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Solar Energy to Optimize the Cost of RO Desalination Plant

Case Study: Deir El-Balah SWRO Plant

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"بسم الله الرَّحْمَنِ الرَّحِيمِ"

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سورة الأنعام (162)

إقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

استخدام الطاقة الشمســـــية لتحسين التكلفـــة في محطات التناضح العكسي للتحليـــة
Solar Energy to Optimize the Cost of SWRO Desalination Plant

اقر بأن ما اشتملت عليه هذه الرسالة إنما هي نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وإن هذه الرسالة ككل، أو أي جزء منها لم يقدم من قبل لنيل درجة أو لقب علمي أو بحثي لدى أية مؤسسة تعليمية أو بحثية أخرى.

DECLARATION

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DEDICATION

… To …

My Beloved Parents, My Wife and My Twin Brother

Hussam

ABSTRACT

Seawater desalination by reverse osmosis (SWRO) is currently considered as one of the most widely used and reliable technology in providing additional water supply for areas suffering from water scarcity. High energy consumption of the Reverse Osmosis plants is one of the biggest challenges, particularly in developing countries such as Palestine. The future demand for fresh water and thus, energy, triggers researchers to find methods to integrate the use of renewable energy for the desalination process.

Palestine has a high solar energy potential, where average solar energy varies between 2.63 kWh/m^2 per day in December to 8.5 kWh/m^2 per day in June, and the daily average of solar radiation intensity on horizontal surface is 5.31 kWh/m^2 per day while the total annual sunshine hours amounts to about 3000 [28].

In this research, the possibilities of using solar energy to optimize the cost of desalination process in Gaza have been studied.

The research focused on the optimal use of solar energy and selection of the most economically feasible configuration of utilizing this source either fully or partially in the SWRO process. Internal Rate of Return (IRR) was used as an economic indicator to analyze the feasibility of establishing a SWRO desalination plant with a capacity of 600 m^3/d in Deir El-Balah based on the optimal energy sources. The available options of energy sources for the proposed desalination plant were as follows:

1- Electricity Energy System (EES)
2- Solar Energy System (Off Grid System)
3- Combined Energy System (On Grid System)

The results for the economic study found that the IRR was 6.6%, 3.80%, and 7.64% for the first, second, and third options respectively. The higher the IRR, the more attractive is the option for the investment. For any project to be feasible or attractive, the IRR should be more than the market interest rate by a comfortable margin. During the analysis period for this study, the average market interest rate in Palestine was 6.43%, hence the third option was found to be the most feasible.

Based on the results, the On Grid Solar System has the ability to balance the system production and Plant power requirements, which is about 105 kwh. The energy cost for the On-Grid System was calculated as 0.13 $/KWh comported to 0.17$/kwh and 0.27$/KWh for the first and second systems respectively.

Considering the On-Grid system, the unit cost for desalinated water was reduced from 1.08 $/m^3 to 0.89 $/m^3 which is about 17% saving.

Keywords: Optimization, Desalination, Solar Energy, IRR and Gaza.

ملخص الدراسة

تعتبر تحلية مياه البحر عن طريق التناضح العكسي (SWRO) واحدة من أكثر التقنيات المستخدمة على نطاق واسع ، حيث يمكن الاعتماد عليها في توفير إمدادات المياه للمناطق التي تعاني من ندرة المياه وشحّها. وإن الارتفاع الواضح في استهلاكات الطاقة من محطات التناضح العكسي هي واحدة من أكبر التحديات الحالية، ولاسيما في البلدان النامية مثل فلسطين ، علما أن الطلب المستقبلي على المياه وما يليه من حاجة للطاقة سيدفع الباحثون لإيجاد طرق دمج مثالية في استخدام الطاقة المتجددة لعملية تحلية المياه.

نجد أن الطاقة الشمسية في فلسطين هي أكثر الطاقات المتجددة وفرة للاستغلال ، حيث تتباين حدّتها ما بين 2.63 كيلو وات ساعة على المتر المربع يوميا في ديسمبر إلى 8.5 كيلو وات ساعة على المتر المربع يوميا في يونيو ، وبمعدل يومي لشدة الإشعاع الشمسي على السطح الأفقي تصل إلى 5.31 كيلو وات في الساعة على المتر المربع لكل يوم ، في حين أن مجموع ساعات سطوع الشمس السنوي يصل إلى حوالي 3000 ساعة.

وبناءا على ما سبق قوله فقد تم البحث خلال هذه الدراسة عن إمكانية استخدام الطاقة الشمسية لتحسين تكلفة محطة لتحلية المياه في قطاع غزة.

ترتكزت الدراسة على الاستخدام الأمثل للطاقة الشمسية واختيار النظام الأجدى اقتصاديا للاستفادة منه كمصدر كلي أو جزئي للطاقة في محطات تحلية مياه البحر القائمة على التناضح العكسي. وبذلك، فقد تم استخدام طريقة (معدل العائد الداخلي) IRR كمؤشر اقتصادي لمقارنة جدوى انشاء محطة تحلية لمياه البحر تقوم على تقنية التناضح العكسي بقدرة إنتاجية تصل إلى 600 كوب يوميا في قطاع غزة اعتمادا على أفضل مصادر الطاقة المتوفرة وهي كالتالي:

١ - نظام الطاقة الكهربية
٢ - نظام الطاقة الشمسية (منفصل عن شبكة الكهرباء)
٣ - النظام المدمج (متصل بشبكة الكهرباء)

نتائج الدراسة الاقتصادية أشارت إلى أن قيمة IRR كانت 6.6٪، 3.80٪، 7.64٪ للخيارات السابقة على التوالي. حيث أن القيمة الأعلى لمعدل العائد الداخلي ستكون أكثر الخيارات الاقتصادية فرصة للاستثمار. فحتى يكون المشروع مجديا وممكنا، ينبغي أن تكون قيمة IRR أعلى من معدل الفائدة المحلية (r) في السوق بهامش بسيط ومريح. وخلال فترة التحليل لهذه الدراسة كان متوسط معدل الفائدة في سوق فلسطين 6.43٪، وبالتالي تم اعتماد الخيار الثالث ليكون الأكثر جدوى بين الخيارات الثلاث.

بناءا على النتائج الاقتصادية فإن النظام ا لمدمج (متصل بشبكة الكهرباء) لديه القدرة على تحقيق التوازن في نظام الإنتاج ومتطلبات استهلاك الطاقة لتشغيل المحطة والتي تصل إلى 105 كيلو وات في الساعة. وقد تم حساب تكلفة الطاقة لهذا النظام فكانت 0.13 دولار أمريكي / كيلو وات في الساعة مقارنة بباقي الأنظمة 0.17 دولار أمريكي / كيلووات في الساعة، 0.27 دولار أمريكي / كيلووات في الساعة للنظام الأول والثاني على التوالي.

النظام المدمج ، سيخفض تكلفة إنتاج وحدة كوب المياه المحلاّة من 1.08 دولار أمريكي إلى 0.89 دولار أمريكي وهو ما يعادل قيمة موفره تصل إلى 17٪ من التكلفة الأساسية بنظام التشغيل التقليدي (الكهرباء).

كلمات مفتاحيه: التحسين، التحلية، الطاقة الشمسية، معدل العائد الداخلي وقطاع غزة.

