

**An-Najah National University**  
**Faculty of Graduate Studies**

**Designing of Reverse Osmosis Desalination Plant  
in Jordan Valley Using Optimal Energy Options  
With Less Environmental Impacts**

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the Degree of Master of Water and Environmental Engineering,  
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## **Dedication**

This thesis is dedicated to:

The sake of Allah, my Creator and my Master,,,,

My great teacher, Mohammed (May Allah bless  
and grant him), who taught us to follow the right ways of life,,,,

My homeland Palestine, the warmest womb,,,,

An-Najah National University; my second magnificent home,,,,

The great martyrs and prisoners, the symbol of sacrifice,,,,

My brothers "martyrs" Kamal and Amjad, the symbol of hope , optimism  
and patience,,,,

My work managers ,Mamoun, Jamil, Ayad, Khalil and Mahmoud,,,,

My colleagues in myjob , Mohsen, Ali, Adham and Basem

My great parents, "AbdUllah and Randa" , who have always loved me  
unconditionally and whose good examples have taught me to work hard for  
the things that I aspire to achieve,,,,

The memory of my father "AbdUllah" , I miss him every day ,,,,

My dearest wife,who leads me through the valley of darkness  
with light of hope and support,,,,

My beloved brothers and sisters,,,,

To all my family, the symbol of love and giving,,,,

My friends who encourage and support me,,,,

All the people in my life who touch my heart,,,,

I dedicate this work....

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Finally, I would like to thank to everybody who was important to the successful realization of thesis, as well as expressing my apology that I could not mention personally one by one .

أنا الموقعة أدناه مقدمة الرسالة التي تحمل العنوان :

**Designing of Reverse Osmosis Desalination Plant in Jordan  
Valley Using Optimal Energy Options With Less  
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## List of abbreviations and symbols

$\pi$	the osmotic pressure (kPa).
$\phi$	shape factor
$\varepsilon$	porosity
$\gamma$	Specific gravity
$\mu$	Fluid viscosity
$\eta$	efficiency of the pump
A	Cross section area of the pipe
$\text{\AA}$	Angstrom
AC	alternating current
ACC	annualized capital cost
AHP	analytic hierarchy process
a.m	Ante meridiem
AP	anti scaling pump
AT	anti scaling tank
ARIJ	Applied Research Institute – Jerusalem
BW	Brackish Water
C	Capita
$^{\circ}\text{C}$	Degree centigrade
CA	cellulose acetate
$C_c$	reject concentration
CD	drag force coefficient
CF	cartridge filter
$C_f$	feed concentration
cm	centimeter
COE	cost of energy
$C_p$	Permeate concentration
D	Diameter of the pipe
D'	depth of filter sand
d	day
DC	direct current
DCC	direct capital cost
DG	Diesel Generator
DT	distribution tank
Eld	Total daily load energy
FAO	Food and Agriculture Organization
g	acceleration of gravity
GVC	Group Christian Volunteers
h1	Head at point 1
h2	Head at point 2
hr	Hour
hL	frictional head loss through the filter
HP-M2	HP motor pump

HOMER	Hybrid Optimization of Multiple Electric Renewable
i	the interest rate (%)
ICC	indirect capital cost
$\rho$	Density
kpa	Kilo Pascal
km	Kilometer
Kw	Kilowatt
Kwp	Kilowatt peak
Ltr	liter
L	Length of the pipe
$L_{plant}$	load factor (%)
LCI	life cycle inventory
$M_{plant}$	daily potable water production of the plant
m	meter
mm	millimeter
$m^3$	Cubic meter
MED	multi effect distillation
mg	milligram
MSF	multistage flash distillation
$\mu m$	Micro meter
$N'$	Number of elements
N	Number of filters
n	Number of forecasting years
n(plant) :	the plant life time
nb	number of membrane that will be used in the plant
$n_{LTMbrn}$	lift time of each membrane
OCO&M	operating and maintenance cost
$OC_{Mbrn}$	the operating cost of the membrane
$OC_{power}$	the energy cost for each kilowatt
Plt	Total power
P and $P_0$	the population separated by the time $\Delta t$
P	population
$P_0$	Current Population
$P_1$	Pressure at point 1 ( tank)
$P_2$	Pressure at point 2 ( pipe exit)
PA	polyamide
PCBS	Palestinian Central Bureau of Statistics
pH	potential of hydrogen
$P_0$	present population
p.m	Post meridiem
$P_{loss}$	Head loss through a pump
$P_{sat}$	the saturation population of the community
ppm	Parts per million
PV	Photovoltaic

XVI

PWA	Palestinian Water Authority
Pw1	input power required at pump 1
Pw2	input power required at pump 2
Q	Total daily permeate flow rate
Q <sub>f</sub>	Feed water Flow rate
Q <sub>p</sub>	Permeate water Flow rate
Q <sub>c</sub>	Concentrate water Flow rate
r	the population growth rate
R	the universal gas constant
R'	recovery
Re	Reynolds number
RO	Reverse Osmosis
ROSA	Reverse Osmosis System Analysis
s	second
SDI	Silt density index
SR	salt rejection
ST	Storage tank
T	the temperature (Kelvin).
t	period of the project
TCC	Total capital cost
td	Total daily operation
TDS	Total dissolved solid
TNPC	Total Net Present Cost
TP- M1	transfer motor pump
TWP	total water price
1v	Velocity at the inlet (point 1 )
2v	Velocity at the outlet (point 2 )
v	Velocity of the fluid ( water )
V	Velocity
va	approach velocity
W	watt
WEC	wind energy conversion
WERU	Water & Environment Research Unit
WHO	World Health Organization
$\sum X_i$	the concentration of all constituents in a solution



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**Abstract**

The objective of this research is to design a reverse osmosis desalination plant in Jordan Valley using clean and sustainable energy source. The village of Az-Zubaidat's well water is taken as a case study. According to World Health Organization (WHO) Az-Zubaidat's well water is not potable and need to be purified. The total dissolved solids(TDS) of Az-Zubaidat's well water is 2100 ppm, which is high and should be less than or equal to 1500 ppm. The population of Az-Zubaidat's Village in 2016 is 1798 capita based on engineering method for forecasting the population and the corresponding water average consumption rate is 150 L/capita/day according to WHO standards.

A reverse osmosis (RO) plant with an average daily drinking water production of 270m<sup>3</sup>/day is designed; the capacity of Az-Zubaidat's well is 120m<sup>3</sup>/hr.

The reverse osmosis technology is considered in this research where feasible and sustainable energy source to power the plant is to be studied and analyzed. Powering the plant using diesel generators is not considered in this study as the running cost is high and exhausts of the generators is

highly polluting. In the meanwhile, connecting to Israeli electrical grid is not considered as an option in this study as it increases the dependency on Israeli side and the capacity offered is limited.

Investigating the possibility of utilizing renewable energy sources, mainly the solar energy to operate the designed plant is the core of this research. The solar energy includes Photovoltaic and wind energy. Az-Zubaidat's village has great potential of solar radiation which reaches about 5.40 kWh/m<sup>2</sup>/day (global horizontal) but the annual average speed is very low and definitely not suitable for electricity generation. Stand-alone hybrid system (off grid) based on PV panels, diesel generator and different storage systems with five configurations are investigated. The five configurations include PV panels with batteries, diesel generator(DG) with batteries, PV panels and DG without batteries, PV panels and DG with batteries and DG without batteries. To investigate the optimal option of the previous configuration is tedious and time-consuming effort and impossible in some cases, so Hybrid Optimization of Multiple Electric Renewable (HOMER) software is utilized. HOMER software facilitates the sensitivity analysis and make it easier to evaluate the many possible system configurations and choose the best one.

The results shows that the configuration consists of PV, DG and battery storage system from the Lead acid batteries is the best as the cost of energy (COE) is 0.462\$/kWh and the cost of potable cubic meter is 0.601\$/ m<sup>3</sup>. Using water distribution tank as a storage system to reduce or exclude the battery energy storage system is analyzed in this research. The results shows that introducing storage tank to the configuration that includes PV,

DG and battery reduces the COE to 0.348\$/kWh and the cost of potable cubic meter is 0.479\$/ m<sup>3</sup>.

## **Chapter One**

### **Introduction**

## **Introduction**

### **1.1 General introduction**

When population growing, water demand for domestic, agricultural and industrial needs is increasing.

Fresh water resources are now widely exploited over the world due to increasing population and the amount of potable water will be decreased so, the other sources of water require some form of treatment before potable use without interruption and with reasonable cost to the consumer.

Desalination technologies have appeared since 1950s at large scale plant with thermal processes like Multi Stage Flash Distillation (MSF) and Multi Effect Distillation (MED). Heating processes became established using the plenty supply of available oil-driven energy for the required heating process[1].

The Reverse Osmosis (RO) process, developed since 1970s, is the main alternative to the previous technologies that require less amount of energy than thermal processes [1].

The desalination of ground water has more interest especially in Jordan Valley region due to high amount of salinity (Total Dissolve solids TDS). The design and operation of treatment plant depends on the feed water quality in order to decide which pretreatment, feed pressure, recovery and waste disposable method is selected since the energy consumption is related directly to feed water TDS[2].

RO is a treatment process used to remove dissolved solutes and large molecules from water or any other solutions by applying high amount of

pressure to feed water that causes a portion of water to cross and diffuse through the surface of membrane called permeate while the remaining of water called concentrate will be rejected out of the system. This process is provide to purify water from a surface, well, Brackish and sea water resources [3].

Reverse osmosis plants are now being used for a variety of applications including semiconductors, food processing, power generation, pharmaceuticals, desalination, biotechnology, coproduced water from oil and gas production, textile, pulp and paper, mine and diary wastewater, process and boiler water, tanneries and beverage industry [3].

One of the significant alternative used to operate RO plants are utility renewable energies mainly PV technologies combined with diesel generator using different types of storage technologies.

The optimization method was developed for the sources of energy configurations using HOMER software and evaluated using economical, technical and environmental performance indicators.

## **1.2 Objectives**

### **1.2.1 General Objectives**

The Aim of this thesis is to design and operate reverse osmosis desalination plant using different types of energy sources and to investigate the feasibility and the environmental impacts of using reverse osmosis technology in water desalination in the Jordan valley in order to make it suitable for drinking uses.

### **1.2.2 Specific objectives**

The main objective of the project is to study the use of conventional and/or non conventional source of energy in water desalination in terms of cost, economic feasibility and its impact on the surrounding environment.

### **1.2.3 Research question and identified problems**

The proposed research aims at giving a reliable answer to the following questions:

- ❖ What are the possible sources of energy which is suitable for water desalination, especially in Palestine?
- ❖ What is the most feasible source of energy which can be used in water desalination with less damage to the environment?
- ❖ What are the environmental impacts of water desalination plant?
- ❖ What is the price of cubic meter is expected for the consumer?

## **1.3 Methodology**

This work was achieved by the following methodology:

### **a. Data collection:**

Taking available options of conventional and nonconventional energies with their products and other information in order to see which techniques can be used.

### **b. Defining Process**

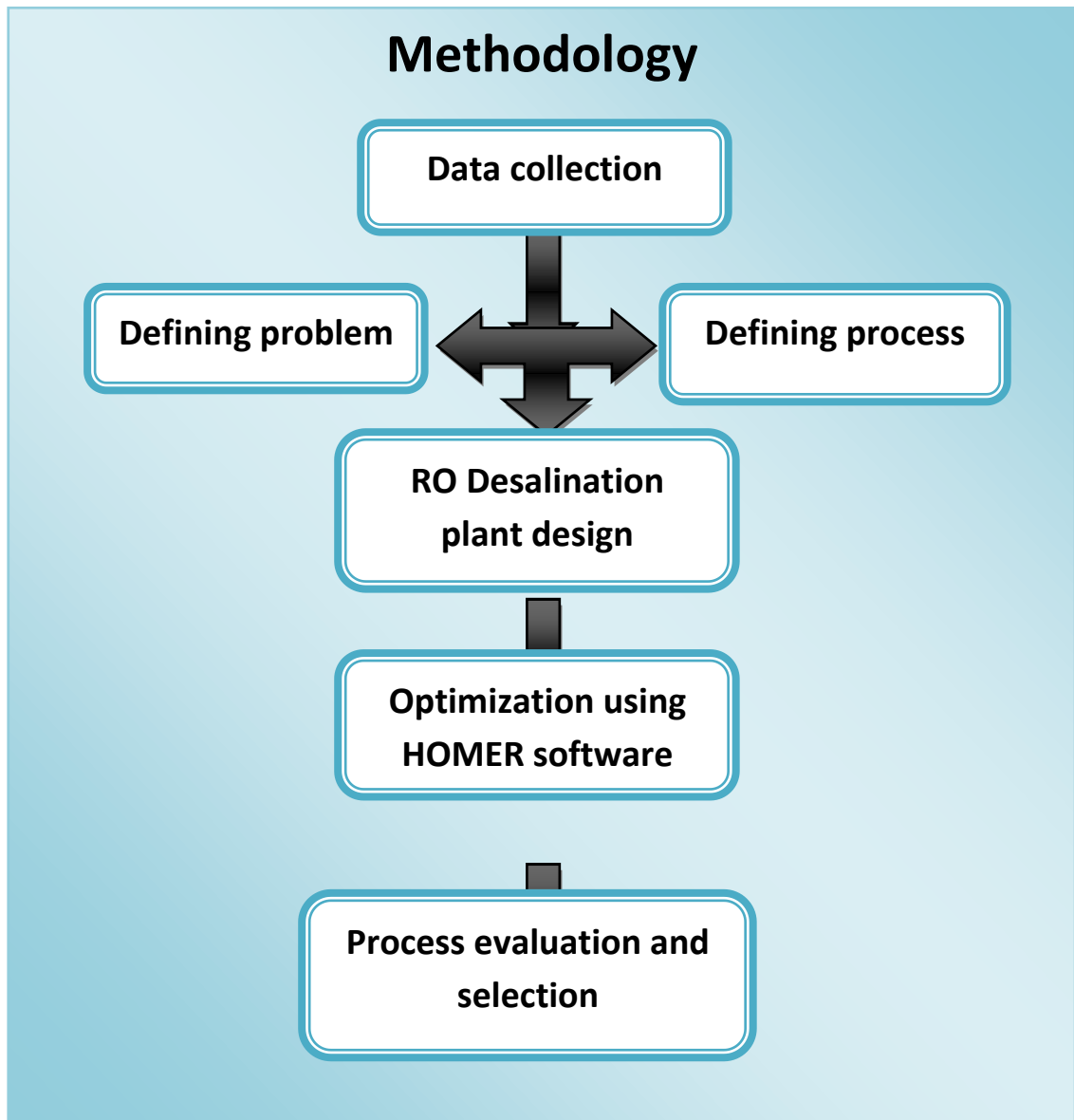
Define the different types of energy technologies from technical point of view and other configurations.

**c. Experimental and Analysis work**

Will be the study of the amount and suitable type of energy needed to run the project, the prices of the necessary equipment, the cost of maintenance will also be the work of testing in the laboratory to identify the amount of total dissolved solids of the source of water feeder for the project.

**d. Process evaluation**

Choose the least expensive method for the proper disposal of brine to minimize harm to the environment and also choose the best source of energy using HOMER software that will be used to operate the project.



**Figure (1.1):** Methodology flowchart[31].

## 1.4 Literature review

### 1.4.1 General Introduction

Water desalination using membrane techniques will be a common one specially in middle east area. Petroleum fuels powered desalination plants



spread in the Arabian Gulf region due to drink water scarcity and availability of large amount of cheap fuel, as the United Arab Emirates and Qatar where giant desalination plants were established. Such diesel powered plants have never been established in Palestine since the fuel prices are very high and it would not be feasible to establish such plants[3].

#### **1.4.2 Renewable energy sources in Palestine**

There are several forms of energy produced from renewable sources used for water desalination. This includes geothermal energy, solar, and wind energy. One of the most renewable energies used nowadays in Palestine is PV(photovoltaic) panels, which convert solar radiation to electricity. Later, the electricity is used to operate the RO processes and produce pure safe drinking water from surface, brackish water or seawater.

#### **1.4.3 Environmental and Feasibility study for the RO plant**

The optimization method was developed for the sources of energy configurations and evaluated using economical, technical and environmental performance indicators. The initial, operating and maintenance cost must be determined in order to calculate the potable water cost for the customer.

Different studies and researches have been implemented to utilize RO technology for water desalination using different types of power sources. The following section introduces some of them.

Franz Trieb and Hans Müller-Steinhagen, present a long-term scenario for the demand of freshwater in the Middle East and North Africa and show how it may be covered by a better use of the existing renewable water sources and by seawater desalination powered with solar energy[4].

Mohammed Rasool Qtaishat and Fawzi Banat, present the main features of a solar powered membrane distillation system along with its basic principles and review efforts of researchers in coupling membrane distillation with solar energy and their cost estimates [5].

Maged A.I. El-Shaarawi et al, estimate the minimum initial cost of photovoltaic (PV) arrays in PV-powered reverse osmosis (PV-RO) desalination systems by thermo-hydro calculations that are based on second law of thermodynamics limitations [6].

Fawzi Banat and Nesreen Jwaied, made an economic assessment to determine the water cost for small scale solar power membrane distillation units. Based on their work, the cost of potable water using distillation method is 15\$/m<sup>3</sup> by the large units [7].

J. V. Benne, D. G. Jirka and J. Largier, The environmental impact assessment (EIA) of any Desalination projects are very necessary, in addition to it should discuss any potential impacts on air, land and marine environments[8].

T. Hoepner, Made the feasibility study of the site project that be done before the construction of the project parts begins[9].

W. R. Everest and T. Murphree, Applied the environmental standards within the plant's operation in order to arrive to good environmental management of high quality projects[10].

Mousa Mohsen and Jamal Jaberevaluate the possibility of using photovoltaic powered scenario as a source of energy to power water desalination projects in Jordan, they found that Shoubak, Aqaba, Azraq and Amman are the most favorable sites for photovoltaic RO desalination systems. With a TDS of 7000 mg/L, the annual amount of water production for these sites was 329, 320, 304 and 301m<sup>3</sup>, respectively; 65% of the treated water is produced in the months of April through September; the driest months in the country [11].

