weekly Load** | | | | **918.528** Watt Hours |
| **The total energy requirement for the RO -system = 667+918.528=1586 Watt Hours** | | | | | | | | | | |

**Design and Sizing of Small – Scale Photovoltaic (PV) Cells**
**powered Reverse Osmosis (RO) Desalination system for**
**Water Supply in Remote Locations**

Dr. Hasan Sh. Majdi

**Table (5): Controller sizing**

| Module short circuit current X modules in parallel X 1.25 = array short amps | | | | `controller | Listed desired |
|---|---|---|---|---|---|
| | | | | Arrays amps | Features |
| 3.11 | 2 | 1.25 | 15.56 | 7.775 | |
| This is the input current that comes from the solar array. The number of parallel strings in the array increases the current. To be on the safe side, it is advised to multiply the result by a safety factor of 1.25. | | | | | |
| Calculating the Controller Load Current This is the output current that is pulled from the batteries through the controller. It is calculated via dividing the total connected DC power by the DC system voltage. The total connected DC power is the total power that all equipment that would run on simultaneously *Total DC Connected Watts / DC System Voltage = Max. DC Load Current* | | | | | |
| 919 | 24 | | 38.5 Amp | | |

**Table (6): The power output and PV current and voltage during the month's change**

| $P_{del}$ | $\eta_{mp}$ | $V_{mp}$ | $I_{mp}$ | |
|---|---|---|---|---|
| 174.944 | 0.038 | 64.810 | 2.969 | Jan |
| 177.133 | 0.038 | 63.968 | 2.733 | Fab |
| 210.67 | 0.039 | 63.097 | 3.251 | Mar |
| 214.138 | 0.040 | 57.787 | 3.069 | Apr |
| 265.601 | 0.042 | 64.701 | 3.815 | May |
| 289.001 | 0.043 | 64.810 | 4.153 | Jun |
| 290.175 | 0.044 | 64.809 | 4.166 | Jul |
| 279.66 | 0.044 | 60.476 | 4.008 | Aug |
| 280.795 | 0.044 | 64.809 | 4.333 | Sep |
| 220.257 | 0.042 | 60.491 | 3.399 | Oct |
| 188.315 | 0.04 | 59.270 | 2.906 | Nov |
| 150.245 | 0.038 | 64.7 | 2.55 | Dec |
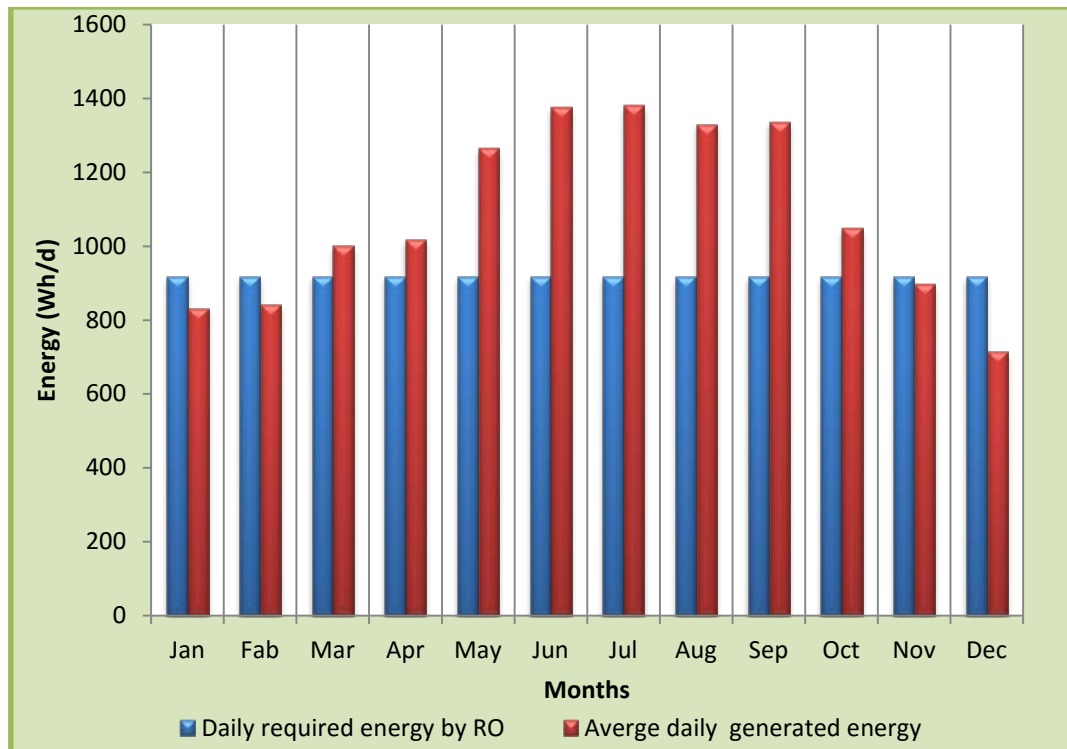
**Figure 6:** Comparison between the average monthly generated energy and the energy during months and that required by the loads to operate the system for 8 h per day.