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Eng. Hussam A. Al-Borsh
June, 2013

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GLOSSARY

Aquifer	a subsurface feature comprised of permeable soil and rock that contains water.
Brine waters	is a concentrated salt solution with more than 35,000 mg/l TDS according to WHO standards.
Capital Cost	capital cost includes the indirect costs associated with the owner's costs of studies, engineering, licenses, interest on working capital, insurance during the construction period as well as the direct capital costs.
Concentrate	generally liquid substances that may contain up to 20% of the water that is treated, and in desalination process it defines as the byproduct, this byproduct contains the contaminants removed from impaired waters during desalination and water purification processes.
Drinking water	contains between 400 and 800 mg/l TDS.
Fouling	the reduction in performance of process equipment that occurs as a result of scale buildup, biological growth, or the deposition of materials.
Ground water	water normally found underground and obtained from wells. Not to be confused with surface water such as rivers, ponds, lakes, or waters above the water table.
Indirect capital cost	the owner's costs associated with such items as studies, planning, engineering, construction supervision, licensing, startup, public relations, and training. These costs are a part of the cost of placing the plant in operation and are in addition to the direct capital costs associated with equipment and contracts for construction.
Membrane	a semi-permeable film. Membranes used in electro-dialysis are permeable to ions of either positive or negative charge. Reverse osmosis membranes ideally allow the passage of pure water and block the passage of salts.
Operating cost	includes labors, energy, chemicals, spare parts and miscellaneous.
Pretreatment	the processes such as chlorination, clarification, coagulation, scale inhibition, acidification, and deaeration that may be employed on the feed water to a water supply purification or desalination plant to minimize algae growth, scaling, and corrosion.
Saline water	water with dissolved solids exceeding the limits of potable water, Saline water may include seawater, brackish water, mineralized ground and surface water and irrigation return flows.
Salinity	is a term used to describe the amount of salt in a given water sample. Salinity is usually referred to in terms of total dissolved solids (TDS), and is measured in milligrams of solids per liter (mg/l). Seawater has a worldwide average of 35,000 mg/l TDS.
Salt	is a catch-all term that incorporates a variety of substances found in source waters, including: calcium, sodium, magnesium,

	carbonate, bicarbonate, sulfate, chloride, potassium, selenium, boron, manganese, fluoride, nitrate, iron, and arsenic.
Seawater	is that water found in the oceans. Seawater has a worldwide average concentration of 35,000 mg/l TDS, 3/4 of which is NaCl.
Surface water	are those waters contained in flowing sources (rivers, streams, etc.) and in still sources (oceans, seas, lakes, man-made reservoirs, etc.)
Land Use	the way in which humans use and modify the land". Usual land uses contain built up, agriculture, urban and infrastructure development

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LIST OF ABBREVIATIONS

Institutions

WHO	World Health Organization
PWA	Palestinian Water Authority
CMWU	Coastal Municipalities Water Utility
PMW	Palestine Monetary Authority
NIS	New Israel Shekel
PLA	Palestine Land Authority
PENRA	Palestine Energy & Natural Resources Authority
GPP	Gaza Power Plant
IEC	Israel Electric Corporation
MASWDP	Middle Area Seawater Desalination Plant
MENA	Middle Area and North Africa
PCBS	Palestinian Central Bureau of Statistics
SEMI	Southern European Mediterranean Islands
UAE	United Arab Emirates
UNDP	United Nation Development Program
USAID	United States Agency for International Development

Variable

EES	Electricity Energy System
SES	Solar Energy System
CES	Combined Energy System
AC	Alternating Current
DC	Direct Current

RO	Reverse Osmosis
SWRO	Sea Water Reverse Osmosis
BW	Brackish Water
BWRO	Brackish Water Reverse Osmosis
CEM	Cation Exchange Membrane
CDF	Cash Flow Diagram
CO2	Carbon Dioxide Gas
LTD	Low Temperature Distillation
MD	Membrane Distillation
MED	Multiple Effect Distillation
MF	Microfiltration
NF	Nanofiltration
PV	Photovoltic
SW	Seawater
STC	Standard Test Conditions
TDS	Total Dissolved Solids
Temp	Temperature
UF	Ultra Filtration
US	United States
UV	Ultra Violet
IRR	Interest Rate of Returned
N_{pv}	Number of PV modules
Sf	Safety factor for PV thermal losses
N_{inv}	Inverter losses
r	The interest rate (%)

n	Life of the system (year) in economical study
E	Energy for each phase (J)

Units

A	Ampere
kV	Kilovolt
kW/hr	Kilo Watt per hour
kW/hr	Kilo Watt per hour
Mcm	Million cubic meter
Mcm	Million cubic meter
MJ	Mega Joule
MW	Mega Watt
NIS	New Israelian Sheqels
NIS	New Israelian Sheqels
Ppm	Part Per Million
Ppm	Part Per Million
Psi	Pound per square inch
Psi	Pound per square inch
V	Volt
S	Micro Siemens

1 INTRODUCTION

1.1 Background

The problem of scarcity of fresh water has been faced by most countries because of increasing consumption and population growth. Gaza Strip, in particular, has a problem in terms of water quantity and quality due to depletion of ground water aquifer and intensive land use exploitation.

The demand for water in Gaza Strip is growing rapidly due to population growth that reached about 1.64 million people, 2012 [1] living in an area of about 365 km^2.

In Gaza Strip, the main source of fresh water comes from the coastal aquifer (shallow aquifer). Where Gaza Strip lies on the seashore with Coastal length of approximately 42 km it forms a long narrow rectangle as illustrated in figure (1.1), so most of the water pumped from water wells has high salinity due to seawater intrusion and does not meet the World Health Organization (WHO) drinking water standards. Therefore, the Palestinian Water Authority (PWA) believes that desalination is a strategic option for Gaza Strip [2].

From an environmental point of view, desalination has less negative impact compared to other solutions. In desalination by RO, the energy used in the system is the most dominating factor. Therefore, economic view for Gaza taken the energy cost of desalination using RO is optimum [3].

Under the current energy crisis in Gaza Strip, it is recommended to utilize the renewable energy sources for desalination purposes. More studies show that solar energy is more feasible among all types of renewable energy for the region climate (Middle East) [4].

By the optimization process, there are many factors that play a rule when a reverse osmosis system is powered by Electricity / solar / combined. The most important challenges of the study are the usage of solar energy with seawater desalination plants that need a high-energy.

At present, Gaza Strip has one seawater desalination plant in Deir El-Balah City that is illustrated in figure (1-1). The plant consists of two-pass RO systems as shown in figure (1-2) with design capacity of 600 m^3/day [5]. The source of seawater comes from two existing beach wells close to the shore and the brine is discharged to the sea.