Johannes Lindemann discuss the use of wind and solar powered desalination systems in the middle east and Arabian gulf, he presents a seawater desalination plant with an average daily drinking water production of 1000m<sup>3</sup>/day planned by different water. The desalination water plant with ultra filtration process is supplied by wind energy with capacity of 750kW with on grid . also he discuss another system as research projectusing RO process with photovoltaic system that has capacity of 4.8kWh with additional battery storage of 60kWh , it produced an average daily production water of 0.8-3m<sup>3</sup>/d [12].

Mohsen and A1- Jayyousi, investigated the feasibility of different desalination technologies to cover the increasing water demand in Jordan. They carried out an AHP multi-criteria analysis considering economic, technical and environmental criteria, and compared the five most important

desalination technologies that will produce potable water from brackish and seawater[13].

Sultan A. Kershrman, prepared the economic analysis of the integrated renewable energy systems predicts water cost for the integration of Grid to wind energy conversion (WEC) and photovoltaic power generation (PV) for small-scale RO desalination plant in Libya, the water cost for the integration of Grid and WEC with RO is €0.8/m<sup>3</sup> and for Grid and PV with RO is €0.9/m<sup>3</sup>[14].

Samer Farid Yousef Yousef, made the economic analysis and environmental impacts of Brackish Water Reverse Osmosis technology for a small project in West Bank- Palestine using solar electric power, the cost of each m<sup>3</sup> potable water is 3.17\$ using battery and 2.33\$ without using battery[15].

Wala' Faheem Al Sheikh Abdallah, evaluate the techno-economic feasibility study for two cases of BWRO desalination project powered by PV panels in West Bank-Palestine using DEEP program, the cost of each m<sup>3</sup> potable water of Marj Na'aja project is 0.423\$ while the cost of each m<sup>3</sup> potable water of Al-Zubaidat project 5.09\$[16].

## **Chapter Two**

### **Study area and water demand**

## 2.1 Study Area

### 2.1.1 Az-Zubaidat Village

Az-Zubaidat Village is a located with 35.4km north of Jericho City in Palestine. Az-Zubaidat Village is bordered by Marj Na'ja Village to the north, Marj al Ghazal to the south, the Jordan River to the east and Tubas City to the west as shown in Figure (2.1) below.

Az-Zubaidat Village is located under sea level with 275m, the average annual temperature is 23°C, the average annual humidity is 48% and the mean annual rainfall is 192mm [17].

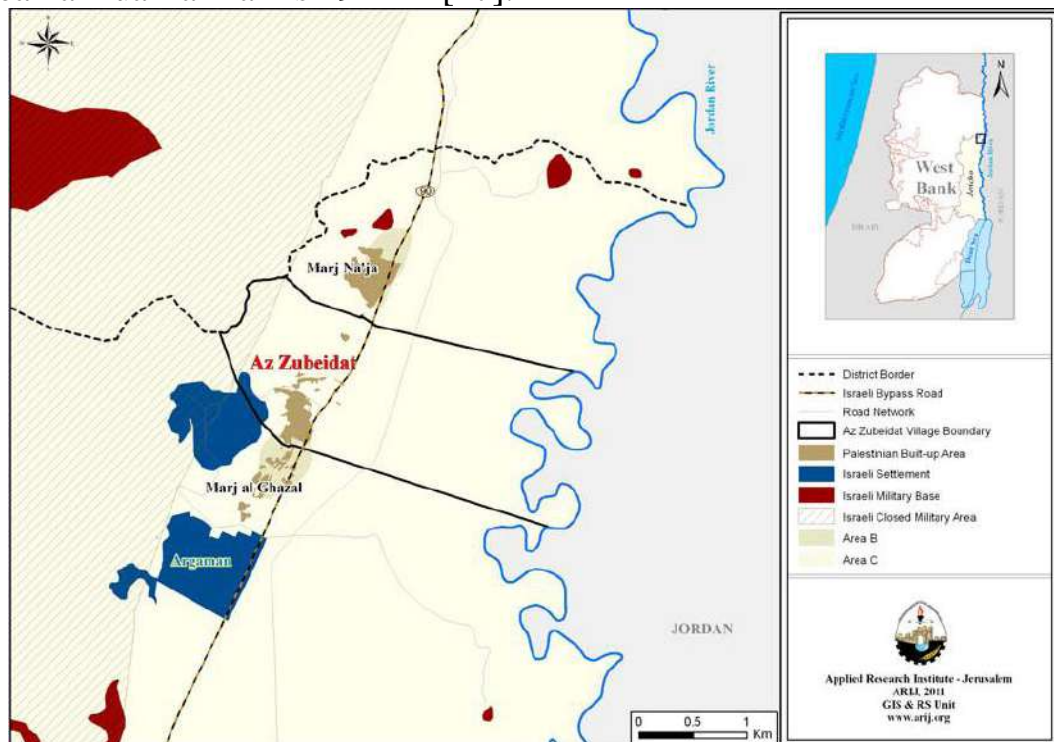


Figure (2.1) : Az Zubaidat location map [17].

### 2.1.2 Population

The total population of Az-Zubaidat Village in 1997 was 968capita; of whom 489 were male and 479 female, The number of households was 85

households living in 85 housing units, while the population of Az-Zubaidat grew in 2007 to 1,357capita; of whom 696 were male and 661 female. The number of households was 199 households living in 199 housing units [18].

### **2.1.3 Water Resources**

The source of drinking water of Az-Zubaidat Village is the Israeli company (Mekerot), with water network constructed in 2001.

The average consumption rate of domestic water in Az-Zubaidat Village is 150L/C/d, the amount of water supplied to the Village in 2011 was 500m<sup>3</sup>/d[19].

The Village has three underground wells, those wells aren't suitable to supply this village as potable water due to high value of total dissolved solid, they would be used only for irrigation of vegetables, grapes and palm trees[19].

The depletion of the groundwater sources through 'Mekerot' privately owned and controlled Israeli wells, which forbidden the Palestinian from excavation new wells and purchase the water only from Mekerot Company, also, the village has two wells controlled by Mekerot Company, namely : Marj Na'ja no. 14 and Argaman no. 29 [17].

## **2.2 Water Demand**

### **2.2.1 Water demand definition**

Water demand is the total amount of water consumed by the customers within the water system during a period of time[20].

There are several factors that can influence the amount of water demand such as education, age, religion and culture of the user himself .

Another factor that affects the amount of water consumption is the purpose for which water is used such as domestic, agricultural or industrial uses.

#### **Types of demand in Az-Zubeidat Village :**

##### **1. Domestic water demand**

In this type, water is used for drinking, bathing and showering, cooking, gardening and houses cleaning, etc .

The average per capita per day consumption is calculated by dividing the total consumption for a year over the number of population over the number of days of that year.

##### **2. Agricultural water demand**

In this type, water is used in agricultural purpose for irrigation and live stock.

### **2.2.2 Population Forecast Method**

There are many methods used to forecast population, but one will choose the best suitable method based on many factors such as engineering experience, judgment, type of the region in which population to be estimated and its location.



The factors which may cause the main change in population are :

- The rate of fertility (increase ).
- The rate of mortality (increase ).
- Migration (increase or decrease ).
- Economic considerations (increase or decrease ).
- Economic development (increase or decrease ) [21].

### **2.2.2.1 Engineering Method**

This method gives a good projection . It is expressed mathematically as :

$$P_t = P_0(1 + r)^n \dots\dots\dots(2.1)$$

Where :

n: Number of forecasting years

P<sub>t</sub> : the population at certain time in the future

P<sub>0</sub>: the present population

r : the population growth rate [22].

Future population estimates based on 1997 PCBS census of population and prescribed growth rate. Estimation of growth rates are based on past surveys of population growth rates in the West Bank between 1967 and 1992. These surveys indicate that these rates generally fluctuated between 1 to 3 percent[23].

The decrease of the overall population was attributed to the combined effect of Palestinian Intifada which began in 1987.

### **2.2.3 Population forecasting for Az-Zubaidat Village**

By applying equation number (1.6) of engineering method :

$$P = P_0(1+r)^n$$

$$P_{(2007)} = P_{(1997)} (1+r)^{10} \rightarrow 1357 = 968(1+r)^{10} \rightarrow r = 3 \%$$

$$P_{(2036)} = P_{(2007)} (1+r)^{29} \rightarrow P_{(2036)} = 1357(1+0.03)^{29} \rightarrow P_{(2036)} = 3197$$

Based on " Guidelines on technologies for water supply system in small communities ", published by WHO on 1993. Water demand is 150L/C/D ( minimum WHO demand for house connections in small communities ).

Targeted average consumption rate is to be 150L/C/d so ;

Total demand = population \* capita demand

$$= 3197 \text{ capita} * 150 \frac{L}{C.d} = 479679.2 \text{ L/d} \approx 480 \frac{m^3}{d}$$

Engineering method would be used in our project because there are only two census of the population in Palestine in 1997 and 2007 and this method applies to them, while the other methods need more than two population analyzes ( three or more) in order to apply them.

## **Chapter Three**

### **Design of Reverse Osmosis Desalination Plant**

### 3.1 Definitions

#### 3.1.1 Osmosis and reverse osmosis principles

Osmosis is a naturally occurring phenomenon and one of the most important processes in nature. It is a process where a weaker saline solution will tend to migrate to a strong saline solution. Examples of osmosis are when plant roots absorb water from the soil and our kidneys absorb water from our blood. Figure(3.1) shows the osmosis principle. A solution that is less concentrated will have a natural tendency to migrate to a solution with a higher concentration[24].

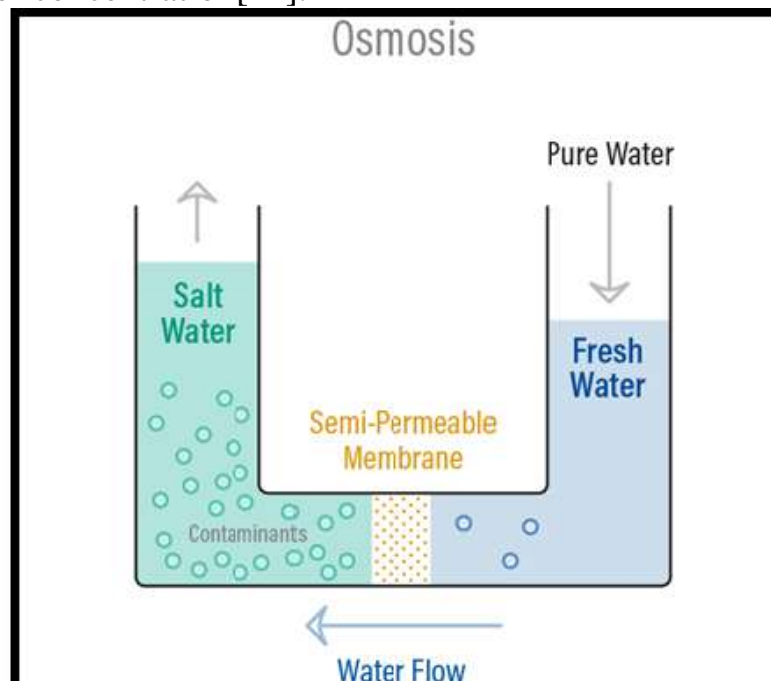


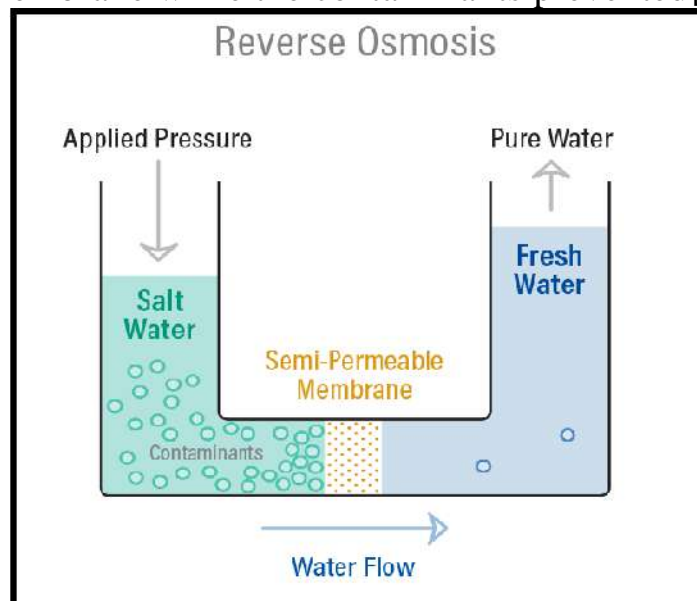
Figure (3.1): Osmosis principle [24].

**Semi-permeable membrane** is a membrane that will allow some atoms or molecules to pass but not others.

**Reverse Osmosis** is a technology that is used to remove a large majority of contaminants from water by pushing the water under pressure through a semi-permeable membrane[24].

Reverse osmosis is the contrary of osmosis process. The osmosis process happens without need any energy assistance while the reverse osmosis process needs energy to the more saline solution. The membrane of the reverse osmosis process is a semi permeable membrane that allows the water molecules to pass through but doesn't allow of dissolved salts, organics and bacteria to pass[24].

The energy required in reverse osmosis process as a pressure to push the water through the membrane that must be greater than the naturally osmosis in order to allow pure water and to hold back the contaminants. Figure(3.2) shows the reverse osmosis process when the pressure applied in the concentrated side, the water forced and pass through the membrane while the contaminants prevented[24].



**Figure (3.2):** Reverse Osmosis principle[24].

A high pressure pump will be used in the reverse osmosis process to increase the pressure in the concentrated side in order to force the water molecules to cross the membrane and almost all dissolved solids will be left the system in the reject stream. If the concentration of the raw water increases the pressure required to the process will be increased. The stream of the water that doesn't allow to cross the membrane is called the reject stream (or concentrate) while the water that allow to cross the membrane is called permeate (or product) water[24].

### **3.1.2Desalination technologies**

There are many desalination processes that used membrane on industrial field; the membrane processes include reverse osmosis, nanofiltration, ultrafiltration and microfiltration. Differences among these processes are shown below, where:

- Microfiltration operates on a particle size of  $0.15 \mu\text{m}$ .
- Ultrafiltration operates on a particle size range of  $0.15$  to  $5 \cdot 10^{-2} \mu\text{m}$ .
- Nanofiltration operates on a particle size range of  $5 \cdot 10^{-2}$  to  $5 \cdot 10^{-3} \mu\text{m}$ .
- Reverse osmosis operates on a particle size range of  $5 \cdot 10^{-3}$  to  $10^{-4} \mu\text{m}$ .

The difference between all filtration processes and RO is for separation mechanism, the separation of the filtration processes membrane made as sieving that retains the large particles and pass the smaller one while in RO the membrane allow to pass the solvent and prevent the solute.

All filtration techniques are used to remove the suspended materials, but the reverse osmosis process is used to remove dissolved salts and nano-filtration is used for partial softening of water [21].

### **3.2 RO Membranes**

There are two major commercial types of RO membranes include Cellulose Acetate (CA) and Polyamide(PA).

The membrane is a semi permeable thin film of polymeric material with thousands angstroms thick of polymeric porous material, the life time of the membranes varies between 3 to 5 years depends on the inlet water quality and the pretreatment system efficiency[25].

#### **3.2.1 Cellulose Acetate Membranes**

The CA membranes made from diacetate and triacetate cellulose, the separation process mechanism is to remove the solvent material by evaporation.

The structure of CA membranes with a surface layer of 0.1 to 0.2 micron is responsible for the salt removal. The membrane film is very porous with high solution permeability. The variations in temperature is responsible to control the amount of water flux and salt rejection[25].

#### **3.2.2 Composite Polyamide Membranes**

The PA membrane has two layers, one is a porous support layer while the other is a semi-permeable layer.

The PA membrane is higher water flux and lower salt pass than CA membrane, In addition to, PA membrane is stable with wide pH range than CA membrane but CA membrane is less degradation of exposure to free chlorine than PA membrane.

When the feed water has high fouling such as surface water supplies, so CA membrane is more applicable than PA membrane because the surface of CA membrane is more stable to free chlorine [26].

### **3.3 Membrane Modules**

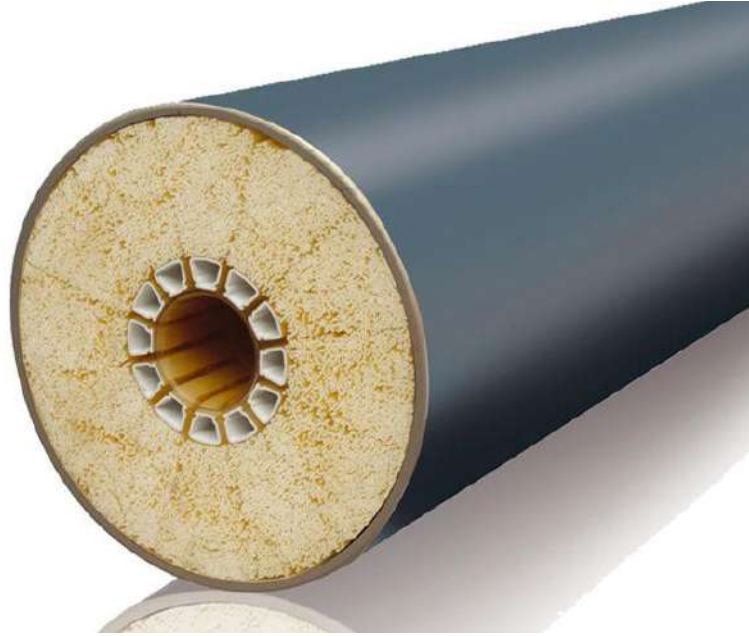
The two major membrane module (membrane element and pressure vessel) used for reverse osmosis applications are hollow fiber and spiral wound. Other types, which include tubular, plate and frame are used in the food and dairy industry.

#### **3.3.1 Hollow Fine Fiber**

This type of membrane is a fine form of hollow fibers, that made from cellulose or non cellulose material with inside diameter of  $42\mu\text{m}$  and outside diameter of  $85\mu\text{m}$ .

Figure (3.3) shows that there are millions of fine fibers collected into a bundle, also there are some plastic tubes work as inlet water distributor, in addition to, there are two ends stream one for permeate water and the other for concentrated water [27].