## 7.    REFERENCES :-

A.  Joycea, David Loureiroa, Carlos Rodriguesa and Susana Castrob," Small reverse osmosis units using PV systems for water purification in rural places", Desalination 137 (2001) 39–44.

A. Chermandi, R. Messalem, "solar driven desalination with reverse osmosis: the state of art", Desalination and water Treatment 7 (2009) 285-296.

A. M. Biltona, Leah C. Kelleyb, Steven Dubowskyb, Photovoltaic reverse osmosis — Feasibility and a pathway to develop technology, Desalination and Water Treatmen, 31 (2011) 24–34 July

Ali Al-Karaghouli and L. L. Kazmerski ," Economic analysis of a brackish water photovoltaic operate (BWRO-PV) desalination system." Energy 10, 2010.

Ali Al-Karaghouli, L.L. Kazmerski , "Optimization and life-cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER software", Solar Energy 84 (2010) 710–714
Ali Al-Karaghouli, L.L. Kazmerski , "Optimization and life-cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER software", Solar Energy 84 (2010) 710–714.

**Design and Sizing of Small – Scale Photovoltaic (PV) Cells**     **Dr. Hasan Sh. Majdi**
**powered Reverse Osmosis (RO) Desalination system for**
**Water Supply in Remote Locations**

AMPAC USA, 2010, Skid Mount Brackish Water Reverse Osmosis Report.

Asmerom M. Gilau and Mitchell J.  " Designing Cost-Effective Sea Water Reverse Osmosis System under Optimal Energy Options for Developing Countries " Carnegie Mellon University, Engineering & Public Policy/ H. John Heinz III

C. Ray  and R. Jain (Ed. ) , Drinking Water Treatment, Strategies for Sustainability , Springer 2011.

D. Herold and A. Neskakis, "A Small PV-Driven Reverse Osmosis Desalination Plant on the Island of Gran Ca-naria," Desalination, Vol. 137, No. 1-3, 2001, pp. 285- 292.

D.P Clarke, Y. M. Al-Abdeli and G. Kothapalli " Modelling Small-Scale Stand-Alone (PV) Energy Systems with Reverse Osmosis Integration " 19th International Congress on Modelling and Simulation, Perth, Australia, 12–16 December 2011 http://mssanz.org.au/modsim2011

El-Manharawy, S. and Hafez, A. Water type and guidelines for RO system design, Desalination, 139, 2001, 97-113.

Fawzi Banat1, Hazim Qiblawey2, Qais Al-Nasser , "Design and Operation of Small-Scale Photovoltaic-Driven Reverse Osmosis (PV-RO) Desalination Plant for Water Supply in Rural Areas", Computational Water, Energy, and Environmental Engineering, 2012, 1, 31.

Kh.Abulqasem,   M.A.   Alghoul,   M.N.Mohammed,   Alshrif.Mustafa,   Kh.Glaisa, Nowshad.Amin, A.Zaharim and K.Sopian ,"Optimization of Renewable Power  System for Small Scale Seawater Reverse Osmosis" ,   Recent Researches in Applied Mathematics, Simulation and Modelling

M.  Thomson, David Infield, A photovoltaic-powered seawater reverse-osmosis system without batteries, Desalination 153 (2002) 1–8.

Rami C Sleiman, Ziyad M Salameh, " Stand-Alone River Water Purification System Powered by Solar Photovoltaic Panels in Haiti , International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181 Vol. 3 Issue 9, September- 2014t

S.S.Phuse a R.S.Shelkeb , " Water Purification System For Remote Areas Using Photovoltaic",   International Journal of Engineering Research and Applications (IJERA) Vol. 2, Issue4, July-August 2012, pp.2014-2018.

William S. Duff , David A. Hodgson , "A simple high efficiency solar water purification system , Solar Energy 7 , 9 (2005) 25–32.