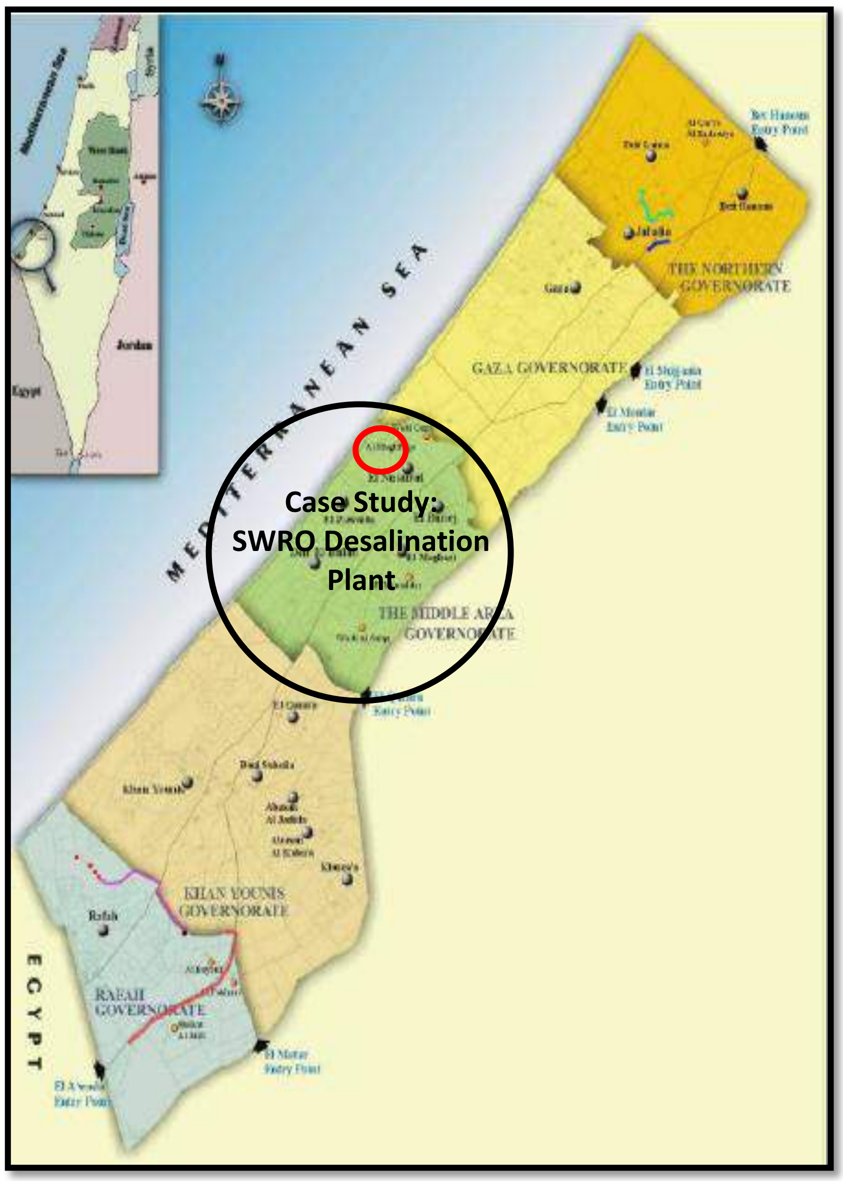


Figure (1-1): Location of SWRO desalination plant

Figure (1-2) Deir El-Balah Plant

1.2 Statement of the Problem

Energy cost in desalination plants comprises about 30% to 50% of the total cost [6] of the produced water based on the type of energy used. Therefore, the total cost of desalination can be reduced significantly by reducing the energy consumption; figure (1-3) has an approximate vision about the cost details for any RO plant [6].

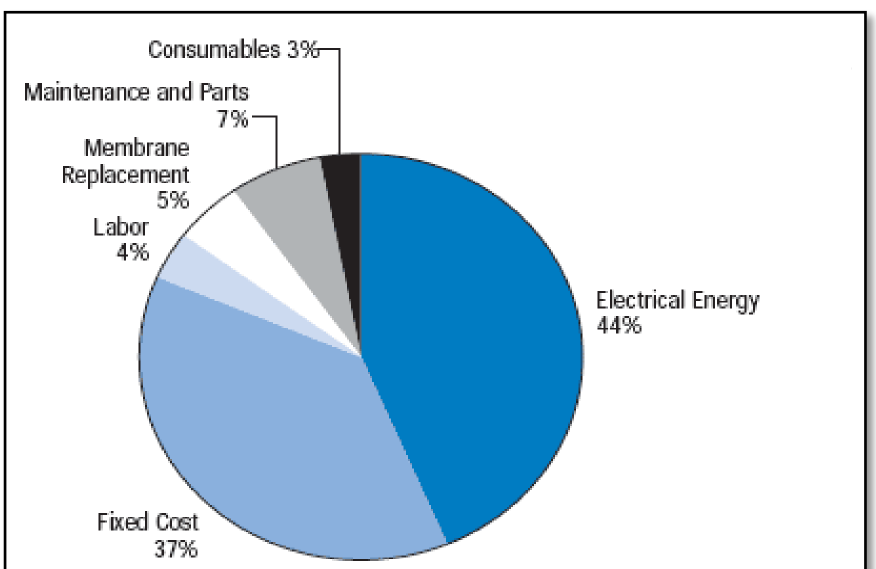


Figure (1-.3) Cost of RO desalination Plant

Reducing the energy consumption by turning partially to renewable energy sources is a challenging problem.

1.3 Justification of the Study

The Gaza strip's energy resources are controlled by Israel, which employs policies to restrict the electrical production capacity of the Palestinian territories.

Relying on Israel for desalination energy is not a secure alternative for water desalination plants in Gaza Strip, especially with the high demand and water shortage in Gaza Strip. Figure (1-4) urges to look for independent sources of energy that are cost competitive. A good alternative can be to investigate the optimal use of renewable energy.

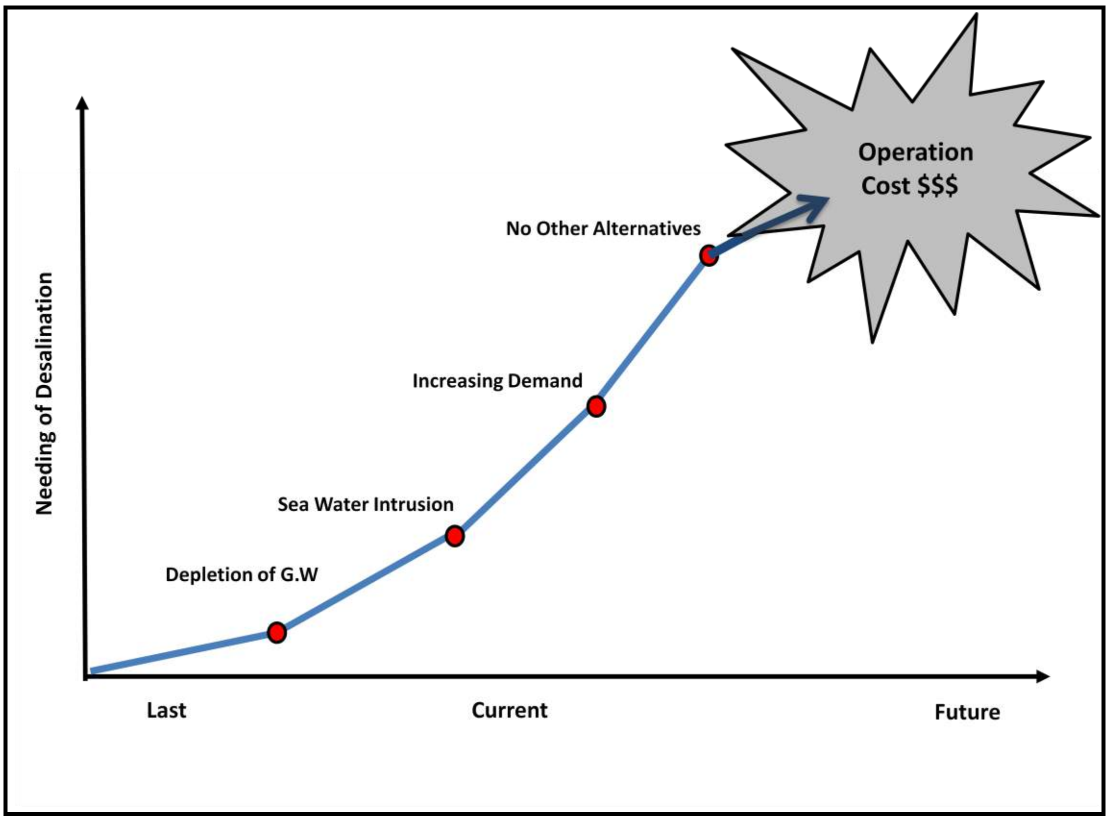


Figure (1-4) Presentation of Increasing Problem

1.4 Aim and Objectives

The aim of this research is to optimize the cost of desalination using the solar energy as a complementary source of energy.

Studying the best configuration to introduce the following specific objectives was pursued in order to achieve the aim above:

- System modeling of energy consumption processes in Deir El-Balah desalination plant.
- Economic feasibility analysis of energy alternatives
- Sizing optimal solar system for optimal energy cost.

1.5 Research Methodology

The complete methodology of the research towards the optimization process for the cost of desalination in Gaza Strip is illustrated in Figure (1-5).