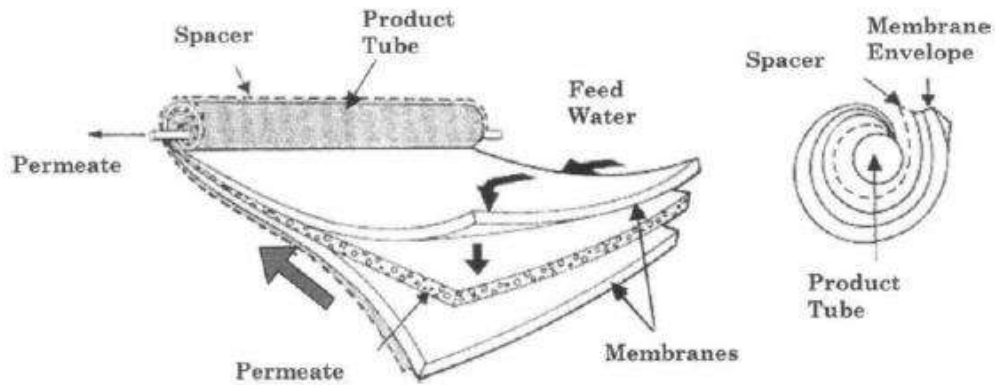
**Figure (3.3):** Hollow fiber membrane[27].

There is a cylindrical shell flows in radial movement inside the hollow fiber membrane that used to collect the permeate water that come from the pressurized feed water through the fiber bundle and exits to the permeate stream.

Hollow fiber modules required feed water of better quality (low concentration of suspended solids) than the spiral wound module configuration[27].

### **3.3.2 Spiral Wound**

Figure (3.4) shows the spiral wound membrane components, it consists of two flat sheets separated with spacer sheet, all three sheets are wound around a permeate tube that has many bores to collect the permeate water[27].



**Figure (3.4):** Spiral wound membrane module[27].

The feed water flow axial through the element, running parallel to the surface of membrane. The spacer make turbulence and reduce concentration polarization.

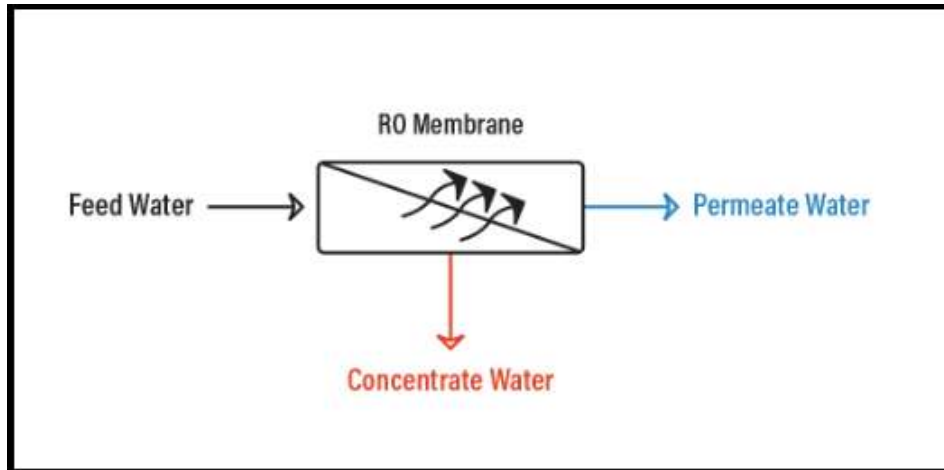
Recovery is responsible for the length of water feed path, the spiral system usually has many stages with three to six membrane elements connected in series in a pressure vessel. The brine stream from the first element becomes the feed to the next element within the pressure vessel while the brine stream from the last element exists to waste.

But the treatment water (permeate) from each element enters the permeate collector tube and exists to permeate stream. The recovery of a single pressure vessel will be operated up to 50% under normal conditions.

### **3.4 Passes and Stages in RO System**

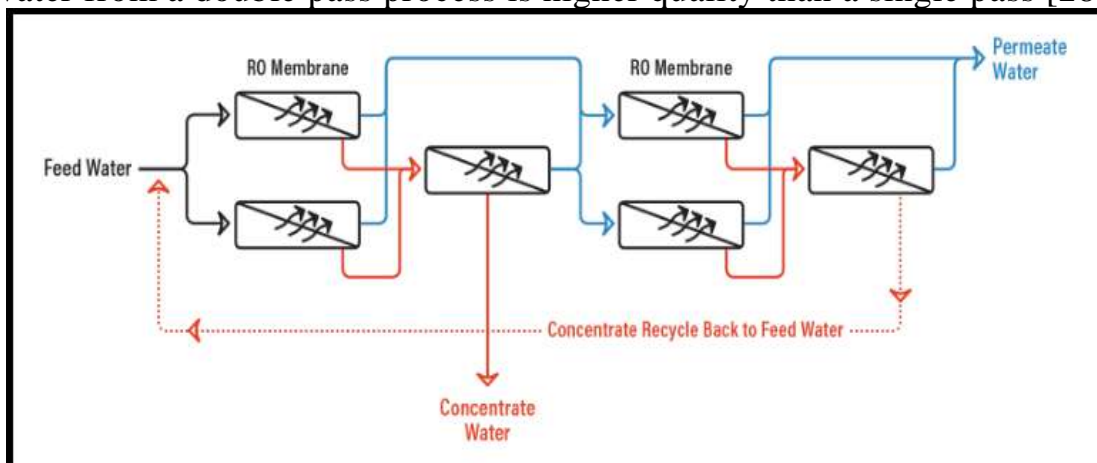
#### **3.4.1 Single and Double Pass RO**

Figure (3.5) shows the single pass RO process lines, the permeate stream is the water that will be distributed to the customer directly [28].



**Figure (3.5):** Single pass RO [28].

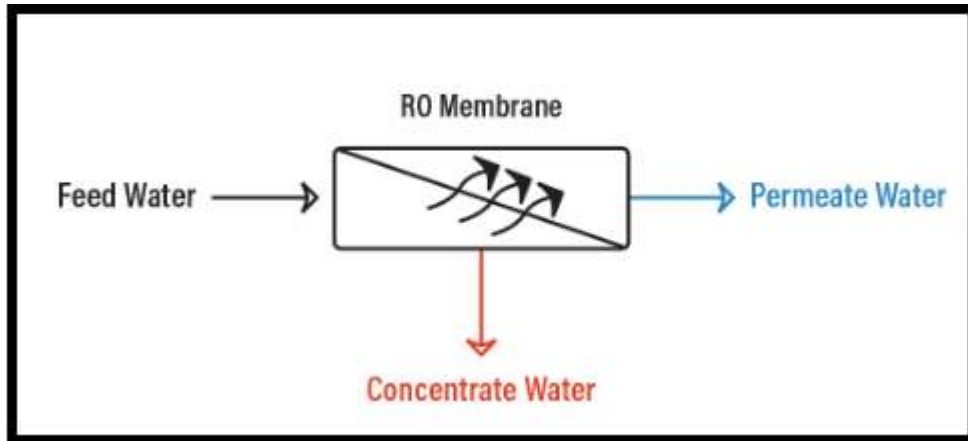
While Figure (3.6) shows a double pass RO process lines, the permeate stream from the first pass becomes the inlet to the second pass so, the water from a double pass process is higher quality than a single pass [28].



**Figure (3.6):** Double pass RO [28].

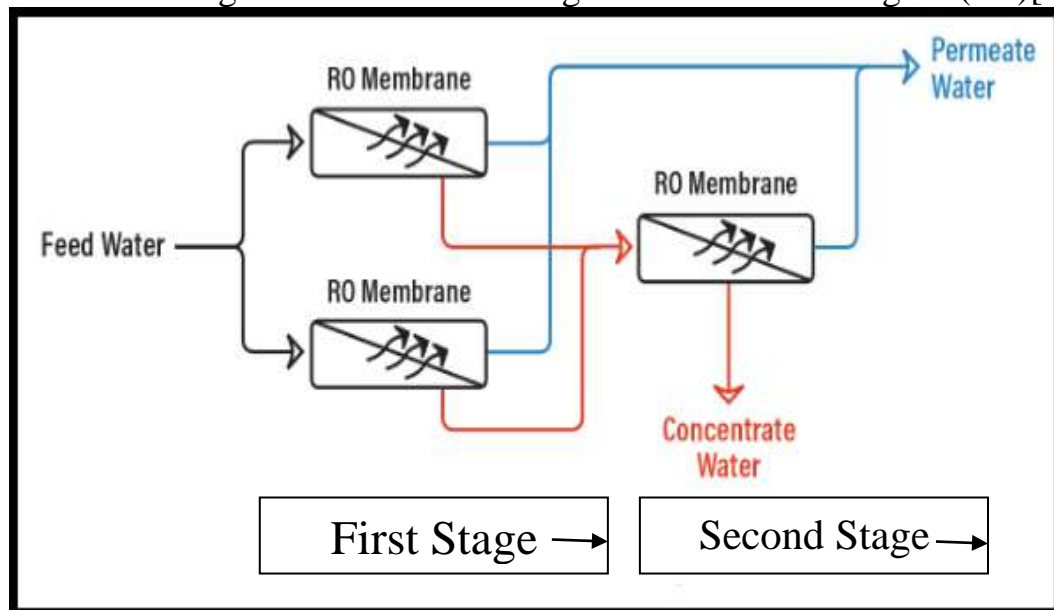
### 3.4.2 One and two stages of RO system

In one stage system, there is one stream for each feed, concentrate and permeate water as shown in Figure (3.7) [29].



**Figure (3.7):** One-stage RO system[29].

While in two stage system, the concentrate from the first stage becomes the inlet to the second stage in order to increase the recovery and the permeate stream for all stages will be collected together as shown in Figure (3.8)[29].



**Figure (3.8):** Two-stage RO system[29].

### Array

An array describes the arrangement of RO membrane in pressure vessel, each pressure vessel contains from one to six membranes. Each stage has unlimited amount of pressure vessels. The reject stream from each stage becomes the inlet stream for the next one and so on[30].

From Figure(3.8) the system is 2:1 array that means the two pressure vessels reject stream becomes the inlet stream for the next one vessel.

### **Recovery**

The recovery is the ratio of permeate flow to feed flow.

The relation between recovery rate and the number of stages is shown in

Table 3.1:

**Table (3.1): the number of stages of RO system and the recovery rate [30].**

<b>Number of stages</b>	<b>Recovery rate ( %)</b>
One	< 50
Two	> 50 and < 80
Three	> 80 and < 90

### **3.5 Reverse osmosis Performance & Design Calculations**

In RO system, there are a number of terms that includes :

- Operating pressure
- Rejection
- Recovery

The design of RO system depends on the quality of the feed water specially the salinity. Figure (3.9) shows a flowchart of an RO desalination plant components.

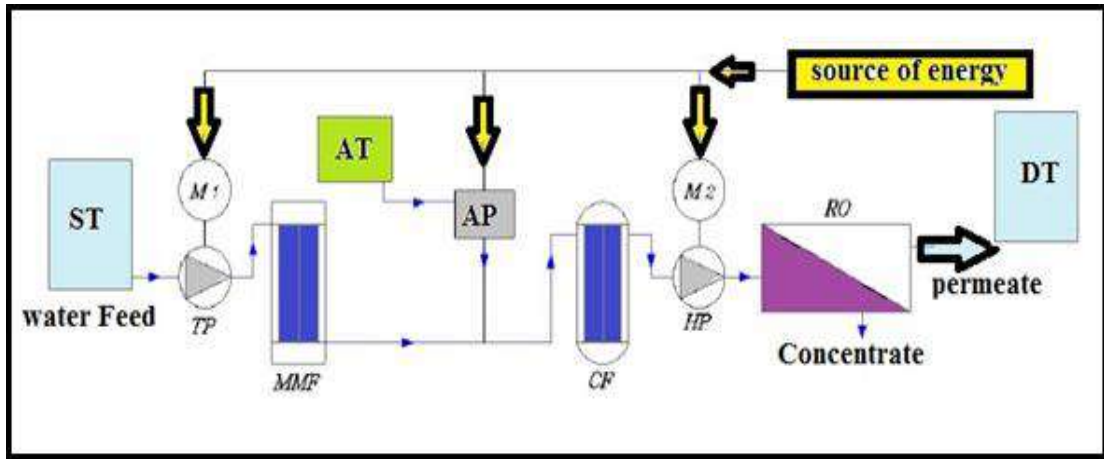


Figure (3.9):Flowchart for RO desalination plant[31].

Where ST stands for Storage tank, TP- M1 stands for transfer motor pump, MMF stands for multimedia filter, AT stands for anti scaling tank, AP stands for antiscaling pump, CF stands for cartridge filter,HP-M2 stands for HP motor pump (RO), RO stands for RO vessels (contain the membranes element) and DT stands for distribution tank.

### 3.5.1 Osmotic and Operating Pressure

The concentration of dissolved salts of a solution is determined experimentally in order to determine the osmotic pressure( $\pi$ ). The osmotic pressure is determine by the following equation:

$$\pi = R T \sum X_i \dots \dots \dots (3.1)$$

where  $\pi$  stands for the osmotic pressure (Kpa),T stands for the temperature (K),R stands for is the universal gas constant,  $8.314\text{Kpa}\cdot\text{m}^3/\text{kg}\cdot\text{mol}\cdot\text{K}$  and  $\sum X_i$  stands for is the concentration of all constituents in a solution ( $\text{kg}\cdot\text{mol}/\text{m}^3$ ).

An approximation for  $\pi$  may be made by assuming that 100ppm of (TDS) equals to  $75.84\text{Kpa}$  ( $\approx 0.76\text{bar}$ ) of osmotic pressure[30].

On 7/11/2016, a water sample that was taken from Az-Zubaidat Village water well. In that sample we found that Total Dissolved Solids (TDS) equals to 2100ppm so, the osmotic pressure will be:

$$\pi = (2100 * 0.76) / 1000 = 1.6 \text{ bar}$$

The operating pressure must be overcome the effects of friction losses of pipes, resistance, Osmotic and permeate pressure in order to achieve the economic permeate flow rate.

### 3.5.2 Rejection

The rejection of salt is known by this formula :

$$SR = \left(1 - \frac{C_p}{C_f}\right) * 100\% \dots \dots \dots (3.2)$$

Where SR stands for salt rejection,  $C_p$  stands for Permeate concentration and  $C_f$  stands for feed concentration

The rejection of salt values (TDS) for many membrane at this period above 99% for sea and BW membranes[30].

### 3.5.3 Permeate Recovery

Recovery is very important parameter in design and operation of RO plant, the recovery is determined by the following formula:

$$R' = \left(\frac{Q_p}{Q_f}\right) * 100\% \dots \dots \dots (3.3)$$

Where  $R'$  stands for recovery,  $Q_p$  stands for permeate water flow rate and  $Q_f$  stands for feed water flow rate.

As the recovery rate increases, the salt concentration on the feed-brine side of the membrane increases, which causes an increase in salt flow rate

across the membrane. In addition, a higher salt concentration in the feed-brine solution increases the osmotic pressure[30].

### **3.6 Desalination plant components**

The components of RO system are :

- Inlet water unit
- Water transfer unit
- Pretreatment units
- Pressure pumping unit
- Membranes unit

#### **3.6.1 Inlet water unit**

The source of feed water quantity and quality is the most important parameter in the design of RO system.

In our project, water supply will be Az-Zubaidat Village water well which has a capacity of 120m<sup>3</sup>/hr, and TDS of 2100ppm, Az-Zubaidat well water will be pumped to storage tank as feed water to RO system.

#### **3.6.2 Water transfer unit**

In this unit, there is a pump used to transfer water from the feed unit( ST) through the pretreatment filters. The osmotic pressure of the system is 1.6 bar depends on the value of TDS. Taking into account the drop from the filters system so, taking a safety factor of 1.1.



**Head loss in media filter:**

The head loss during multimedia filter can be determined using Rose equation: [21]

$$hL = \frac{1.067 * (Va)^2 * D'}{\phi * g * \epsilon^4} * \frac{C_D}{d'} \dots\dots\dots(3.4)$$

Where hL stands for frictional head loss through, V<sub>a</sub> stands for approach velocity, D' stands for depth of sand filter and C<sub>D</sub> stands for drag force coefficient, φ stands for shape factor, g stands for acceleration of gravity, ε stands for porosity and d' stands for diameter of sand grains

The main parameters for anthracite and sand layers that will be used to calculate the friction head loss through the filter are shown in Table (3.2).

**Table (3.2): Main parameter for dual-media filter**

Parameter / granular Type	Anthracite	Sand
Mean Diameter of granules(mm)	0.8	0.4
Porosity	0.55	0.45
Specific Gravity	1.75	2.65
Depth(m)	0.4	0.5
Shape factor (φ)	0.82	0.73
Width * length (m)	0.4*0.4	0.4*0.4

$$(a) Va(sand) = \frac{Q}{A_s} = \frac{500 \left( \frac{m^3}{d} \right)}{0.4m * 0.4m * 86400 \left( \frac{s}{d} \right)} = 0.036 \left( \frac{m}{s} \right) \dots\dots\dots(3.5)$$

$$(b) Re(sand) = \frac{\phi * d * Va}{\nu} = \frac{0.73 * 0.0004 * 0.036}{9 * 10^{-7}} = 13.18 \dots\dots\dots(3.6)$$

$$(c) C_D = \left( \frac{24}{Re} \right) + \left( \frac{3}{Re^{0.5}} \right) + 0.34 = \left( \frac{24}{13.18} \right) + \left( \frac{3}{13.18^{0.5}} \right) + 0.34 = 2.99 \dots\dots\dots(3.7)$$

$$(d)hL = \frac{1.067 * (Va)^2 * D' * C_D}{\varphi * g * \varepsilon^4} * \frac{1}{d} = \frac{1.067 * 0.036^2 * (\frac{m}{s}) * 0.5}{0.73 * 9.81 * (\frac{m}{s^2}) * 0.45^4} * \frac{2.99}{0.0004} \cong 15.8m$$

You can do the same steps (a-d) to calculate the head loss for anthracite.

The main results that calculated for anthracite and sand layers are shown in Table (3.3).

**Table (3.3): Main results for dual-media filter**

variable / granular type	Anthracite	Sand
Va(m/s)	0.036	0.036
Re	23.47	13.18
C <sub>D</sub>	1.98	2.99
hL(m)	2.11	15.8

$$N = 0.0195 * (Q_f)^{0.5} = 0.0195 * (500)^{0.5} \left( \frac{m^3}{d} \right) = 0.4 = 1(\text{filter})$$

Total head loss during multimedia filter = 15.8+2.11  $\approx$ 18m \*1.1 (safety factor) = 20 m

Water transfer pump specified as follows:

The output flow rate is 32m<sup>3</sup>/hr at 20m head with about 2bar (each bar is equal to 10.2m head).

The main dimensions for feed water tank that will be used to calculate the friction head loss through are shown in Figure (3.10).

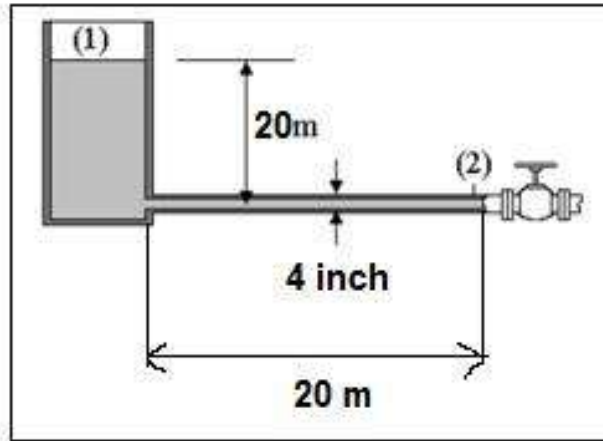


Figure (3.10): Feed water tank dimensions[31].

**Head loss before water transfer pump:**

Using Bernoulli equation between point 1 and 2: [32]

$$P_1 + \rho gh_1 + \frac{\rho v_1^2}{2g} = P_2 + \rho gh_2 + \frac{\rho v_2^2}{2g} + P_{loss} \dots \dots \dots (3.8)$$

$$P_{loss} = f \frac{L}{D} \frac{V^2}{2g} \gamma \rho \dots \dots \dots (3.9)$$

$$f = \frac{64}{Re} \dots \dots \dots (3.10)$$

$$Re = \frac{\rho V D}{\mu} \dots \dots \dots (3.11)$$

$$V = \frac{Qf}{A} \dots \dots \dots (3.12)$$

$$A(\text{pipe}) = \frac{d^2 \pi}{4} = \frac{0.1016^2 \pi}{4} = 0.0081(m^2) \dots \dots \dots (3.13)$$

– by applying equations from (3.8) to (3.13) :

$$V = 1.1 \frac{m}{s}$$

$$Re = 124850$$

$$f = 0.00051$$

$$P_{loss} = 6.17 \text{ pa}$$

$$P_2 = 195 \text{ kpa} = 1.95 \text{ bar}$$

**Power needed for water transfer pump:**

$$P_{w1}(\text{watt}) = \frac{\rho * g * Q_f * \text{head}}{\eta} = 4140 \text{ watt}$$

for more details see appendix A1

The main specifications of suggested water transfer pump (Figure 3.11) are: [33]

- ❖ Pump type : CM50-125A / Pentax company / made in Italy
- ❖ Material : Iron
- ❖ Q/ H performance : maximum flow 72 m<sup>3</sup>/hr , H: 24.5 m
- ❖ Supply voltage : 400 volt
- ❖ Motor power : 4.2 Kw (5.5 hp)
- ❖ Efficiency : 0.42



**Figure (3.11):** Water transfer pump[31]

### 3.6.3 Pretreatment unit

Due to equilibration times, adsorption and filtration actions of soils in the aquifer, well water have low turbidity and Silt Density Index(SDI) compared with surface water from rivers, lakes and ponds. Surface water in

contrast have high turbidity, SDI and natural organic matter derived from abundance of biotic life.

The proper pretreatment of raw water to make it compatible as feed water to RO must involve a total system approach for continuous, consistent and reliable operation.

Pretreatment is very important step that increase the efficiency and life expectancy of the membrane element by reducing fouling and scaling[34].

Due to the earth's geological layers before reach to ground water, the pretreatment system consists of sand or dual filter, inhabitation system and cartridge filters.

#### **Screening (media filter):**

Sand filters remove only relatively large solids (normally in the range of 40 micron and larger).

Removing suspended solids smaller than 40 microns requires filters with either two or three layers of filter media. These are referred to as dual-media filters or multi-media filters. When sized properly and with the correct configuration of filter media, these filters can remove suspended solids as small as 5 micron.

Media filter consist of dual layer filter ( sand and anthracite filter) that used to remove suspended and colloidal solids that may found in well water with small quantities[35,36].

The main specifications of dual-media filter are:

- ❖ The grain size: 0.5 mm (fine sand ) is and 0.8 mm ( anthracite).
- ❖ Column : armored fiber glass

❖ Column dimension : 16 inch \* 65 inch[39]

The components of dual media filter are shown in Figure (3.12).

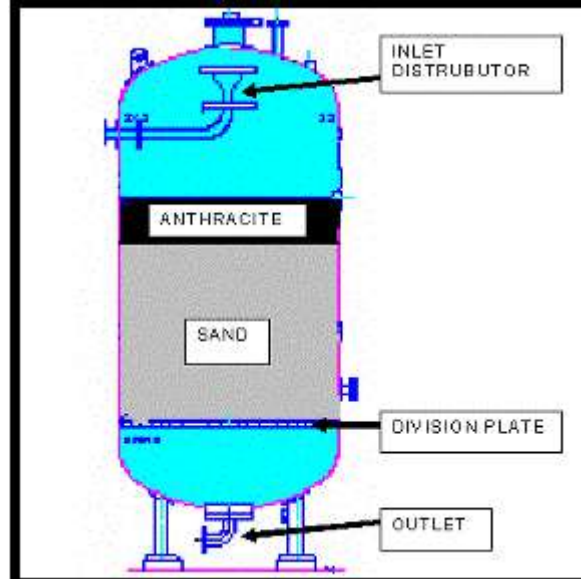


Figure (3.12): Dual-media filter[31].

### Scale inhibitor

RO antiscalants, sometimes called scale inhibitors, are specialized chemical formulations that are added to increase the solubility of sparingly soluble salts. In reverse osmosis system Calcium Carbonate ( $\text{CaCO}_3$ ), Calcium Sulfate ( $\text{CaSO}_4$ ), Strontium Sulfate ( $\text{SrSO}_4$ ), Barium Sulfate ( $\text{BaSO}_4$ ) and Calcium Fluoride ( $\text{CaF}_2$ ) are the most common scales of concern. The use of such antiscalants can form an essential component in the operation of well-run reverse osmosis systems[34].

The most scale inhibitors used commonly are sodium hexametaphosphate (SHMP), organophosphonates and polyacrylates.

Organophosphonates are more effective and stable than SHMP. They act as antifoulants for insoluble aluminum and iron, keeping them in solution.

Polyacrylates are generally known for reducing silica scale formation via a dispersion mechanism. Polymeric organic scale inhibitors are also more effective than SHMP.

If the operating recovery in RO brackish water plants above 35% then a scale inhibitor is recommended [37].

RO scale inhibitor that have been expertly developed to meet the following criteria:

- ❖ Safe to handle and safe in use.
- ❖ Good scale prevention properties.
- ❖ Membrane compatibility.
- ❖ Stable and effective across a wide pH range.
- ❖ Compatibility with other products.
- ❖ Cost affectivity.

The main specifications of inhibitor pump ,Figure (3.13), are :

- ❖ Material of pump : PVC
- ❖ Maximum flow rate : 2(L/hr)
- ❖ Maximum head : 50 m
- ❖ Voltage : 220 v
- ❖ Power : 0.5 kW
- ❖ Pump efficiency : 0.42[33].



**Figure (3.13):**Antiscalant pump[31].

### **Cartridge filter (CF):**

A melt blown filter cartridge is a "depth" type filter that is good for the removal of relatively uniform sized particles throughout the body of the filter.

The cartridge filter is the last defense for protecting the membrane elements, it has a minimum pretreatment so it doesn't considered as a basic pretreatment element even for ground water sources [38,39].

Two filters will be installed in the system each of 40inch in length and 2.5 inch in diameter.

There are four basic types of filter cartridges:

- ❖ Melt Blown (Solid) Filter Cartridges
- ❖ String Wound Filter Cartridges
- ❖ Pleated Filter Cartridges
- ❖ Media Cartridges: Activated Carbon(GAC), Alumina and more.

There were many applications for filter cartridges such as drinking water, boilers, washing machines, pre-filtration in water treatment, seawater desalination, process water and chemical processes[38].

The main specifications of cartridge filter, Figure (3.14), are: [39]



- ❖ Type : Poly propylene String Wound Filter
- ❖ Length : 40 inch
- ❖ Filter diameter : 2.5 inch



**Figure (3.14):** Cartridge filter[34].

### 3.6.4 Membrane Element Unit

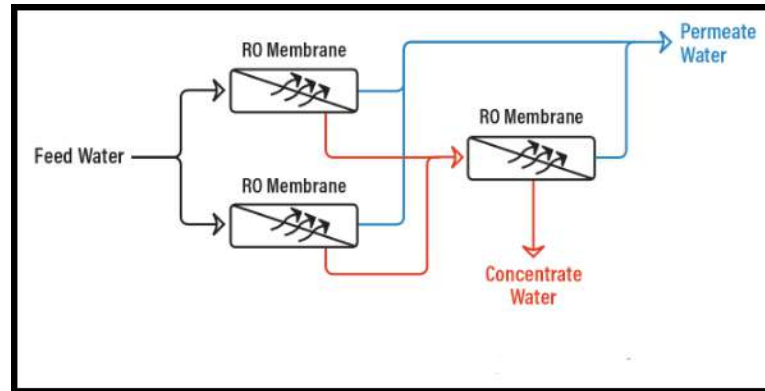
A spiral wound membrane elements FILMTEC(BW-30-440i) are used in this system with 4 inch in length and diameter[27].

The main specifications of membrane element are:

- ❖ Type :Hard fiber glass
- ❖ Active element area : 37 m<sup>2</sup>
- ❖ Rejection of salt : 99.5%
- ❖ Pressure :41 bar
- ❖ Maximum feed flow : 3.6(m<sup>3</sup>/hr)
- ❖ Maximum drop : 0.9 bar
- ❖ Flux :33(l/m<sup>2</sup>/hr)[40].

In our system, we suggest to install three vessels, two vessels are connected in parallel (first stage) and the third one (second stage) connected in series

as shown in Figure (3.15), each vessel contains six RO membrane elements connected in series.



**Figure (3.15):** Two stages RO membranes[29].

### Equations used in RO system:

There are many formula's used to design RO desalination plant, as shown below:

$$(a) \text{Number of elements (N')} = \frac{Q_p}{\text{Flux} * \text{active surface area (a)}}$$

$$= \frac{500 \left( \frac{m^3}{day} \right) * \left( \frac{day}{24hr} \right) * \left( \frac{1000L}{m^3} \right)}{33 \left( \frac{L}{m/hr} \right) * 37(m^2)} = 17.06 \text{element} \cong 18 \text{element}$$

$$(b) \text{Number of vessels} = \frac{18}{6} = 3 \text{vessel} (\text{Every vessel contains 6 element})$$

(c) Number of stages:

According to (Filmtec membranes) = 2 stages

$$(d) \text{Recovery} = \left( \frac{Q_p}{Q_f} \right) * 100\% = \frac{20.8}{32} * 100 = 65\%$$

To achieve 65% recovery of 32 (m<sup>3</sup>/hr) feed water, 2:1 array could be used where the first stage has two RO vessels, each operating at 16m<sup>3</sup>/hr and 40% recovery, while the second stage has one RO vessel operating at 19.2m<sup>3</sup>/hr and 40% recovery.

The permeate flow rate from the first stage would be:

$$(16 \text{ m}^3/\text{hr}) * (0.4) * (2 \text{ RO vessels}) = 12.8 \text{ (m}^3/\text{hr)}.$$

The concentrate from the first stage  $(32(\text{m}^3/\text{hr}) - 12.8(\text{m}^3/\text{hr}))$   
 $= 19.2(\text{m}^3/\text{hr})$ .

The permeate flow rate from the second stage would be:

$$(19.2 \text{ m}^3/\text{hr}) * (0.4) * (1 \text{ RO vessels}) = 7.7 \text{ (m}^3/\text{hr)}.$$

The total permeate flow from the system would be:  $12.8 + 7.7 = 20.5 \text{ (m}^3/\text{hr)}$

The recovery would be  $20.5 \text{ (m}^3/\text{hr}) / 32(\text{m}^3/\text{hr}) \approx 65 \%$ .

$$(e) \text{ Rejection} = 1 - \frac{C_p}{C_f} \Rightarrow 0.995 = 1 - \frac{C_p}{2100} \Rightarrow C_p = 10.5 \text{ ppm}$$

(f) Flow balance and mass balance:

$$Q_f = Q_p + Q_c \rightarrow 32 = 20.8 + Q_c \rightarrow Q_c = 11.2 \text{ (m}^3/\text{hr)}$$

$$Q_f * C_f = Q_p * C_p + Q_c * C_c \rightarrow 32 * 2100 = 20.8 * 10.5 + 11.2 * C_c \rightarrow C_c = 5980.5 \text{ ppm [41, 42].}$$

### 3.6.5 High pressure pumping unit

This pump is installed between cartridge filter and the RO membrane elements; to pump water from the output of cartridge filter through the RO vessels to distribution tank.

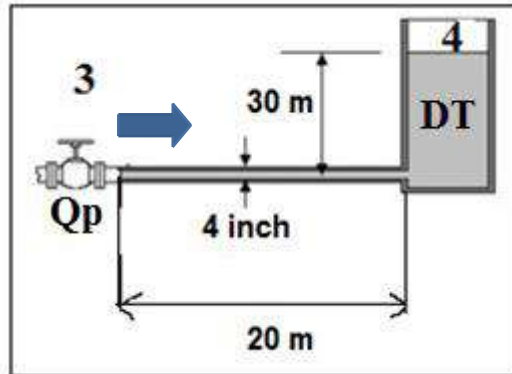
The feed flow is  $32 \text{ m}^3/\text{hr}$  and the operating pressure must be:

Operating pressure > permeate pressure + membrane resistance + friction loss

**Membrane resistance (pressure drop) = 0.9 bar** (depends on type of membrane element)

**Permeate pressure:**

The main dimensions for water distribution tank that will be used to calculate the friction head loss through are shown in Figure (3.16).



**Figure (3.16):** Water distribution tank dimensions[31].

Applying the same equations from (3.8) to (3.13):

Using Bernoulli equation between point 3 and 4:[32]

$$P_4 + \rho gh_4 + \frac{\rho v_4^2}{2g} + P_{loss} = P_3 + \rho gh_3 + \frac{\rho v_3^2}{2g}$$

$$p_{loss} = f \frac{L V^2}{D 2g} \gamma \rho$$

$$f = \frac{64}{Re}$$

$$Re = \frac{\rho V D}{\mu}$$

$$V = \frac{Q_P}{A}$$

$$(a) A(\text{pipe}) = 0.0081(\text{m}^2)$$

$$(b) V = 0.77 \frac{\text{m}}{\text{s}}$$

$$(c) Re = 87637$$

$$(d) f = 0.00073$$

$$(e) p_{loss} = 4.33 \text{ pa}$$

$$(f) P_3 = 293125 \text{ pa} = 2.93 \text{ bar} \cong 3 \text{ bar}$$

Operating pressure  $> (90000\text{pa} * 18 \text{ element} ) + 293117\text{pa} + 4.33\text{pa} = 1913130 \text{ pa}$

Operating pressure  $> 19.1 \text{ bar} \approx 20 \text{ bar} \approx 200\text{m (head)} (10\text{m} \approx 1 \text{ bar})$

For RO pump:

$$P_{w2}(\text{watt}) = 41399(\text{watt}) = 41.4(\text{kW})$$

For more details see appendix A2.

### **Power needed for antiscaling pump :**

$P_{w3} = 0.35 \text{ kW}$  ( from anti scaling pump specification )[33].

Total power( $P_{lt}$ ) =  $P_{w1} + P_{w2} + P_{w3} = 4.1 + 41.4 + 0.35 = 45.540 \text{ kW/hr}$

$E_{dl} = P_{lt} * t_d = 45.54(\text{kW/hr}) * 10(\text{hr/day}) = 455.4\text{kW/day}$ [43].

Each  $\text{m}^3$  need =  $455.4 (\text{kW/day}) / 500 (\text{m}^3/\text{day}) = 0.91\text{kW/m}^3$ .

## **ChapterFour**

### **Case Study: Az-Zubaidat Village**

## **4.1 Introduction**

In West Bank and Gaza strip, all types of fossil fuels are imported from Israeli companies as well as most of the electrical energy.

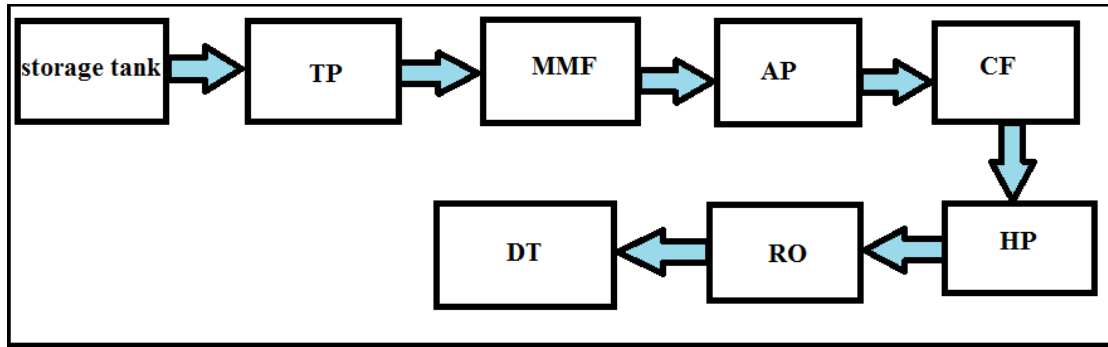
The conventional sources of energy includes coal, petroleum and natural gas. The main sources of conventional energies are fossil fuels. Nowadays, many countries are used fossil fuels as a basic source of energy to meet their requirement.

The Non-conventional sources of energy includes solar, geo-thermal and wind energy that is considered as the energy of the future. There is continuous research for developing these sources to make it more feasible.

## **4.2 The Case Study Load Profile**

The total energy require in RO processes are the energy needs to transfer water from feed tank to dual media filter and cartridge filter, the energy required to add antiscalant to water, then the energy required to transfer water from the output of cartridge filter through the RO vessels to distribution tank and last the energy required to operate other process controls and instruments.