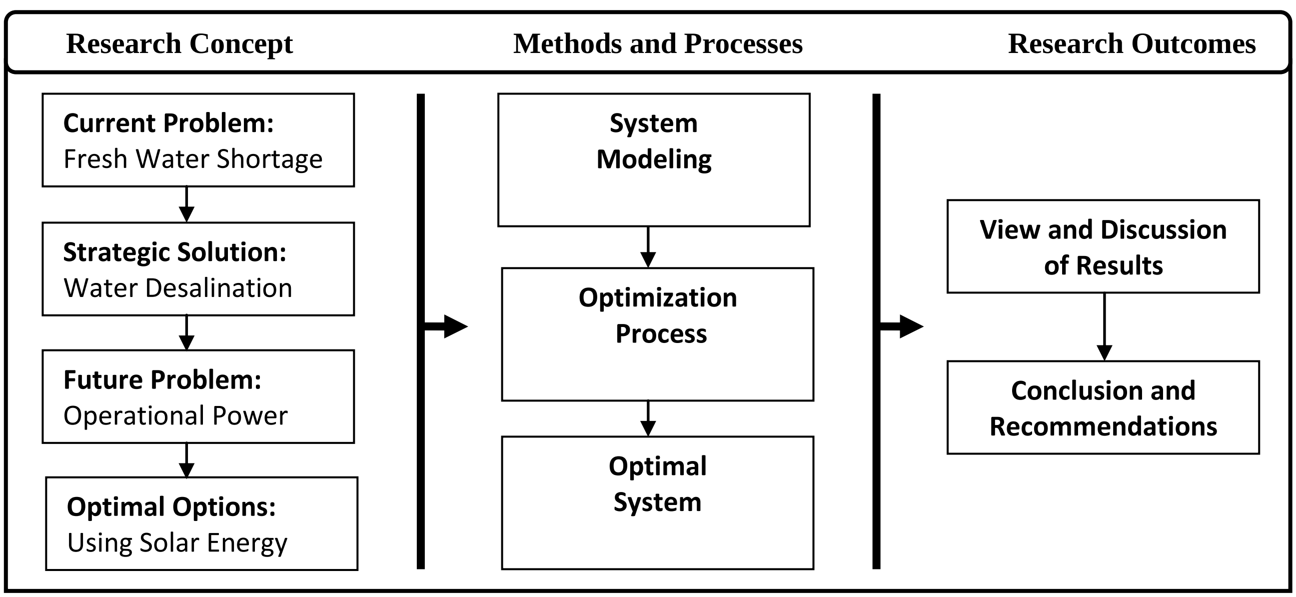


Figure (1-5) Research Methodology

Methodology consists of three main stages. The first stage is the research concept, where several topics were analyzed considering the current water situation and shortage as well as the future energy crises to run and operate the water desalination plants in order to reach an optimal option to face energy and costs problems by solar energy PV systems.

In the second stage, It consists of three main steps. There can be selection of optimal system, which depends on two processes, modeling and optimization respectively for power sources of SWRO Desalination Plant.

Figure (1-6) presents the three main cases of modeling of energy, which depends on the different energy sources powered by Electricity Energy System (EES), Solar Energy System (SES), and Combined Energy System (CES).

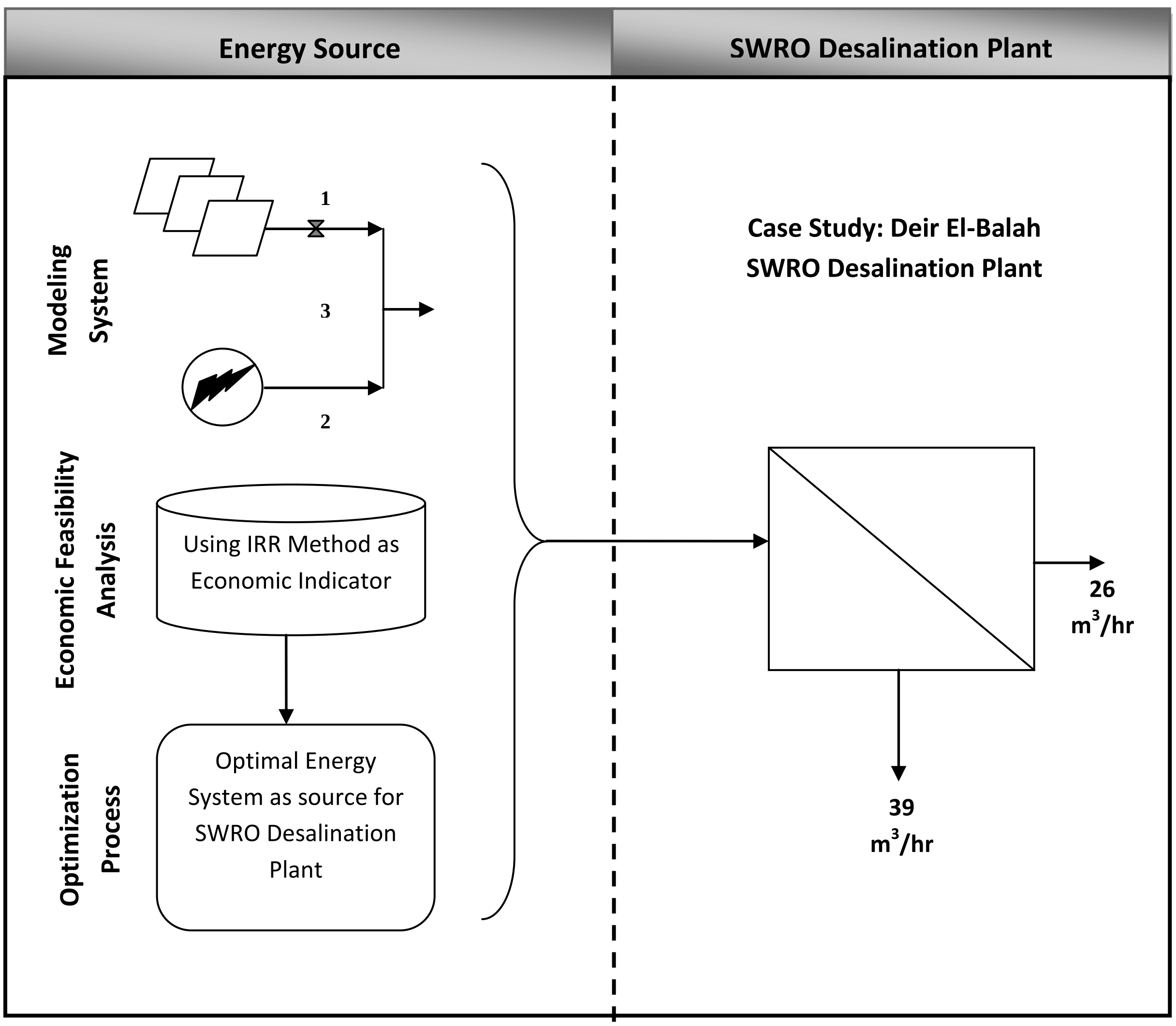


Figure (1-6): Methods and Processes

View and discussion of results are illustrated in the final stage while obtaining results and performing analysis of these results are completed in stage two.

1.6 Research Structure

This research consists of seven chapters, as follows:

Chapter One: Introduction

Chapter Two: Literature Review

Chapter Three: Background and Case Study

Chapter Four: Economic Feasibility Model

Chapter Five: Optimal Energy System

Chapter Six: Discussion and Analysis

Chapter Seven: Conclusions and Recommendations

2 LITERATURE REVIEW

2.1 General Definition

2.1.1 Reverse Osmosis (RO)

- **Description:**

  Reverse osmosis is the most widespread type of membrane based on desalination process. It is a process used to separate water from colloidal and dissolved matter using pressure-driven transport through a membrane. In this process, the osmotic pressure is used by applying external pressure higher than the osmotic pressure on the seawater. Thus, water flows in the reverse direction to the natural flow across the membrane, leaving the dissolved salts to retain by the membrane with an increase in salt concentration. No heating or phase separation change is necessary [7].

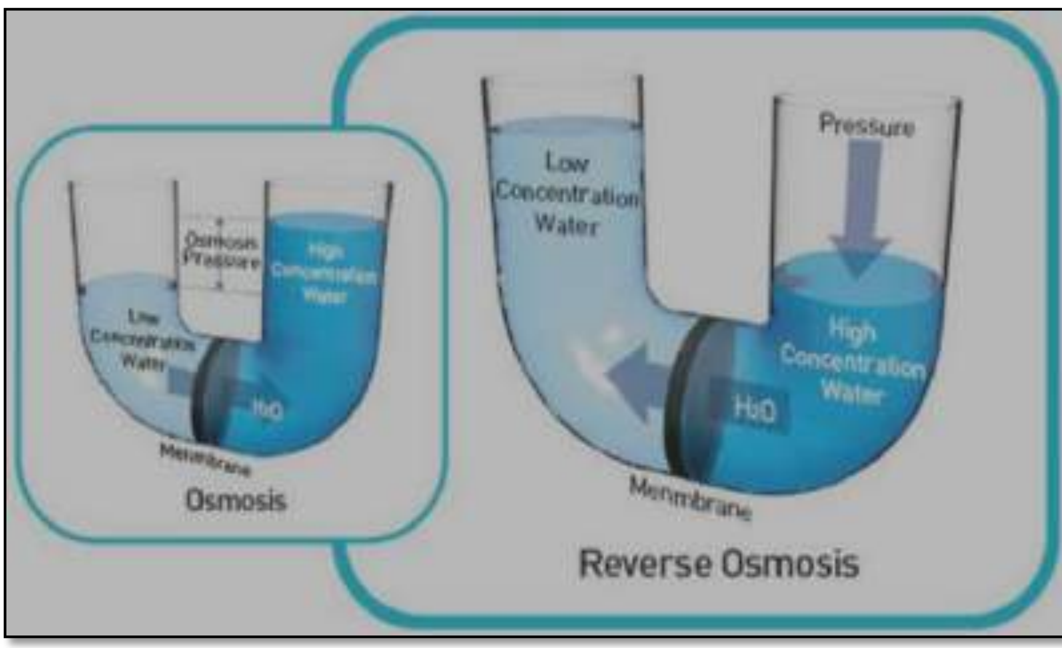


Figure (2-1) Principle of RO membrane filter

- **Major Components of RO System**

Following processes are followed in reverse osmosis system:

a) Pretreatment

The feed water before introduction to membrane is pretreated for adjusting the pH, removing suspended solids, and to control scaling which is the caused by constituents such as calcium sulphate.

b) Pressurization

The pressure of the pretreated feed water is raised by the pump to make it suitable for the membrane and the salinity of the feedwater.

c) Separation

The dissolved salt is obstructed by the permeable membranes whereas desalinated water is allowed to pass through. Thus the membrane separates the product feed water into freshwater product stream and a concentrated brine reject stream. However, small amount of salt passes through the membrane and remains in the product water no membrane is as perfect as to filtrate all the salts present in the water. The popular membrane that are used for reverse osmosis process (RO) are spiral wound and hollow fine fiber membranes. These membranes are mainly used for brackish water and seawater desalination.

d) Stabilization

The pH adjustment and degasification of the product water is necessary before it is made fit for consumption. The pH value of the water is raised from the level of 5 to 7 by passing the water through an aeration column [8].

Table (2.1): The advantages and disadvantages of RO filtration system [10]:

Advantages	**Disadvantages**
The system is simple which is easy to operate and install, cost of installation is low.	The membranes have sensitivity to misuse, It requires purification pretreatment,

It requires lower energy than distillation Its problems with corrosion lower than distillation. The water recovery rates higher than distillation. RO technologies can remove organic and inorganic contaminants such as bacteria and pesticides.	operation of RO plant requires materials and equipment with high quality standards, Brine must be disposed carefully to avoid negative environmental impacts. There is possibility of existence of bacterial growth on the membranes, so it can occur odor and taste to the water. RO plants require a reliable energy source.

The following figure show comparison between membrane types for removal efficiency [10]:

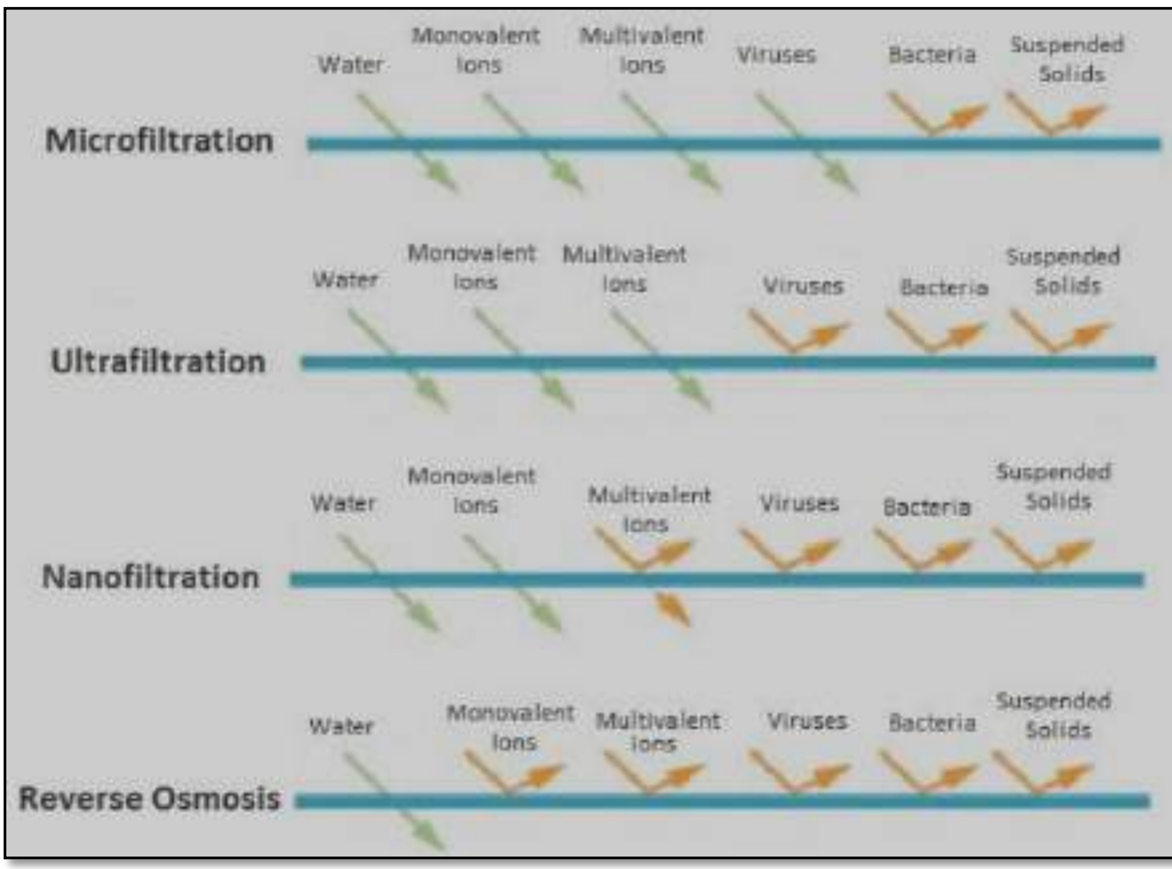


Figure (2-2): MF, UF, NF and RO membrane process characteristics

2.1.2 Photovoltaic (PV) System

PV cells are the direct conversion of sunlight into electricity, highly reliable and is often chosen because it offers the lowest life-cycle cost, where grid electricity is not available and where internal-combustion engines are expensive to maintain. PV is a rapidly developing technology with costs falling year on year, and this will soon lead to its broad application in systems requiring larger powers [9].

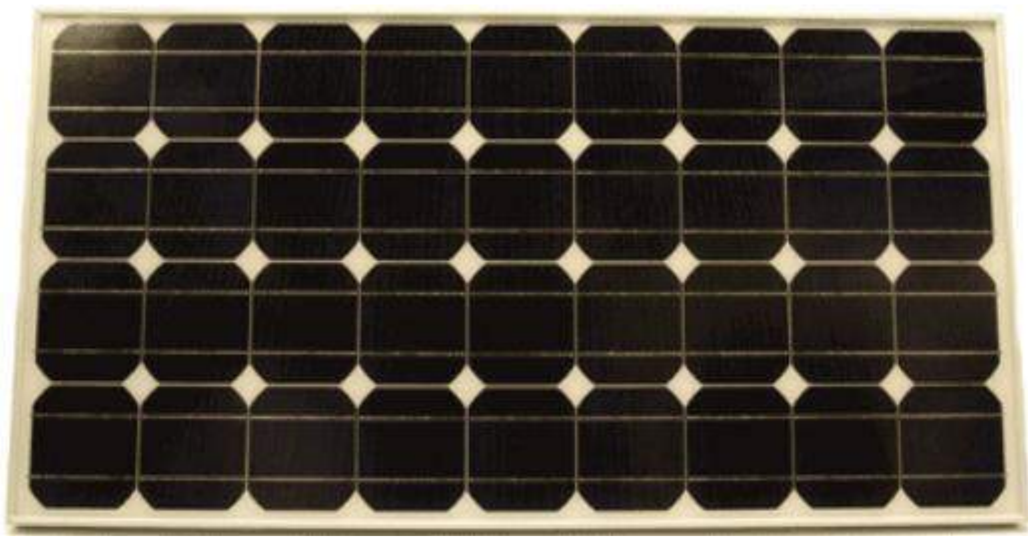


Figure (2-3): Photovoltaic cell

- **Structure of a Solar Cell**

The PV cells are made from semiconductor material mainly from silicon, for practical operation, solar cells are usually assembled into modules which have long lifetime by the range of 20 years or more [9].