The equipments of the RO desalination plant are shown in Figure (4.1).



**Figure (4.1):**Schematic diagram for RO desalination plant[31].

The amount of energy needed to operate the system is shown in Table(4.1):

**Table (4.1) : Hourly load data**

Name of items	Power (kW)
Anti scaling pump	00.35
Transfer motor pump	04.10
High pressure motor pump	41.40
Others( air conditioner, lightening ..etc)	05.00
<b>Total hourly power = 51.00kW/hr</b>	

The system will be designed at the present need of water and at the present amount of energy needed to operate the project.

The population at 2016 is 1798 capita and the demand of each capita is 150 (Liter/ day), so the total amount of water needs daily is 270m<sup>3</sup>, each m<sup>3</sup> need 0.91kW, so the total amount of energy needs daily is 246kW.

Assumed the operating hours will be 24hr/ day, so the energy required to operate the system will be 10.25kW/hr, but the energy consumed during the day and night is different, so the distribution of water consumption will be multiplied by a factor.

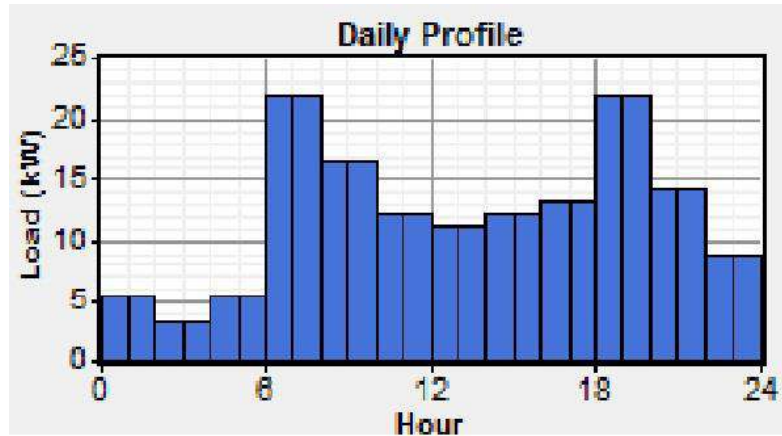
The Distribution of water consumption factor during day and night is shown in Table (4.2) below [44].



**Table (4.2): Distribution of water consumption during day and night**

Hour	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24
Factor	0.5	0.3	0.5	2.0	1.5	1.1	1.0	1.1	1.2	2.0	1.3	0.8

So the daily load during day and night in kW/hr is shown in Figure (4.2) below.



**Figure (4.2) :** daily load in system of scenario 1 [31].

### **The proposed Scenarios for operating the proposed desalination plant**

In general, there are two main scenarios for electrifications using renewable energy sources which are standalone and grid connected systems.

In standalone systems the local electrical system is completely responsible for feeding the load all over the day and because the renewable energy sources are not constant all over the day a backup system is normally with storage system. This system is preferable in this research because it gives more independency from electrical grid which is owned by Israeli companies.

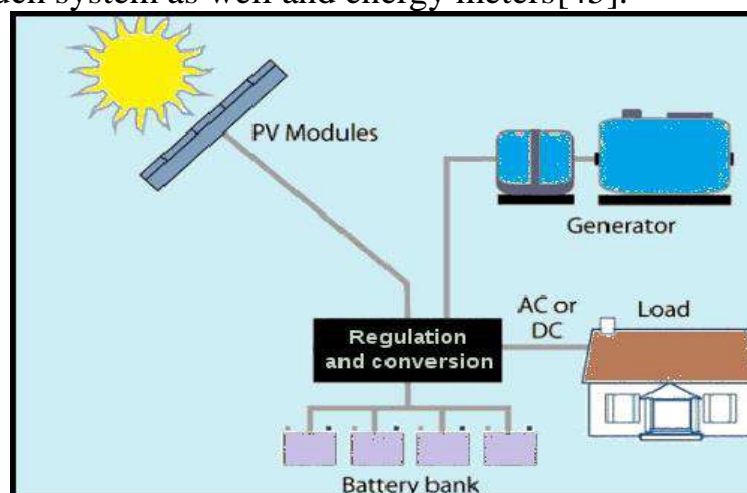
The grid connected system in another scenario for supporting the electrical load but it is not going to be studied in this research as it increases the dependency on the Israeli electrical companies.

### 4.3 Standalone System

For many people, powering their homes or small business using a small renewable energy system in not connected to the electricity grid called a stand-alone system, makes economic sense and appeals to their environmental values. Stand-alone systems generally take advantage of a combination of techniques and technologies to generate reliable power, reduce costs and minimize inconvenience[45].

Az-Zubaidat village region is located in C area that means it is under Israeli occupation control, the source of energy (electricity) is only from Israeli grid connection which can be disconnected at any time. This means that standalone system will be more logical options[45].

The proposed stand alone system as shown in Figure (4.3) is mainly based on renewable energies like PV and wind turbine in addition to diesel generator which is used as a backup. The storage system using batteries is utilized in such system as well and energy meters[45].



**Figure (4.3):** Schematic diagram of Standalone system[31].

The energy storage system is important parameter in standalone system as renewable energy sources are not reliable at all the day[45].

The technical parameters of the proposed energy sources of the previous configurations are illustrated below :

#### **4.4 Photovoltaic system**

The proposed systems are mainly depends on photovoltaic panels which is the most important source of energy in our work.

##### **4.4.1 Photovoltaic Panels (PV)**

Palestine has a high solar energy potential and it's located between 34°:20' - 35 °:30' East and 31 °:10' - 32 °:30' North.

The solar radiation on horizontal surface varies from 2.65kWh/m<sup>2</sup> per day in December to 8.34kWh/m<sup>2</sup> per day in June.

Photovoltaic(PV) system is able to supply electric energy to a given load by directly converting solar energy through the photovoltaic effect. The system structure is very flexible. PV module are the main building blocks, these can be arranged into arrays to increase electric energy production[46].

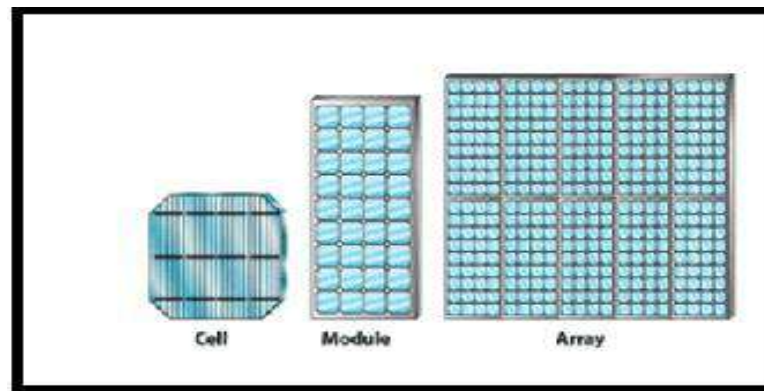
The amount of solar radiation varies with the passage of time during the day, solar cells can work between the hours of 6 a.m. to 6 p.m, after 6 p.m the spare storage system will be used to compensate the shortage of PV panels energy[46].

PV panels (solar cell) is an electronic devices that converts sunlight directly into electricity characterized by an output voltage and current without the need to heat the air or water.

There are two types of PV technology:

1. Crystalline.
2. Thin-film[47].

The following Figure (4.4) shows photovoltaic : cell, module and array :



**Figure (4.4) :** Photovoltaic system shape[48].

**Cells :** Films, thin squares, or discs of semiconductor device that convert sun light into direct current DC electricity.

**PV modules** consists of PV cell circuits scaled in an environmentally protective laminate and are the fundamental building block of PV system.

**Panels :** Include one or more PV modules assembled as pre-wired, field-installable unit.

**PV array** is the complete power-generating unit, and that's a group of modules that are electrically connected in series or in parallel.

PV modules are connected in series to obtain higher output voltages while PV modules are connected in parallel to obtain greater current .

Stationary structures are usually used with flat-plate systems. These structures tilt the PV array at a fixed angle and this angle is called tilt angle (The angle between the sun irradiation rays and vertical lines)[48].

The tilt angle in the target area varies between 23° in summer and 45 °in winter.

The maximum tilt angle to be 45 ° as fixed mounting structures[46].

In the energy sources, they are designed at the current situation, all the instruments of the energy system can be expanded when there will be needed in the future; because if the system expanded to the requirements of energy to 20 years ( project period ) the life of the instruments will be decreased and the instruments will be damaged .

The population at 2016 is 1798 capita and the demand of each capita is 150Liter/day, so the total amount of water needs daily is 270m<sup>3</sup>, each m<sup>3</sup> need 0.91kW.hr, so the total amount of energy needs daily is 246kW.hr.

This project must be effective year round, so it must be sized for the months which receive the least sunlight per day in addition to night hours.

These months occur during the rainy season, from December to March, so the spare storage system will be used to compensate the shortage of energy.

The solar radiation of Marjna'ja village is shown in Table(4.3):

**Table (4.3) : The solar radiation of Marjna'ja village[46].**

Month	Solar radiation (kw.hr/d/m <sup>2</sup> )
January	3.01
February	3.38
March	5.05
April	6.7
May	7.05
June	8.34
July	7.69
August	7.29
September	5.92
October	4.65
November	3.28
December	2.65

The solar radiation of Az-Zubaidat doesn't recorded but Marjna'ja is very near to Az-Zubaidat village so it can be used in this project.

The specifications of PV panels that will be used in the project are :

- PV type : polycrystalline solar modules
- Electrical performance: 0.385 (watt/m<sup>2</sup>)
- Life time and warranty: 20 years
- PV price: 2 (\$/watt )[49].

#### **4.5 Wind turbine**

Wind turbines are commercially common used on a wide range of producing power.

Wind energy is another renewable energy source that could be used without producing by-products that are harmful to nature. Like solar power, harnessing the wind is dependent upon weather and location.

The fins of a windmill rotate in vertical plane, which is kept perpendicular to the wind by means of a tail fin. As wind flow crosses the blades of the windmill, it is forced to rotate and can be used to generate electricity[50].

Most of wind turbines have three bladed rotor as shown in Figure (4.5) with horizontal axis type, but some of them have two blades to make them lighter, more flexible and to reduce the cost[50].



**Figure (4.5) :** Photo of wind turbine[31].

The wind speed of Marjna'ja village is shown in Table (4.4):

**Table (4.4) :** The wind speed of Marjna'ja village[46].

Month	Wind speed (m/s)
January	1.025
February	0.8789
March	0.8789
April	1.2505
May	0.8727
June	0.9260
July	0.9288
August	1.044
September	0.6671
October	0.8153
November	1.0169
December	0.9087

The average wind speed is 0.934m/s, due to the position of the village ( under sea level), wind turbine is insufficient to produce energy; so it will be omitted from the optimization of energy sources.

#### **4.6 Batteries (Lead acid batteries)**

Batteries store electricity for use during times that your system is not producing electricity (the resource is not available).

The lead acid batteries typically used for systems of life time from 5 to 10 years. In addition to these batteries provide electricity over long periods and can continuously charge and discharge up to 80% of their capacity for its life period[51].

The stand-alone system need batteries to store power sufficient to meet the system requirements during periods of cloudy weather, low wind or at night time [51].

The size and number of batteries depends on the system desired using HOMER program that will be shown in the next chapter[51].

The specifications of Batteries that will be used in the project are : [49]

- Battery type : mol battery(Lead acid battery)
- Battery size : 200 ampere , 12 volt , 2.4 (kWh)
- Battery price : 420 ( \$ )

#### **4.7 Inverter**

The Direct Current (DC) electricity must first be converted to Alternating Current (AC) electricity using inverters. The inverter does not produce any power; the power is provided by the DC source.



An inverter converts the DC electricity from sources such as PV panels, batteries and other sources to AC electricity. The electricity can be at any required voltage; it can operate AC equipments[48].

The size and numbers of inverter depends on the system desired load (kW) using HOMER program that will be shown in the next chapter.

For any future additional loads you want to enlarge the renewable energy system components so, it is essential an inverter with a larger input and output rating than you currently need to replace it with a larger one later[48].

The specifications of inverter, Figure (4.6), that will be used in the project are : [49]

- Inverter type : VWM converter(stand alone installation)
- Inverter size : depending on PV size
- Life time:15 years
- Inverter price : 250 ( \$/kW )
- Efficiency: 98%



**Figure (4.6) :** Photo of inverter[31].

## **Instrumentation**

Includes meters and other instruments allow to monitor the energy sources, system's battery voltage, the amount of power consumed ...etc.

### **4.8 Diesel Generator**

The most nonconventional source of energy that used widely specially in petroleum states is fuel.

A diesel generator is the combination of a diesel engine with an electric generator to generate electrical energy. A diesel compression-ignition engine often is designed to run on fuel oil, but some types are adapted for other liquid fuels or natural gas[52].

Diesel generating sets are used in places without connecting to a power grid, or as emergency power-supply if the grid fails, as well as for more complex applications such as those used in hospitals and water plant[52].

The plant brings generator sets online and takes them offline depending on the demands of the system at a given time.

The size and numbers of diesel generator depends on the system desired load (kW) using HOMER program that will be shown in the next chapter.



**Figure (4.7) :** Photo of diesel generator[53].

The specifications of DG that will be used in the project are : [49]

- DG type : Basic Diesel Generator
- DG size : depending on PV size .
- Cooling Method: Air Cooled
- Engine Model: 198f
- Frequency: 50Hz
- Life time : 15,000 (hr)
- Continuous work : 12 (hr)
- DG price : 100 ( \$/kW )

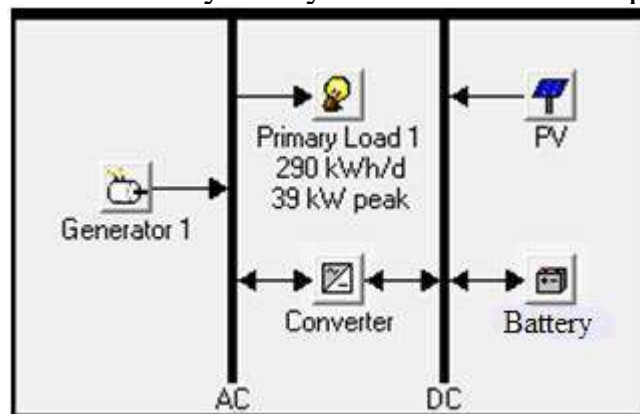
## **Chapter Five**

### **Optimization of power configurations for operating the Reverse Osmosis desalination plant**

There are different configurations going to be investigated in this research, mainly :

1. Photovoltaic panels with batteries
2. Diesel generator with batteries
3. PV panels and diesel generator without batteries
4. PV panels and diesel generator with batteries
5. Diesel generator without batteries.

The above configurations are complicated as they include different systems as shown in Figure (5.1), so to finding the optimum size of each component is not easy, in this work we utilize special software that is specialized for finding the optimum size of hybrid systems like HOMER program.



**Figure (5.1):** Schematic diagram of Standalone system (off-grid) configurations

## 5.1 Homer program

HOMER is the micro power optimization model, simplifies the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications[54].

Because there are large different variations in technology options such as cost and energy sources that make the selection of the best technology is

complex so, HOMER's optimization make it easier to evaluate many different configurations[54].

This model needs input data to make the simulation such as cost of components, resources, types and the capacity. HOMER displays the results in many tables and figures that make the comparison between different configurations more easier [54].

HOMER makes the energy balance for each system configuration and determine the feasibility for each one (if it is achieve the power demand) also decides how and when to operate the generator and use the batteries.

In addition to it is determine the system cost for installing and operating the processes over the life time of the project[54].

Hybrid systems compromises between some renewable energy sources that used to supply with electrical power so, any reduction of power generation from one source can be compensated directly from the other source to keep the continuity of power supply.

Also the use of non conventional sources reduce the energy price for a long period.

Different scenarios for energy storage are investigated in this research like Lead acid batteries and Water distribution tank system.

## **5.2 Optimization using HOMER program**

### **5.2.1 Stand alone system (off-grid)**

Two scenarios will be discussed as storage system :

- 1- Chemical energy storage system(Lead acid batteries )

## 2- Water distribution tank system

In the first scenario, the storage system is lead acid batteries, the batteries are designed to provide electricity over long periods, and can repeatedly charge and discharge up to 80% of their capacity.

In addition to, when using Wind or photovoltaic stand-alone system the batteries need to be used to store power sufficient to meet the system needs during anticipated periods of cloudy weather, low wind or at night time.

But in the second scenario, a water distribution tank will be used to store water in order to achieve demand. When the water level of storage tank decreased, the system will operate to compensate the shortage of water at any time during the day without using batteries.

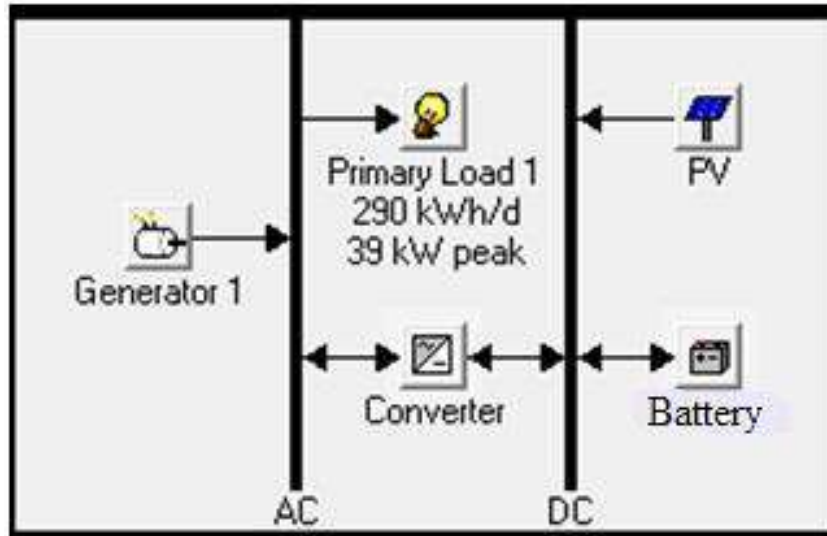
All basic data of renewable energies is collected and input to HOMER software in order to give the most economic, flexibility, efficiency and reliability source (from five hybrid systems in this study) that will be used to electrifying the project.

### **5.2.1.1 Chemical energy storage system (Lead acid batteries )**

The batteries can be used as storage device and as alternative source of energy when the power generation from the other sources of energy is weak so, it is used to substitute the deficit.