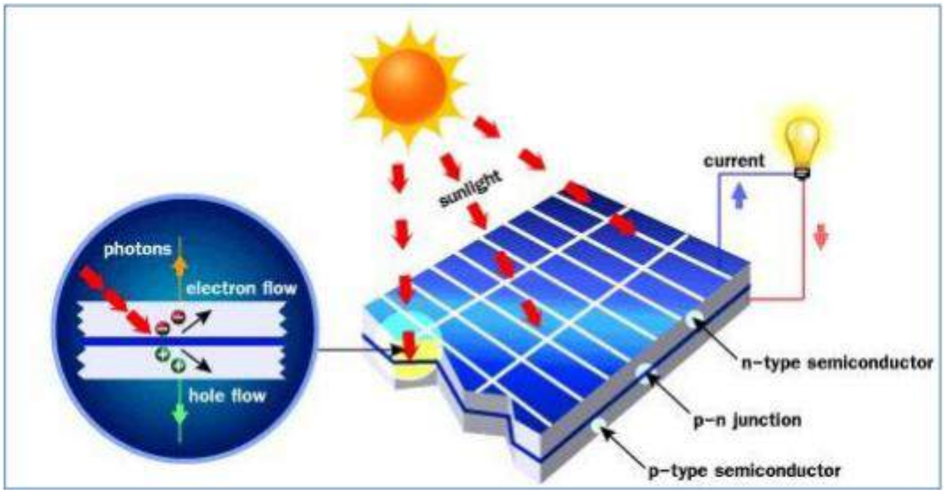


Figure (2-4): Schematic diagram shows PV system components

A typical multi-layered solar cell is consisted of the following layers[10]:

- Cover glass: this is a clear glass layer that provides outer protection from the elements.
- Transparent adhesive: this holds the glass to the rest of the solar cell.
- Anti-reflective coating: this substance is designed to prevent the light that strikes the cell from bouncing off so that the maximum energy is absorbed into the cell.
- Front contact: transmits the electric current.
- N-type semiconductor layer: this is a thin layer of silicon which has been doped with phosphorous.
- P-type semiconductor layer: this is a thin layer of silicon which has been doped with boron.
- Back contact: transmits the electric current.
- The module: a number of solar cells electrically connected to each other and mounted in a support frame, they are designed to supply electricity at a certain voltage, such as a common 12 volts system. The current produced is directly dependent on how much light strikes the module.

  Multiple modules can be wired together to form an array. Photovoltaic modules and arrays produce DC electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

- Cell junction: it's limited to the portion of the sun's spectrum whose energy is above the band gap of the absorbing material, and lower-energy photons are not used.

- **PV working Principle:**

  Sunrays holds a huge number of photons which composed of packets of energy, each photon carries energy with an amount that is corresponding to the wavelength of the light, when photons hit PV panel they cause three reactions; they may be reflected or absorbed, or they may pass right through, only the absorbed photons generate electricity.

  To induce the electric field, the absorbed photons should flow through two sandwiched separate semiconductor layers. The "P" and "N" layers which correspond to "positive" and "negative" because of their abundance of holes or electrons (the extra electrons make an "N" type because an electron actually has a negative charge).

  Although both materials are electrically neutral, N-type silicon has excess electrons and P-type silicon has excess holes. Sandwiching these together creates a P-N junction at their interface, thereby creating an electric field.

  The two semiconductors act as a battery, creating an electric field at the surface where they meet (known as the "junction"). It's this field that causes the electrons to jump from the semiconductor out toward the surface and make them available for the electrical circuit. At the same time, the holes move in the opposite direction, toward the positive surface, where they await incoming electrons[10].

- **Solar cells types**

  The three most common approaches are summarized below:

- Monocrystalline Silicon - This type of solar cell uses a single layer of silicon for the semi-conductor. In order to produce this type of silicon it must be extremely pure which means it is the most expensive type of solar cell to produce.
- Polycrystalline Silicon - To make polycrystalline silicon cells liquid silicon is poured into blocks that are subsequently sawed into plates. This type of approach produces some degree of degradation of the silicon crystals which makes them less efficient. However, this type of approach is easier and cheaper to manufacture.

- Amorphous Thin Film Silicon - This type of solar cell uses layers of semiconductor that are only a few micrometers thick (about 1/100th the thickness of a human hair). This lower the material cost but makes it even less efficient than the other types of silicon. However, because it is so thin this type of cell has the advantage that it can be placed on a wide variety of flexible materials in order to make things like solar shingles or roof tiles [10].

- **Advantages of PV:**

  The photovoltaic systems exhibit the advantageous features of being silent and nonpolluting, and of having no detectable visual or audible emissions. Photovoltaic systems are inherently stand-alone systems; they require no connection to an existing power source nor any supply of fuel. Photovoltaic systems have advantages over conventional power sources particularly where:

- generates free energy from the sun,
- has no moving parts to break down thus requiring minimal maintenance,
- non-polluting energy reduces emissions: has no direct impact on the environment,
- photovoltaic cells (PV) are modular, you can start with a small system and expand as your needs increase,
- systems have a long life & durability since the PV cells last for (25-30) years.
- increases public safety and aids in providing a safe working environment in areas where mains power is difficult to access,
- PV cells make no noise and give off no exhaust,
- allow the use of electricity in remote areas where it would be expensive or impossible to run power lines, and
- high quality construction and components.

- **Types of PV System**

There are two major types connection of the system if it's connected to the main grid or it stands alone without any connection, these types are [11]:

- Off Grid Systems.
- On Grid Systems.

1- Off-Grid Systems

They are also called stand-alone systems. Although they are most common in remote locations without utility grid service, off grid solar- electric systems can work anywhere. These systems operate independently from the grid to provide loads with electricity, and there are many types of this system.

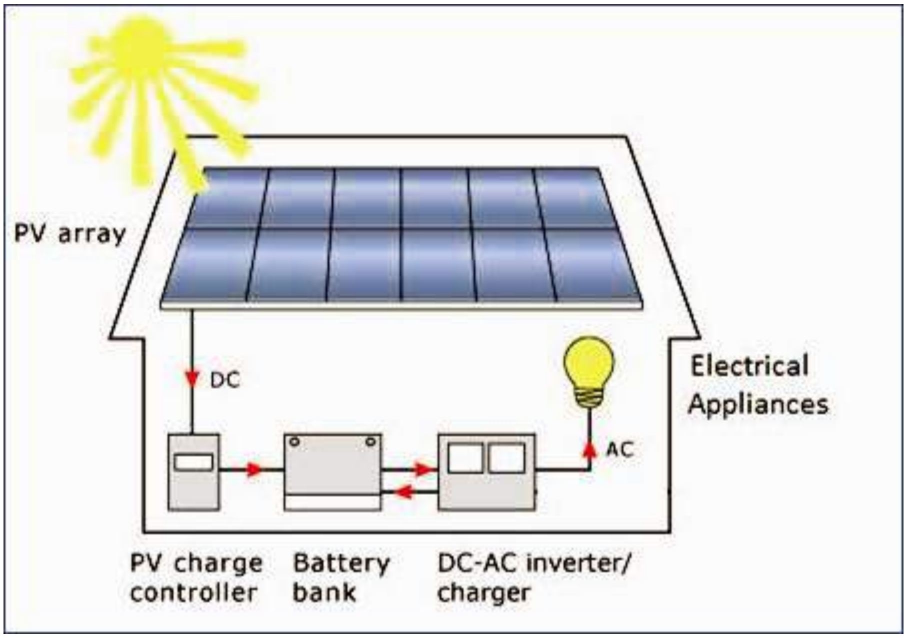


Figure (2-5): Off Grid Solar System

2- On-Grid Systems

They are also called Grid-tied system or utility interactive. Grid-tied systems are designed to operate in parallel with and interconnected with the electric utility grid.

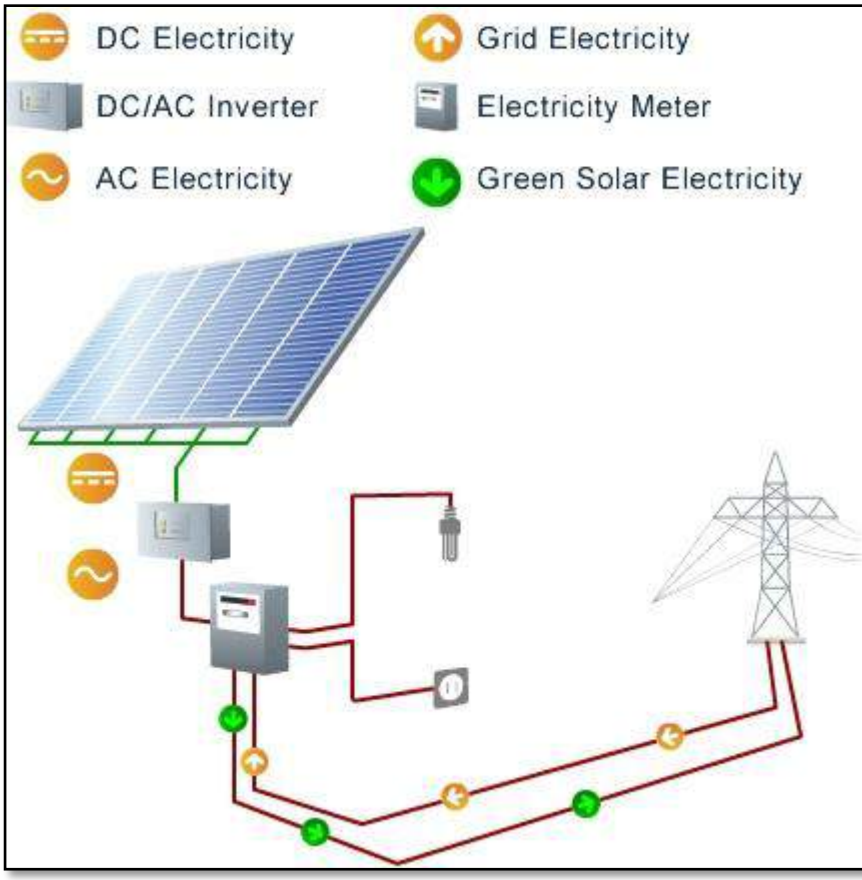


Figure (2-6): On Grid Solar System

2.1.3 Internal Rate of Return (IRR)

- **Definition:**

  The internal rate of return on an investment or project is the "annualized effective compounded return rate" or discount rate that makes the net present value of all cash flows (both positive and negative) from a particular investment equal to zero [12].

  In more specific terms, the IRR of an investment is the interest rate at which the net present value of costs (negative cash flows) of the investment equals the net present value of the benefits (positive cash flows) of the investment.

  Internal rates of return are commonly used to evaluate the desirability of investments or projects. The higher a project's internal rate of return, the more desirable it is to undertake the project. Assuming all other factors are equal among the various projects, the project with the highest IRR would probably be considered the best and undertaken first.

A firm (or individual) should, in theory, undertake all projects or investments available with IRRs that exceed the cost of capital. Investment may be limited by availability of funds to the firm and/or by the firm's capacity or ability to manage numerous projects.

- **Uses of IRR:**

  Important: Because the internal rate of return is a rate quantity, it is an indicator of the efficiency, quality, or yield of an investment. This is in contrast with the net present value, which is an indicator of the value or magnitude of an investment.

  An investment is considered acceptable if its internal rate of return is greater than an established minimum acceptable rate of return or cost of capital. In a scenario where an investment is considered by a firm that has equity holders, this minimum rate is the cost of capital of the investment (which may be determined by the risk-adjusted cost of capital of alternative investments). This ensures that the investment is supported by equity holders since, in general, an investment whose IRR exceeds its cost of capital adds value for the company (i.e., it is economically profitable).

2.1.4 Net Present Value (NPV)

Net present value is the present value of net cash inflows generated by a project including salvage value, if any, less the initial investment on the project. It is one of the most reliable measures used in capital budgeting because it accounts for time value of money by using discounted cash inflows.
Before calculating NPV, a target rate of return is set which is used to discount the net cash inflows from a project. Net cash inflow equals total cash inflow during a period less the expenses directly incurred on generating the cash inflow [13].

- **Advantage and Disadvantage of NPV**

  - **Advantage:** Net present value accounts for time value of money. Thus it is more reliable than other investment appraisal techniques which do not discount future cash flows such payback period and accounting rate of return.
  - **Disadvantage:** It is based on estimated future cash flows of the project and estimates may be far from actual results.

2.1.5 Optimization Process

Engineering project design and optimization can be effectively approached using concepts of systems analysis. A system can be defined as a set of components or processes that transform resource inputs into product (goods and services) outputs [14].

2.2 Previous Studies

2.2.1 Integrating the solar distiller with the air-conditioning system

K. Ghali , N. Ghaddar, and A. Alsaidi (2010) Integrating the solar distiller with the air-conditioning system can increase the condensate output from the solar stiller while meeting the cooling load needs. The operation of the combined solar distillation and air conditioning system has been modeled and simulated to predict distillate output from the cooling coil for the combined system for a residential space application in the suburbs of Beirut. An optimization problem is formulated to optimize the integrated system operation for minimum energy consumption while meeting the hourly cooling load and the daily fresh water need of 100 liters. The design variable in the optimization study is the fresh air flow rate that passes through the distiller and mixes with return air for the constant volume space supply fan. The optimization problem is solved for a 10-hour of operation of the combined system for the summer months: June, August and October. It is found that the cost of fresh water production of the combined system is 0.108 kWh/ liter for the month of August and 0.12 kWh/liter of fresh water in October [15].

2.2.2 Solar-Driven Reverse Osmosis (RO)

Andrea Ghermandi and Rami Messalem (2009) Reduce operational costs, and improve environmental sustainability by solar-driven reverse osmosis desalination. The experience with solar desalination is investigated based on the analysis of 79 experimental and design systems worldwide. Our results show that photovoltaic-powered reverse osmosis is technically mature and — at unit costs as low as US$ 2–3 per m^3 — economically cost-competitive with other water supply sources for small-scale systems in remote areas. Under favourable conditions, hybrid systems with additional renewable or conventional power sources perform as good as or beter than photovoltaic-powered reverse osmosis. Have been suggested that in the short-term, solar RO desalination will gain shares in the market of small-scale desalination in remote areas. Concentrating solar power technologies have the highest potential in the medium-term for breakthrough developments in large-scale solar desalination [16].

2.2.3 Designing Cost-Effective Sea Water Reverse Osmosis System under Optimal Energy Options for Developing Countries.

Asmerom M. Gilau and Mitchell J. Small (2006) analyzes the cost-effectiveness of a stand alone small-scale renewable energy powered sea water reverse-osmosis (SWRO) system for developing countries. Have been introduced a new methodology; an energy optimization model which simulates hourly power production from renewable energy sources. Using the results of the model, have been computed hourly water production for a two stage SWRO system with a capacity of 35m3/day. According to our results, specific energy consumption is about 2.33kWh/m3, which is a lower value than that achieved in most of the previous designs. Using a booster pump, energy recovery turbine and appropriate membrane, specific energy consumption could be decreased by about 70%. Furthermore, the energy recovery turbine could reduce water cost by about 41%. Still, power cost is the major component of the total investment constituting about 80% of the total cost of the SWRO system. Our results show that, wind powered system is the cheapest and a PV powered system, the most expensive, with about 0.50$/m3 and 1.00$/m3, respectively. By international standards, for example, in China, these values are considered economically feasible. Detailed simulations of RO system design, energy options, power and water costs, and life cycle analysis are discussed [17].