The solar radiation from solar panels is stored in battery that will be used specially during cloudy, rainy days and during the period of night.

The components of hybrid system are PV panels, DG, batteries and converter as shown in Figure(5.2).



**Figure (5.2) :** Energy flow diagram of scenario 1



Table 5.1 shows the input data entered to the HOMER software.

**Table (5.1) : Homer software input data for the optimal solution of scenario 1**

<b>component</b>	<b>Size</b>	<b>Life time</b>	<b>Purchase cost (\$/kW)</b>	<b>Replacement cost (\$/kW)</b>	<b>Maintenance cost (\$/year)</b>	<b>Quantity</b>
PV module	0, 1, 5, 10, 25, 35, 45, 50, 55 kW	20 years	2000	2000	100	----
Diesel generator	0, 1, 5, 15, 20, 25 kW	15,000 hr	100	100	5	1
Battery	Vision6FM200D (12V,200Ah)	917 kWh	420	420	21	0, 1, 5, 10, 20, 25, 35, 40, 45
converter	0, 1, 10, 15, 20, 25, 30 kW	15 year	250	250	12.5	1

The price that shown in Table (5.1) is collecting from local market for the individual .

## Optimization Result

HOMER makes many iterations for each configuration in order to gain the optimal result for the hybrid energy system as shown in Figure (5.3).

Sensitivity Results		Optimization Results									
Double click on a system below for simulation results.											
			PV (kW)	D.G (kW)	Battery	Conv. (kW)	Initial Capital	Operating Cost (\$/yr)	Total NPC	COE (\$/kWh)	
			25	20	4	20	\$ 56,880	43,073	\$ 550,921	0.462	
				20	4	10	\$ 5,480	51,367	\$ 594,657	0.503	
			35	25		20	\$ 75,700	48,887	\$ 636,430	0.529	
				25			\$ 2,500	56,149	\$ 646,519	0.540	

Figure (5.3) :Optimization Result of system of scenario 1

## Hybrid system results:

The amount of electricity produced by individual hybrid system is shown in Table (5.2) below :

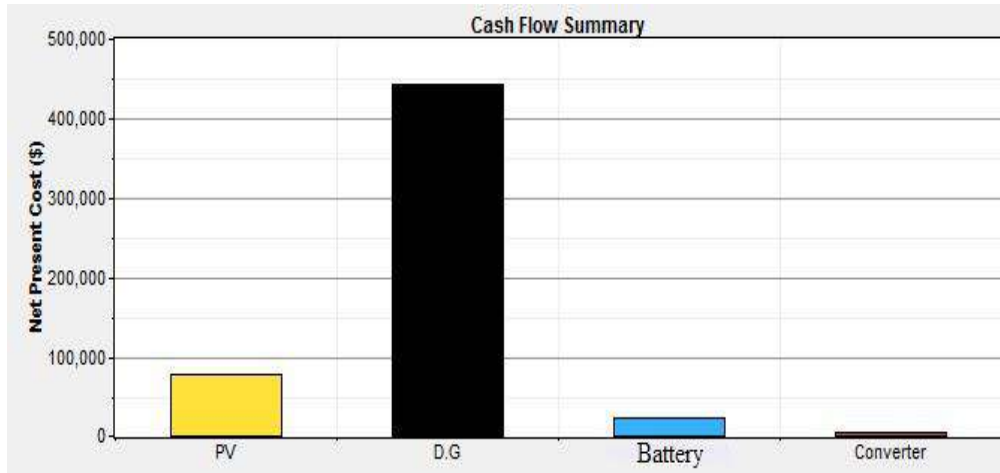
Table(5.2) : The output energy production of scenario1

production	kWh/yr	%
PV array	39,570	33
D.G	78,902	67
Total	118,471	100 %

It is noticed from the previous table that the Diesel generator is the base load of this hybrid system with 67% participation of total generated electricity.

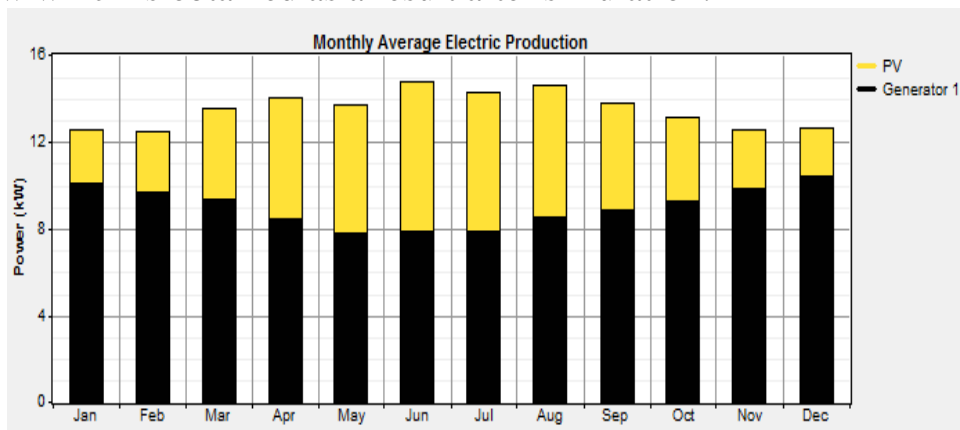
## Cost Summaries :

The Net present cost of hybrid system component type after HOMER software simulation is shown in Figure (5.4).



**Figure (5.4) :** Cash summary by component type of system of scenario 1

The average amount of electricity produced monthly by this hybrid system of PV and DG without using batteries is shown in Figure (5.5) below which is obtained as a result after simulation.



**Figure (5.5) :** The amount of electricity produced monthly by hybrid system of scenario 1

The five configuration systems of scenario 1 is explained in more details and ordered from the most feasible to least one as following :

**Configuration 1: The PV , diesel generator, battery and power converter** configuration, is the most feasible system for the many iterations of PV-DG-battery and power converter systems which were

optimized with the HOMER program. The components of this system are PV modules with 25kW, DG of 20kW, 4 batteries, and a 20kW converter. The COE of this system is 0.462\$/kWh and the Total Net Present Cost (TNPC) is 550,921\$ as shown in Table (5.3).

**Table (5.3) : The net present cost for PV-diesel generator-battery-power converter hybrid system of scenario1**

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	(\$)	(\$)	(\$)	(\$)	(\$)	(\$)
PV	50,000	0	28,675	0	0	78,675
Generator 1	2,000	10,204	4,056	427,230	-356	443,134
Battery	1,680	21,724	1	0	3	23,407
Converter	3,200	1,335	1,835	0	-665	5,705
System	56,880	33,263	34,566	427,230	-1,018	550,921

**Configuration 2: Diesel generator, battery and converter**

The second economic system is a DG, battery and power converter. The components of this system are DG with 20kW, 4 batteries and 10kW converter.

The COE is 0.503\$/kWh and the TNPC is 594,658\$ as shown in Table (5.4).

**Table (5.4): The net present cost for diesel generator, battery and power converter hybrid system of scenario 1**

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	(\$)	(\$)	(\$)	(\$)	(\$)	(\$)
Generator 1	2,000	12,351	4,757	547,637	-586	566,159
Battery	1,680	23,660	1	0	-51	25,289
Converter	1,800	751	1,032	0	-374	3,209
System	5,480	36,762	5,790	547,637	-1,012	594,658

### Configuration 3: PV, diesel generator and power converter

A PV, diesel generator and converter is the third economic system as energy suppliers. The components of this system are PV modules with 35 kW, DG with 25kW, and 20kW converter.

The COE of this system is 0.529\$/kWh and the TNPC is 636,430\$ as shown in Table (5.5).

**Table (5.5): The net present cost for PV, diesel generator and power converter hybrid system of scenario 1**

Component	Capital (\$)	Replacement (\$)	O&M (\$)	Fuel (\$)	Salvage (\$)	Total (\$)
PV	70,000	0	40,145	0	0	110,145
Generator 1	2,500	14,056	4,382	500,277	-634	520,580
Converter	3,200	1,335	1,835	0	-665	5,705
System	75,700	15,392	46,361	500,277	-1,299	636,430

### Configuration 4: Diesel Generator

A DG is the fourth economic system as energy suppliers with capacity of 25kW.

The COE of this system is 0.540\$/kWh and the TNPC is 646,520\$ as shown in Table (5.6).

**Table (5.6): The net present cost for diesel generator hybrid system of scenario1**

Component	Capital (\$)	Replacement (\$)	O&M (\$)	Fuel (\$)	Salvage (\$)	Total (\$)
Generator 1	2,500	15,875	5,023	623,372	-250	646,520
System	2,500	15,875	5,023	623,372	-250	646,520

### Configuration 5: PV, battery and converter

A PV, battery and converter is the least economic system as energy suppliers. The components of this system are PV modules with 140kW, 480batteries and 50kW converter.

The COE of this system is 0.738\$/kWh and the TNPC is 859,624\$ as shown in Table (5.7).

**Table (5.7): The net present cost for PV, battery and power converter hybrid system of scenario 1**

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	(\$)	(\$)	(\$)	(\$)	(\$)	(\$)
PV	280,000	0	160,579	0	0	440,579
Battery	201,600	221,745	1	0	-11,075	412,270
Converter	3,800	1,586	2,179	0	-790	6,775
System	485,400	223,331	162,759	0	-11,865	859,624

The comparison between the five configuration systems of previous scenario 1 is more explained in Table 5.8.

**Table (5.8): comparison of various hybrid energy system of scenario 1**

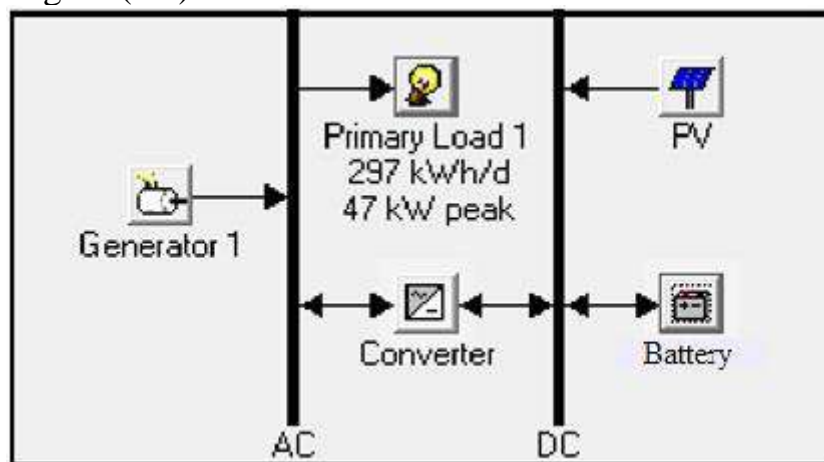
Configuration	PV module size (kW)	D.G (kW)	Battery (number)	Converter (kW)	Initial capital cost(\$)	Operating cost(\$)	NPV (\$)	COE (\$/kWh)
PVwith batteries	25	20	40	20	056,880	43,073	550,921	0.462
DG with batteries	0.0	20	40	10	005,480	51,367	594,657	0.503
PV and DG without batteries	35	25	0.0	20	075,700	48,887	636,430	0.529
PV and DG withbatteries	0.0	25	0.0	0	002,500	56,149	646,519	0.540
DG without batteries.	140	0	480	50	485,400	32,627	859,624	0.738

### 5.2.1.2 Water Distribution Tank System

In this scenario, the storage system is water distribution tank that will use to store water in order to achieve demand, when the water level of storage tank decreased, the system will be operate to compensate the needed water during the sunshine hours without using batteries or with small batteries.

There were different size of PV panels, diesel generator with different capacities (kW) are considered in this study. A diesel generator is designed to achieve the power demand.

The components of this system are PV, DG, batteries and converter as shown in Figure (5.6).



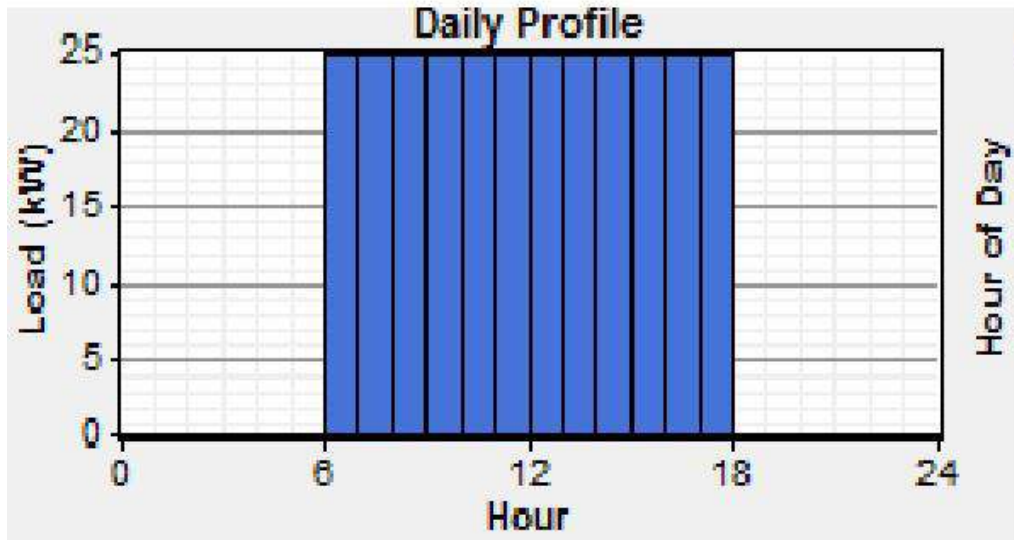
**Figure (5.6) :** Energy flow diagram for the hybrid energy system of scenario 2

But the system will be designed at the present need of water and at the present amount of energy needed to operate the project.

The population at 2016 is 1798capita and the demand of each capita is 150 Liter/ day, so the total amount of water needs daily is  $270\text{m}^3$ , each  $\text{m}^3$  need  $0.91\text{kW.hr}$ , so the total amount of energy needs daily is  $246\text{kWh}$ .



Assumed the operating hours will be 10hr/ day, so the energy required to operate the system will be 25kW/hr that is shown in Figure (5.7).



**Figure(5.7) :** hourly load (during sunshine hours) of scenario 2 [31]

HOMER analyzes the system configurations from the lowest to the highest TNPC and the optimal solution is the lowest TNPC.

The system takes into account the calculations for each costs such as capital, replacement, operation and maintenance, fuel cost and interest. HOMER displays simulation results in a variety of tables and graphs which helps to compare configurations and evaluate them on their economic merits.

Table 5.9 shows the input data and specifications of the components to the HOMER software.

**Table (5.9) : Homer software input data for the optimal solution of scenario 2**

component	Size	Life time	Purchase cost (\$/kW)	Replacement cost (\$/kW)	Maintenance cost (\$/year)	Quantity
PV module	0, 1, 35, 45, 50, 55, 60 kW	20 years	2000	2000	100	----
Diesel generator	0, 1, 5, 15, 20, 25, 28, 30, 35kW	15,000 hr	100	100	5	1
Battery	Vision6FM200D (12V,200Ah)	917 kWh	420	420	21	0, 1, 5, 10, 20, 25, 35, 40, 45
converter	0, 1, 30, 32, 35, 38, 40, 45, 50, 55 kW	15 year	250	250	12.5	1

The price that shown in Table (5.9) is collecting from local market for the individual .

## Optimization Result

HOMER makes many iterations for each configuration in order to gain the optimal result for the hybrid energy system as shown in Figure (5.8).

		PV (kW)	D.G (kW)	Battery	Conv. (kW)	Initial Capital	Operating Cost (\$/yr)	Total NPC	COE (\$/kWh)
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	55	25	20	45	\$ 124,600	26,863	\$ 432,717	0.348
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	45	25		30	\$ 95,900	32,645	\$ 470,339	0.385
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		30	4	1	\$ 4,980	46,684	\$ 540,441	0.444
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		35			\$ 3,500	48,172	\$ 556,032	0.449

Figure (5.8) :Optimization Result of system of scenario 2

The amount of electricity produced by individual hybrid system is shown in Table (5.10) below :

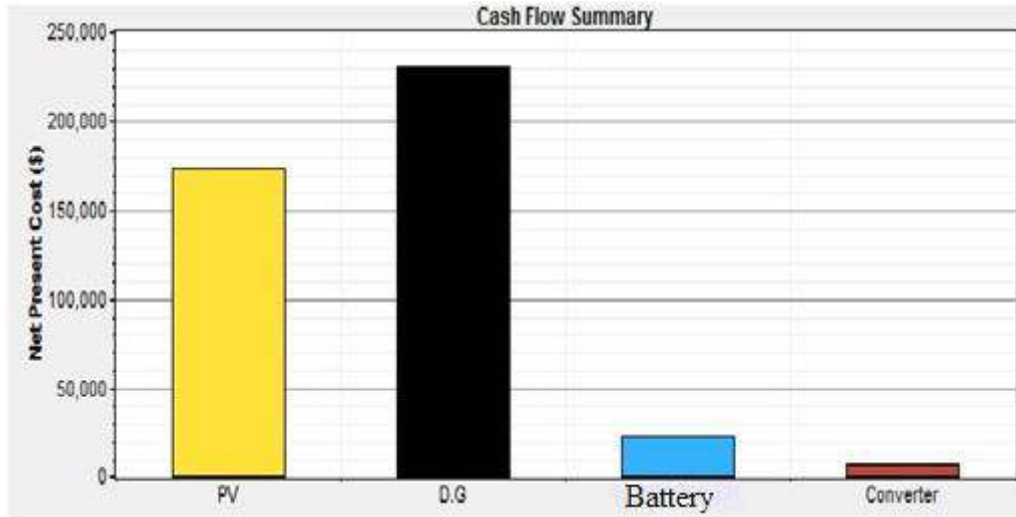
Table(5.10): The output energy production of scenario 2

production	Kwh/yr	%
PV array	87,053	67
Generator	44,930	34
Total	131,983	100

It is noticed from the previous table that the PV panels is the base load of this hybrid system with 67% participation of total generated electricity.

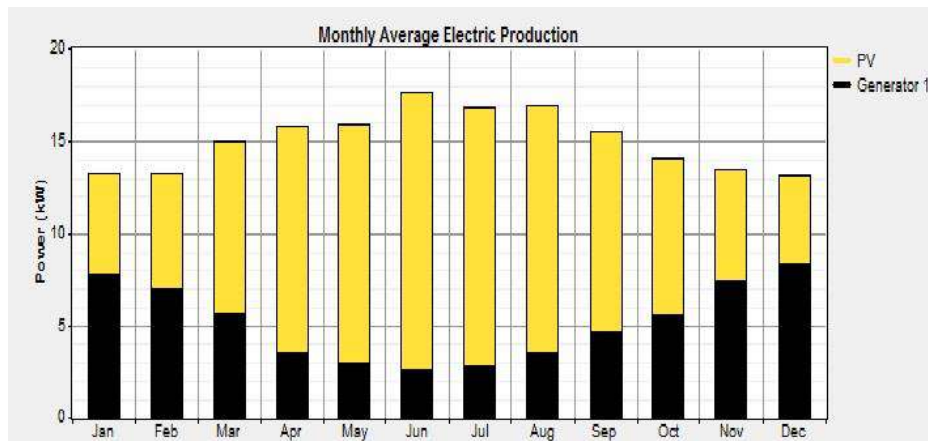
### Cost Summaries :

The Net present cost of hybrid system component type after HOMER software simulation is shown in Figure (5.9).



**Figure (5.9) :** Cash summary by component type of system of scenario 2

The average amount of electricity produced monthly by this hybrid system of PV and DG without using batteries is shown in Figure (5.10) below which is obtained as a result after simulation.



**Figure (5.10) :** The amount of electricity produced monthly by hybrid system of scenario 1

The five configuration systems of scenario 2 is explained in more details and ordered from the most feasible to least one as following :

**Configuration 1:** The PV, diesel generator, battery and power converter configuration, is the most feasible system for the many iterations of PV-DG-battery and power converter systems which were

optimized with the HOMER program. The components of this system are PV modules with 55kW, DG of 25kW, 20 batteries, and a 45kW converter.

The COE of this system is 0.348\$/kWh and TNPC is 432,717\$ as shown in Table (5.11).

**Table (5.11) : The net present cost for PV-diesel generator-battery-power converter hybrid system of scenario 2**

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	(\$)	(\$)	(\$)	(\$)	(\$)	(\$)
PV	110,000	0	63,085	0	0	173,085
Generator 1	2,500	3,869	1,427	223,094	-532	230,357
Battery	8,400	14,390	1	0	-112	22,679
Converter	3,700	1,544	2,122	0	-769	6,597
System	124,600	19,803	66,634	223,094	-1,414	432,717

### **Configuration 2:PV, diesel generator and converter**

The second economic system is a PV, DG, and power converter. The components of this system are PV modules with 45kW, DG with 25kW, and 30kW converter. The COE of this system is 0.385\$/kWh and the TNPC is 470,339\$ as shown in Table (5.12).

**Table (5.12): The net present cost for PV-diesel generator- power converter hybrid system of scenario 2**

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	(\$)	(\$)	(\$)	(\$)	(\$)	(\$)
PV	90,000	0	51,615	0	0	141,615
Generator 1	2,500	6,886	2,344	311,363	-429	322,663
Converter	3,400	1,419	1,950	0	-707	6,062
System	95,900	8,304	55,908	311,363	-1,136	470,339

### Configuration 3: Diesel generator, battery and power converter

A DG battery and converter is the third economic system as energy suppliers. The components of this system are DG with 30kW, 4 batteries and 1kW converter.

The COE of this system is 0.444 \$/kWh and the TNPC is 540,441\$ as shown in Table (5.13).

**Table (5.13): The net present cost for diesel generator, battery and power converter hybrid system of scenario 2**

Component	Capital (\$)	Replacement (\$)	O&M (\$)	Fuel (\$)	Salvage (\$)	Total (\$)
Generator 1	3,000	9,655	2,592	520,227	-910	534,563
Battery	1,680	3,785	1	0	-122	5,343
Converter	300	125	172	0	-62	535
System	4,980	13,565	2,765	520,227	-1,095	540,441

### Configuration 4: Diesel generator

A DG is the fourth economic system as energy suppliers with capacity of 35kW.

The COE of this system is 0.449\$/kWh and the TNPC is 556,032\$ .

**Table (5.14): The net present cost for diesel generator hybrid system of scenario 2**

Component	Capital (\$)	Replacement (\$)	O&M (\$)	Fuel (\$)	Salvage (\$)	Total (\$)
Generator 1	3,500	10,004	2,512	540,191	-175	556,033
System	3,500	10,004	2,512	540,191	-175	556,033

### Configuration 5:PV, battery and converter

A PV, battery and converter is the least economic system as energy suppliers. The components of this system are PV modules with 150Kw, 300 batteries and 50kW converter.

The COE of this system is 0.564\$/kWh and the TNPC is 675,182\$ .

**Table (5.15): The net present cost for PV, battery and power converter hybrid system of scenario 2**

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	(\$)	(\$)	(\$)	(\$)	(\$)	(\$)
PV	300,000	0	172,049	0	0	472,049
Battery	126,000	70,358	1	0	0	196,358
Converter	3,800	1,586	2,179	0	-790	6,775
System	429,800	71,943	174,229	0	-790	675,182

The comparison between the five configuration systems of previous scenario 2 is more explained in Table 5.16.

**Table (5.16) : comparison of various hybrid energy system of scenario 2**

<b>Configuration</b>	<b>PV module size (kW)</b>	<b>D.G (kW)</b>	<b>Battery (number)</b>	<b>Converter (kW)</b>	<b>Initial capital cost(\$)</b>	<b>Operating cost(\$)</b>	<b>NPC (\$)</b>	<b>COE (\$/kWh)</b>
PV and D.G with batteries	55	25	20	45	124,600	26,863	432,717	0.348
PV and D.G without batteries	45	25	0	30	95,900	32,654	470,339	0.385
DG with batteries	0	30	4	1	4,980	46,684	540,441	0.444
DG without batteries	0	35	0	0	3,500	48,172	556,032	0.449
PV with batteries	150	0	300	50	429,800	21,394	675,182	0.564



### **5.2.2 Grid Connection (on grid)**

Electrical grid is an interconnected network for delivering electricity from suppliers to consumers. It consists of generating stations that produce electrical power, high-voltage transmission lines that carry power from distance sources to demand centers, and distribution lines that connect individual customers.

Power stations may be located near a fuel source, at a dam site, or to take advantage of renewable energy sources, and are often located a way from heavily populated areas. The electric power which is generated is stepped up to a higher voltage at which it connects to the electric power transmission network .

A grid-connected system allows to power our home, business or any system with renewable energy during the year ( daily as well as seasonally). Any excess electricity that produce is fed back into the grid. When renewable resources are unavailable, electricity from the grid supplies your needs, eliminating the expense of electricity storage devices like batteries[55].

## **Chapter Six**

**Economic analysis and environmental impacts of  
using reverse osmosis desalination plant powered by  
different sources of energy**

The project will be operated using several sources of energy. The economic analysis and the environmental effects will be done to choose the best source of energy.

The total project cost will be calculated as the present value of the project, and includes all cost items expected during the assumed project life of 20 years, the feasibility evaluation should take into account the capital, operating and maintenance cost.

The initial investment including building construction, pumps, piping, energy cabling and transformers, membrane, filters, plant design electronic components and assembling. The cost of maintenance varies between 5 to 10% from the capital cost, the main energy costs come from the electric power needed to run the process pumps[56].

### **6.1 Economic analysis of using RO plant powered by PV panels and D.G**

The cost of PV panels, diesel generator, batteries, inverters and charge controller are entered in HOMER program to give the cost of energy as (\$/kW).

The cost of each component (capital cost), operating and maintenance cost of the project are shown in Table (6.1).

**Table (6.1): Direct capital cost of the project [33,49].**

Component	Quantity (#)	Price (\$)	Life time (years)	Total price (\$)
Transfer pump	1	900	20	900
Dual filter	2	2000	5	4000
Cartridge filter	2	500	5	1000
Anti scaling pump	1	200	20	200
High pressure pump	1	10,000	20	10,000
RO membrane elements	18	700	5	12600
pipes , valves , gages	1	4000	20	4000
Installation	1	2500	20	2500
Electrical control panel	1	1200	20	1200
instruments	1	2000	20	2000
Direct capital cost of the project(DCC)				38700
Operating and maintenance cost ( 5 % of capital cost ) C <sub>O&amp;M</sub>				

land, storage tank and distribution tank are already available.

**Economic analysis equations**

Total Capital Cost (TCC) is equal to the sum of Direct Capital Cost (DCC) and Indirect Capital Cost (ICC).

$$TCC (\$) = DCC (\$) + ICC(\$) \dots\dots\dots (6.1)$$

The DCC includes all equipments and membranes .

The ICC includes constructions and well water cost , it is equal to 27 % of DCC [57].

that means :

$$ICC(\$) = 0.27 * DCC (\$) \dots\dots\dots(6.2)$$

The Annual Operating and Maintenance Cost (OC<sub>O&M</sub>) is considered to be the cost of labor, maintenance, chemical, membrane replacement and insurance cost that equal to 5 % of the TCC : [57]

$$C_{O\&M} (\$) = 0.05 * TCC(\$) \dots\dots\dots(6.3)$$

The operating cost is calculated in (\$/year) as shown below :

$$OC = OC_{power} + OC_{O\&M} + OC_{Mbne} \dots \dots \dots (6.4)$$

$OC_{power}$  = the energy cost for each kilowatt (\$/Kw) (using HOMER program results)

$$OC_{O\&M} = 0.05 * TCC(\$)$$

$$OC_{Mbne} = \frac{\text{Price (\$/member)} * (nb)}{n_{LT Mbne}} \dots \dots \dots (6.5)$$

Where  $OC_{Mbne}$  stands for the operating cost of the membrane, nb stands for number of membrane that will be used in the plant and  $n_{LT Mbne}$  stands for lift time of each membrane (years)[58].

The Annualized Capital Cost (ACC) in (\$/year) is calculated using chauvel formula : [59]

$$ACC = (TCC) * \frac{i * (1+i)^{n(plant)}}{(1+i)^{n(plant)} - 1} \dots \dots \dots (6.6)$$

Where i stands for the interest rate (%) and n(plant) stands for the plant life time (years).

The Total Potable Water Price (TWP) in (\$/m<sup>3</sup>) is calculated by the following equation :

$$TWP = \frac{ACC + OC}{M_{plant} * 365 * L_{plant}} \dots \dots \dots (6.7)$$

Where  $M_{plant}$  stands for daily potable water production of the plant (m<sup>3</sup>/day) and  $L_{plant}$  stands for load factor (85%)[60].

### 6.1.1 Water Distribution Tank system :

Using the same five cases that optimized by HOMER program in the previous chapter (5), Table (6.2) shows the energy cost when the storage system is water distribution tank.

Table (6.2): Energy cost when the distribution tank used as the storage system

Configuration	PV module size (kW)	D.G (kW)	Battery (number)	Converter (kW)	COE (\$/kWh)
PV and D.G with batteries	55	25	20	45	0.348
PV and D.G without batteries	45	25	0	30	0.385
DG with batteries	0	30	4	1	0.444
DG without batteries	0	35	0	0	0.449
PVwith batteries	150	0	300	50	0.564

Configuration 1: PV panels , D.G , Battery and converter

Applying the equations from (6.1) to (6.7) to calculate the cost of cubic meter of water :

From table (6.1), DCC = 38700 \$

ICC(\$ ) = 10449\$

So, TCC = 49149\$

$C_{O\&M}$  (\$) = 2457.45\$

$$\bullet OC_{power} = 31208.81 \left( \frac{\$}{year} \right)$$

$$\bullet OC_{Mbne} = 2520 \left( \frac{\$}{year} \right)$$

So ,OC = 36186.26 (\$/year).

$$ACC = 3943.84 \left( \frac{\$}{\text{year}} \right)$$

$$TWP = 0.479 \left( \frac{\$}{\text{m}^3} \right)$$

For more details see Appendix A3

Using the same equations from (6.1) to (6.7) to calculate the cost of cubic meter of water for the other configurations :

TCC, DCC, ICC,  $OC_{\text{Mbne}}$  and  $OC_{\text{O\&M}}$  are fixed values for all the configurations, the other results would be shown in Table (6.3) below :

**Table(6.3) : The cost of cubic meter of water for the other configurations of scenario 1**

Configuration	OC (\$/year)	OC(power) (\$/kW. year)	TWP (\$/m <sup>3</sup> )
PV and D.G with batteries	36186.26	31208.8	0.479
PV and D.G without batteries	39504.44	34526.9	0.518
DG with batteries	44795.59	39818.1	0.581
DG without batteries	45243.99	40266.5	0.587
PVwith batteries	55557.25	50579.8	0.710

From the previous table, The difference for the total water price between the first four configurations and the last one is due to high prices of generating power from use more batteries and big size of solar panels that have high purchase cost; so the TWP would be higher than the other four configurations.

### 6.1.2 Chemical energy storage system (Lead acid batteries )

Using the same five cases that optimized by HOMER program when the storage system is batteries, Table (6.4) shows the energy cost when the storage system is Lead acid batteries.

**Table (6.4): Energy cost when the batteries used as the storage system**

Configuration	PV module size (kW)	D.G (kW)	Battery (number)	Converter (kW)	COE (\$/kWh)
PV with batteries	25	20	4	20	0.462
DG with batteries	0	20	4	10	0.503
PV and DG without batteries	35	25	0	20	0.529
PV and DG with batteries	0	25	0	0	0.54
DG without batteries	140	0	480	50	0.738

Configuration 1: PV panels, D.G, Battery and converter

Applying the equations from (6.1) to (6.7) to calculate the cost of cubic meter of water :

From Table (6.1), DCC = 38700 \$

ICC(\$ ) = 10449\$

So , TCC = 49149\$

$C_{O\&M}$  (\$) = 2457.45\$

$$\bullet OC_{power} = 41432.4 \left( \frac{\$}{year} \right)$$

$$\bullet OC_{Mbne} = 2520 \left( \frac{\$}{year} \right)$$

So ,OC =46409.84 (\$/year)

$$ACC = 3943.84 \left( \frac{\$}{year} \right)$$



$$TWP = 0.601 \left( \frac{\$}{\text{m}^3} \right)$$

For more details see Appendix A4

Using the same equations from (6.1) to (6.7) to calculate the cost of cubic meter of water for the other configurations :

TCC, DCC, ICC,  $OC_{\text{Mbn}}$  and  $OC_{\text{O\&M}}$  are fixed values for all the configurations, the other results would be shown in Table (6.5) below :

**Table(6.5) : The cost of cubic meter for the other configurations of scenario 2**

Configuration	OC (\$/year)	OC(power) (\$/kW. year)	TWP (\$/m <sup>3</sup> )
PV with batteries	46409.841	41432.39	0.601
DG with batteries	50086.74	45109.29	0.645
PV and DG without batteries	52418.43	47440.98	0.672
PV and DG with batteries	53404.92	48427.47	0.684
DG without batteries	71161.65	66184.20	0.896

From the previous table, The difference for the total water price between the first four configurations and the last one is due to high prices of generating power from use more batteries and big size of solar panels that have high purchase cost; so the TWP would be higher than the other four configurations.

## 6.2 Environmental assessments

The life cycle inventory inputs and outputs of processes in any plant is the total effects on our environment.

The inputs of RO desalination plant include raw material (water), chemicals and source of electricity (energy) while the outputs are brine water and emissions of greenhouse or any other gases.

The inputs of the project (water and chemicals) don't have any bad effects because water is coming from the ground. The chemicals (anti scalant) are used in small quantities and will be consumed totally to prevent scaling.

The electricity consumed by the desalination processes is mostly responsible of the total plant life cycle impacts. The energy cost is the maximum cost of the operating cost in this project.

This study is focused on the use of most economic alternative energy source and less environmental impacts.

There are many advantages of PV panels such as it operates in a long life (20 years) with low maintenance, it generates energy without producing any emissions or any bad gases and it operates silent[61].

The production of electricity may needed to use fuels ( like diesel generator) which combustion emits CO<sub>2</sub>, thus have a bad effects on the surrounding environment (air pollution).

Air pollution emissions from fossil fuels is the most energy related bad impacts on human health that causes of morbidity and mortality in the world compared with renewable energy technology.

The greenhouse gases emissions produced by the combustion of fossil fuel of diesel generator during its lifetime are shown in Table (6.6).

The reduction in the renewable energy cost that can be used as energy suppliers instead of fossil fuels is the penalty cost.

**Table (6.6): The amount of gaseous emissions for diesel generator over its lifetime.**

Pollutant	Emissions (kg/yr)
Carbon dioxide	103,350
Carbon monoxide	255
Unburned hydrocarbons	28.3
Particulate matter	19.2
Sulfur dioxide	208
Nitrogen oxides	2,276

On the other hand, brine discharge is one of the largest sources of wastewater from the desalination plant, brine effluents have a strong negative impacts on the environment due to their high concentration of salts and other pollutant contents.

The physiochemical effects of rejected water are related to their salinity, temperature and constituents that could change the physiochemical properties of the receiving water. This change may have adverse effects on marine life if it would be discharged to the nearest sea or spring [61].

It was reported that unconcerned disposal of reject brine water (particularly into unlined ponds or pits) could create pollution of the ground water and soil due to the increase of salinity that may decrease plant and soil productivity[62].

## Results and Conclusion

The input data are analyzed, characterized and tabulated systematically using the HOMER software in order to determine the most economic hybrid system of the five hybrid systems are proposed in this study.

Different scenarios for energy storage are investigated in this research like Lead acid batteries and Water distribution tank system.

The analysis results from the Lead acid batteries scenario show that, among five hybrid systems for supplying electrical requirements, the most economical is PV modules with 25 kW, DG of 20 kW, 4 batteries, and a 20 kW converter hybrid system, which has a Cost Of Energy (COE) of 0.462 \$/kWh and the cost of potable cubic meter is 0.601\$/ m<sup>3</sup>.

The components of second economic system are the configuration that includes the DG with 20kW, 4 batteries and 10kW converter. The COE is 0.503\$/kWh and the cost of potable cubic meter is 0.645\$/ m<sup>3</sup>.

The components of third economic system are the configuration that includes the PV modules with 35 kW, DG with 25 kW, and 20 kW converter. The COE of this system is 0.529\$/kWh and the cost of potable cubic meter is 0.672\$/ m<sup>3</sup>.

The fourth configuration that includes only a diesel generator of 25kW. The COE of this system is 0.540\$/kWh the cost of potable cubic meter is 0.684\$/ m<sup>3</sup>.

The configuration that includes PV modules with 140kW, 480 batteries and 50kW converter has a COE0.738\$/kWh. The cost of potable cubic meter is 0.896\$/ m<sup>3</sup>.

The results from the Water distribution tank scenario show that the most economical system is PV modules with 55kW, DG of 25kW, 20 batteries, and a 45kW converter. The COE is 0.348\$/kWh and the cost of potable cubic meter is 0.479\$/ m<sup>3</sup>.

The next feasible configuration is the that includes PV modules with 45 kW, DG with 25kW, and 30kW converter. The COE of this system is 0.385\$/kWh and the cost of potable cubic meter is 0.518\$/ m<sup>3</sup>.

The COE obtained from the system includes DG with 30kW and 4 batteries is 0.444\$/kWh and the cost of potable cubic meter is 0.581\$/ m<sup>3</sup>.

The only DG configuration with 35kW Obtains a COE of 0.449\$/kWh. The cost of potable cubic meter is 0.587\$/ m<sup>3</sup>.

The least economic system components are PV modules with 150kW, 300 batteries. The COE of this system is 0.564\$/kWh and the cost of potable cubic meter is 0.710\$/ m<sup>3</sup>.

### **Recommendations**

- ❖ It is recommended to use PV panels as major source of energy to produce electricity for operating the plant.
- ❖ Studying the combination between the two scenarios (water distribution tank and lead acid batteries) in order to get more accurate and best results.
- ❖ Studying the use of another water desalination method and comparison it with RO method.
- ❖ Studying the use of other sources of power such as grid connected hybrid system.

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## **Appendices**

Appendix A1 : Head loss before water transfer pump calculations

Appendix A2 : High pressure pumping unit calculations

Appendix A3 : The cost of cubic meter water using Water Distribution  
Tank Scenario

Appendix A4 : The cost of cubic meter water using Batteries Scenario

### Appendix A1 : Head loss before water transfer pump calculations

Using Bernoulli equation between point 1 and 2: [29]

$$P_1 + \rho gh_1 + \frac{\rho v_1^2}{2g} = P_2 + \rho gh_2 + \frac{\rho v_2^2}{2g} + P_{loss} \dots \dots \dots (5.8)$$

$$P_{loss} = f \frac{L V^2}{D 2g} \gamma \rho \dots \dots \dots (5.9)$$

$$f = \frac{64}{Re} \dots \dots \dots (5.10)$$

$$Re = \frac{\rho V D}{\mu} \dots \dots \dots (5.11)$$

$$V = \frac{Qf}{A} \dots \dots \dots (5.12)$$

$$A(\text{pipe}) = \frac{d^2 \pi}{4} = \frac{0.1016^2 \pi}{4} = 0.0081(m^2) \dots \dots \dots (5.13)$$

by applying equations from (5.8) to (5.13):

$$V = \frac{35(m^3 / hr)}{0.0081m^2} * \frac{1hr}{3600s} = 1.1 \frac{m}{s}$$

$$Re = \frac{997 \left( \frac{kg}{m^3} \right) * 1.1 \left( \frac{m}{s} \right) * 0.1016m}{0.89 * 10^{-3} \left( \frac{pa}{s} \right)} = 124850$$

$$f = \frac{64}{\text{Re}} = \frac{64}{124850} = 0.00051$$

$$P_{\text{loss}} = f \frac{L V^2}{D 2g} \gamma \rho = 0.00051 * \frac{20m}{0.1016m} * \frac{1.1^2 m/s}{2 * 9.81 \left(\frac{m}{s^2}\right)} * 1 * 997 \left(\frac{kg}{m^3}\right) = 6.17 \text{ pa}$$

$$P_1 + \rho g h_1 + \frac{\rho v_1^2}{2g} = P_2 + \rho g h_2 + \frac{\rho v_2^2}{2g} + P_{\text{loss}}$$

$$0 + (997 \left(\frac{kg}{m^3}\right) * 9.81 \left(\frac{m}{s^2}\right) * 20m) + 0 = P_2 + 0 + \frac{997 \left(\frac{kg}{m^3}\right) * 1.2^2 m/s}{2} + 6.17$$

$$P_2 = 195 \text{ kpa} = 1.95 \text{ bar}$$

### Power needed for water transfer pump:

$$P_{w1}(\text{watt}) = \frac{\rho * g * Qf * \text{head}}{\eta}$$

$$= \frac{997 \left(\frac{kg}{m^3}\right) * 9.81 \left(\frac{m}{s^2}\right) * 32 \left(\frac{m^3}{hr}\right) * \left(\frac{1hr}{3600s}\right) * 20m}{0.42} = 4140 \text{ watt}$$

## Appendix A2 : High pressure pumping unit calculations

Applying the equations from (5.8) to (5.13):

Using Bernoulli equation between point 3 and 4:[29]

$$P_4 + \rho gh_4 + \frac{\rho v_4^2}{2g} + P_{loss} = P_3 + \rho gh_3 + \frac{\rho v_3^2}{2g}$$

$$P_{loss} = f \frac{L}{D} \frac{V^2}{2g} \gamma \rho$$

$$f = \frac{64}{\text{Re}}$$

$$\text{Re} = \frac{\rho V D}{\mu}$$

$$V = \frac{Q_P}{A}$$

$$(a) A(\text{pipe}) = \frac{d^2 \pi}{4} = \frac{0.1016^2 \pi}{4} = 0.0081(\text{m}^2)$$

$$(b) V = \frac{22.5(\text{m}^3 / \text{hr})}{0.0081\text{m}^2} * \frac{1\text{hr}}{3600\text{s}} = 0.77 \frac{\text{m}}{\text{s}}$$

$$(c) \text{Re} = \frac{997 \left( \frac{\text{kg}}{\text{m}^3} \right) * 0.77 \left( \frac{\text{m}}{\text{s}} \right) * 0.1016\text{m}}{0.89 * 10^{-3} \left( \frac{\text{pa}}{\text{s}} \right)} = 87637$$



$$(d) f = \frac{64}{\text{Re}} = \frac{64}{87637} = 0.00073$$

$$(e) p_{\text{loss}} = f \frac{L V^2}{D 2g} \gamma \rho = 0.00073 * \frac{20m}{0.1016m} * \frac{0.77^2 m/s}{2 * 9.81 \left(\frac{m}{s^2}\right)} * 1 * 997 \left(\frac{kg}{m^3}\right) = 4.33 pa$$

$$(f) P_4 + \rho g h_4 + \frac{\rho v_4^2}{2g} + P_{\text{loss}} = P_3 + \rho g h_3 + \frac{\rho v_3^2}{2g}$$

$$0 + (997 \left(\frac{kg}{m^3}\right) * 9.81 \left(\frac{m}{s^2}\right) * 30m) + 0 + 4.33 = P_3 + 0 + \frac{997 \left(\frac{kg}{m^3}\right) * 0.77^2 m/s}{2}$$

$$P_3 = 293125 pa = 2.93 bar \cong 3 bar$$

Operating pressure > (90000pa \* 18 element) + 293117pa + 4.33pa =  
1913130 pa

> 19.1 bar  $\approx$  20 bar  $\approx$  200m (head) (10m  $\approx$  1 bar)

For RO pump:

$$Pw2(\text{watt}) = \frac{1000 \left(\frac{kg}{m^3}\right) * 9.81 \left(\frac{m}{s^2}\right) * 32 \left(\frac{m^3}{hr}\right) * \left(\frac{hr}{3600s}\right) * 200m}{0.42} = 41399 \text{ watt}$$

### Appendix A3 : The cost of cubic meter water using Water Distribution Tank Scenario

Configuration 1: PV panels , D.G , Battery and converter

Applying the equations from (4.1) to (4.7) to calculate the cost of cubic meter:

To calculate total capital cost(TCC) using formula (4.1) :

$$TCC (\$) = DCC (\$) + ICC(\$)$$

The DCC includes equipments , membranes and Concentrated brine disposal.

From table (4.1) , DCC =US\$ 38700 \$

The ICC includes constructions and owners cost , it is equal to 27 % of direct capital cost, using formula (4.2) :

$$ICC(\$) = 0.27 * DCC = 0.27*38700 = US\$ 10449$$

So , TCC = 38700 + 10449 = US\$ 49149

- To calculate the annual operating and maintenance cost (OCO&M) using formula (4.3) :

$$C_{O\&M} (\$) = 0.05 * TCC = 0.05 * 49149 = US\$ 2457.45$$

- The operating cost is calculated in (\$/year) using formula (4.4) :

$$OC = OC_{power} + OC_{O\&M} + OC_{Mbne}$$

- $OC_{power}$  = how much the energy cost for each kilowatt (\$/kW) (using HOMER program results) =

$$0.91 \left( \frac{kw}{m^3} \right) * 270 \left( \frac{m^3}{day} \right) * \frac{365day}{year} * 0.348 \left( \frac{\$}{kw} \right) = 31208.81 \left( \frac{US\$}{year} \right)$$

- To calculate the operating cost of the membrane using formula (4.5) :

$$\bullet \text{OC}_{\text{Mbne}} = \frac{\text{Price (\$/member)} * (\text{nb})}{n_{\text{LT Mbne}}} = \frac{700(\$/\text{membrane}) * 18}{5 \text{ years}} = 2520 \left( \frac{\text{US\$}}{\text{year}} \right)$$

So ,OC = OC<sub>power</sub>+ OC<sub>O&M</sub>+ OC<sub>Mbne</sub>

$$= 31208.81 + 2457.45 + 2520 = 36186.26 \text{ (US\$/year)}$$

The ACC in (\$/year) is calculated using formula (4.6) :

$$\text{ACC} = (\text{TCC}) * \frac{i * (1+i)^{n(\text{plant})}}{(1+i)^{n(\text{plant})} - 1} = 49149 * \left( \frac{0.05 * (1.05)^{20}}{(1.05)^{20} - 1} \right) = 3943.84 \left( \frac{\text{US\$}}{\text{year}} \right)$$

The total potable water price (TWP) in \$/m<sup>3</sup> is calculated using formula

(4.7) :

$$\text{TWP} = \frac{\text{ACC} + \text{OC}}{M_{\text{plant}} * 365 * L_{\text{plant}}} = \frac{3943.84 * 36186.26}{270 \text{ m}^3 * 365 * 0.85} = 0.479 \left( \frac{\text{US\$}}{\text{m}^3} \right)$$

## Appendix A4 : The cost of cubic meter water using Batteries Scenario

Configuration 1: PV panels, D.G, Battery and converter

Applying the equations from (4.1) to (4.7) to calculate the cost of cubic meter :

To calculate total capital cost(TCC) using formula (4.1) :

$$TCC (\$) = DCC (\$) + ICC(\$)$$

The DCC includes equipments , membranes and Concentrated brine disposal.

From table (4.1) , DCC =US\$ 38700 \$

The ICC includes constructions and owners cost , it is equal to 27 % of direct capital cost, using formula (4.2) :

$$ICC(\$) = 0.27 * DCC = 0.27*38700 = US\$ 10449$$

$$\text{So , } TCC = 38700 + 10449 = US\$ 49149$$

To calculate the annual operating and maintenance cost (OC<sub>O&M</sub>) using formula (4.3) :

$$C_{O\&M} (\$) = 0.05 * TCC = 0.05 * 49149 = US\$ 2457.45$$

The operating cost is calculated in (\$/year) using formula (4.4) :

$$OC = OC_{\text{power}} + OC_{O\&M} + OC_{\text{Mbne}}$$

OC<sub>power</sub> = how much the energy cost for each kilowatt (\$/kW) (using

HOMER program results) =

$$0.91 \left( \frac{kw}{m^3} \right) * 270 \left( \frac{m^3}{day} \right) * \frac{365day}{year} * 0.462 \left( \frac{\$}{kw} \right) = 41432.4 \left( \frac{US\$}{year} \right)$$

To calculate the operating cost of the membrane using formula (4.5) :

$$\bullet \text{OC}_{\text{Mbne}} = \frac{\text{Price (\$/member)} * (\text{nb})}{n_{\text{LT Mbne}}} = \frac{700(\$/\text{membrane}) * 18}{5 \text{ years}} = 2520 \left( \frac{\text{US\$}}{\text{year}} \right)$$

$$\text{So ,OC} = \text{OC}_{\text{power}} + \text{OC}_{\text{O\&M}} + \text{OC}_{\text{Mbne}}$$

$$= 41432.4 + 2457.45 + 2520 = 46409.84 \text{ (US\$/year)}$$

The ACC in (\$/year) is calculated using formula (4.6) :

$$\text{ACC} = (\text{TCC}) * \frac{i * (1+i)^{n(\text{plant})}}{(1+i)^{n(\text{plant})} - 1} = 49149 * \left( \frac{0.05 * (1.05)^{20}}{(1.05)^{20} - 1} \right) = 3943.84 \left( \frac{\text{US\$}}{\text{year}} \right)$$

The total potable water price (TWP) in \$/m<sup>3</sup> is calculated using formula

(4.7) :

$$\text{TWP} = \frac{\text{ACC} + \text{OC}}{M_{\text{plant}} * 365 * L_{\text{plant}}} = \frac{3943.84 * 46409.84}{270 \text{m}^3 * 365 * 0.85} = 0.601 \left( \frac{\text{US\$}}{\text{m}^3} \right)$$

جامعة النجاح الوطنية  
كلية الدراسات العليا

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قدمت هذه الأطروحة استكمالاً لمتطلبات الحصول على درجة الماجستير في هندسة المياه  
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2017 م

ب

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### الملخص

تعد منطقة وادي الأردن منطقة مناسبة و مثالية لاستخدام أفضل مصدر للطاقة المتجددة وهي الطاقة الشمسية بسبب كثافة الإشعاع الشمسي العالية والعدد المرتفع لساعات أشعة الشمس السنوية، حيث يعتبر مناخ هذا الموقع شبه استوائي، حار وجاف في الصيف ودافئ خلال فصل الشتاء ، حيث يتراوح متوسط درجات الحرارة الشهرية ما بين 16 درجة مئوية في فصل الشتاء إلى 35 درجة مئوية في الصيف. تهدف هذه الرسالة إلى تصميم محطة تحلية المياه باستخدام أفضل مصدر للطاقة وأقل تأثيرا على البيئة، حيث تم اخذ قرية الزبيدات كحالة خاصة، ووفقا لمنظمة الصحة العالمية وجد أن مياه بئر الزبيدات غير صالحة للشرب لان كمية المواد الصلبة الذائبة فيها بلغت حوالي 2100 جزء من المليون في حين أن المسموح به هو اقل أو يساوي 1500 جزء من المليون .

تناولت هذه الأطروحة في البداية عدد السكان في قرية الزبيدات في محافظة أريحا، وذلك من أجل تصميم المحطة بناء على احتياجات السكان لمياه الشرب في تلك المنطقة، حيث بلغ عدد سكان القرية بعد إجراء الحسابات في العام 2016 إلى 1798 نسمة ووفقا لمنظمة الصحة العالمية فإن معدل استهلاك الفرد اليومي للمياه هو 150 (لتر/فرد.يوميا )، أي أننا بحاجة إلى 270 م<sup>3</sup> يوميا.

تم تصميم محطة تحلية المياه باستخدام تقنية الأسمزوية العكسية وباستخدام تكنولوجيا الأغشية وكانت قدرة البئر الذي تم التصميم بناء عليه هي 120 (م<sup>3</sup>/ساعة).

حيث ركز هذا البحث على دراسة وتحليل مصادر الطاقة المستدامة والممكنة لتشغيل المحطة، وخلال التصميم حاولنا التقليل من استخدام مولد الديزل كمصدر لإنتاج الكهرباء لما له من اثر سلبي على البيئة نتيجة الأدخنة الصاعدة منه نتيجة الاحتراق وبالإضافة إلى غلاء سعر التشغيل للمولد، وكما تم استبعاد استخدام الطاقة الكهربائية المزودة مباشرة من الجانب الإسرائيلي وذلك من أجل محاولة الاعتماد كلياً على المحطة بالإضافة إلى أن كمية الطاقة الكهربائية المزودة لنا محدودة.

وتناول البحث إمكانية استخدام مصادر الطاقة المتجددة لتشغيل محطة التحلية وتشمل الطاقة الشمسية وطاقة الرياح، حيث أن متوسط الإشعاع الشمسي في قرية الزبيدات كبير ويقدر بحوالي 5.4 كيلو واط لكل متر مربع، أما بالنسبة إلى طاقة الرياح فقد تم استبعادها وذلك لان سرعة الرياح الموجودة غير كافية لتشغيل التوربينات وإنتاج الطاقة الكهربائية .

كما تم عمل مقارنة بين 5 أنظمة وهي خلايا شمسية مع بطاريات، مولد ديزل مع بطاريات، خلايا شمسية ومولد ديزل بدون بطاريات، خلايا شمسية ومولد ديزل مع بطاريات ومولد ديزل بدون بطاريات وذلك من أجل اختيار أفضل مصدر للطاقة لتزويد المشروع بالكهرباء باستخدام برنامج خاص (هومر) وذلك لوجود العديد من الخيارات وصعوبة اختيار أفضل مصدر للطاقة يدويا وتحتاج وقتاً طويلاً وبعضها مستحيلاً.

حيث بينت نتائج التحليل من الناحية الاقتصادية بعد المقارنة ما بين 5 أنظمة أن أفضل مصدر للطاقة اللازمة لتغطية احتياجات المشروع بالكهرباء باستخدام البطاريات كمصدر لتخزين الطاقة هو مكون من خلايا شمسية، مولد ديزل، بطاريات ومحول كهربائي، حيث بلغ سعر الطاقة 0.462 (دولار / كيلو واط .ساعة ) في حين بلغ سعر المتر المكعب من المياه باستخدام هذا المصدر هو 0.601 دولار / م<sup>3</sup> بينما



ث

كان استخدام خزان توزيع المياه كمصدر للتخزين وتوفير الطاقة كمحاولة للتقليل من أو استبعاد استعمال البطاريات مكون من خلايا شمسية، مولد ديزل، بطاريات و محول كهربائي ، حيث قل سعر الطاقة إلى 0.348 (دولار / كيلو واط .ساعة ) في حين قل سعر المتر المكعب من المياه باستخدام هذا المصدر إلى 0.479 دولار / م<sup>3</sup>.