2.2.4 Optimizing Lower Energy Seawater Desalination, The Affordable Desalination Collaboration

Stephen Dundorf, John MacHarg, Thomas F. Seacord (2006) Using a combination of energy efficient, commercially available reverse osmosis (RO) technologies including pumps, membranes and energy recovery equipment, the ADC has demonstrated that seawater reverse osmosis can be used to produce water at an affordable cost and energy consumption rate comparable to other supply alternatives. The ADC's demonstration scale seawater reverse osmosis (SWRO) treatment system uses pressure exchanger technology (ERI) for energy recovery. The RO array consists of 3 each x 7 element 8" DIA pressure vessel. The flux and recovery can be varied from 6-9 gfd and 35-60% respectively. The overall capacity of the system can be varied from approximately 200-300 m3/day (50,000-80,000 gpd) The research and demonstration work being conducted by the ADC is divided into two phases. The first phase of testing was completed in March 2006 and took place at the US Navy's Seawater Desalination Test Facility in Port Hueneme, California. It included testing three membrane sets and arying flux and recovery to seek the most affordable operating point. The most affordable operating point was estimated by calculating the net present value for each tested condition, accounting for both capital and operating costs. The second phase, scheduled to start in spring 2007, includes testing and demonstrating additional manufacturers' membranes through a similar protocol as Phase I, which involved DOW membranes exclusively. Demonstrating additional membranes (DOW, Hydranautics, Toray, Koch), will validate the results from Phase I and show that they can be achieved with several manufacturers' membranes. DOW's "next generation" hybrid-membrane system, involving internally staging membranes of different performance down a single 7-elemenet pressure vessel, will be tested. In Phase II the ADC will also test and demonstrate advanced prefiltration technologies, such as ultrafiltration membranes, which have seen only limited use in seawater desalination. Finally the ADC will develop and test new process designs that are possible as a result of the isobaric energy recovery technologies. As a natural result of pressure exchanger (PX) technology in particular, there are new kinds of flow schemes that may improve the performance of higher recovery seawater and brackish water systems [18].

2.2.5 Optimization Of Seawater RO Systems Design

Mark Wilf Ph. D. and Kenneth Klinko,2006 Has trend of investment and water cost in RO seawater systems is being evaluated. The cost data used for this evaluation are based on published information from operation of actual RO seawater installations and recent studies. The effect on process economics of major design parameters: recovery rate and feed water salinity based on three representative seawater water sources: Mediterranean, Atlantic and Pacific Ocean on energy consumption is analyzed. The objective of this evaluation is to determine economic feasibility of operating of seawater systems at higher recovery rates versus process optimization based a prevailing economic parameters. The optimized system design was compared with the design of recent large seawater installations: 10,000 m3/day plant at Eilat, Israel, 40,000 m3/day seawater plants at Larnaca, Cyprus and the design proposed for the 95,000 m3/day RO plant at Tampa, Florida [19].

3 BACKGROUND AND CASE STUDY

3.1 Energy Source in Gaza Strip

3.1.1 Electricity History in Gaza Strip

- The Gaza strip has seen the beginning of the electricity generation plant in 1935, under the privilege of a foreign private company.
- During the forties, the British mandate had contributed in the expansion of the electricity network to serve the army camps.
- Air network system was employed to distribute power with 3.3 kV for high pressure, and 380V for the internal distribution network (low pressure).
- In 1969, great parts of electricity network were joined to Israeli network through three main transformers with overall capacity of 1200 kV.
- On May 1994, the Palestinian authority received its responsibilities, and despite many obstacles, work has begun to set up new generation electricity in 1999.
- the plant started operation on June 2002, and the commercial operation began in April, 2004.
- The station did not operate with full capacity because the fuel required for operation was not always available.
- The Gaza Strip is supplied with electricity from main sources, shown in the next figure:

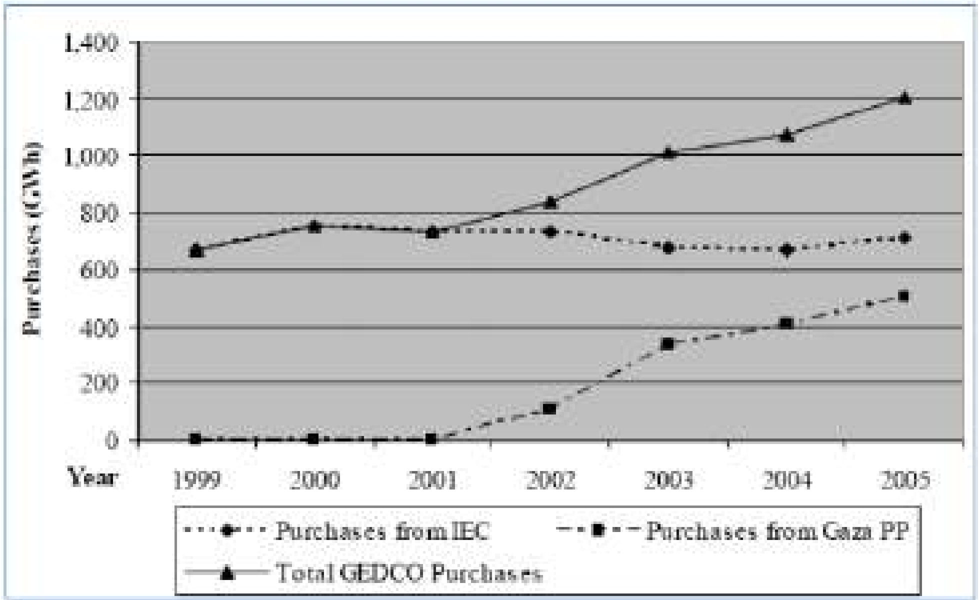


Figure (3-1) Gaza's total supply of power

The three main sources are :

a) The Israel Electric Cooperation IEC provides 120 MW to north and central Gaza (about 60% of the electrical supply to Gaza),

b) The Gaza Power Plant GPP provides 65 MW to the southern area (but relies on fuel supplied by Israeli firms), and

c) Egypt provides 17 MW to Rafah area. However, the total 202 MW consumed does not meet the increased demand which amount in 2007 at 240 MW, but now is 360 MW.

- Following the bombardment of the power station the Gaza strip has complained of periodical suspension of electric current for 8-12 hours a day, in accordance with emergency daily time table prepared by Electricity Company.
- Now the power station supplies Gaza city with about 80% of its demand, and the Middle Area with 90% of electricity needs, which equivalent to the needs of 500,000 people, and the productive capacity of the power station is approximately 140 MW.

3.1.2 Electrical Catastrophe in the Gaza Strip

It is known that the Gaza strip has a high population growth rate, where it has a high electricity demand. Since the Gaza strip's energy resources are controlled by Israel, which employed policies to restrict the electrical production capacity of the Palestinian territories. As a result, the Palestinian economy and the infrastructure had suffered from major distortions and underdevelopment. The lack of an adequate infrastructure in the Palestinian territories for nearly four decades has impeded any real growth of energy and caused chronic energy problems.

The situation has worsened after Israel's bombing of the power plant in June 2006, this result in the loss of about 90 MW of electrical power required to supply the Gaza strip daily needs, this has led to stop the power plant for about four months causing a remarkable deficiency in electricity generation.

3.1.3 Energy for desalination

Energy cost in desalination plants is about 30% to 50% of the total cost of the produced water based on the type of energy used. Therefore, the total cost of desalination can be reduced a lot by reducing the energy consumption which is about 50% of the total desalination cost.

On the other hand, if the desalination plants are dependent on Israel, that would be a risky alternative since if Israel stops providing energy, these desalination plants could not operate. It is of great importance to look for independent sources of energy that might be as low as Israeli pricing. A good alternative can be the use of renewable energy.

That means, if the desalination plants are fully based on the Gaza power plant, the cost of the desalination process will be potential for adversely affecting the environment.

3.2 Water Desalination in Gaza Strip

3.2.1 History of BW & SW RO Desalination in The Gaza Strip:

- The first RO plant in the Gaza Strip was built in 1991 in Deir al Balah town by EMS a subsidiary of Mekkorot Company. This plant is constructed to desalinate brackish water.

- In 1997-1998 and through an Italian development cooperation program two RO plants were constructed in Khan Younis to desalinate two brackish water wells.

- In 1998, USAID financed a BWRO plant built in Gaza Industrial Zone designed to supply water to the surrounded industrial complexes and adjacent part of Gaza city.

- In 1999 the private sector -local companies- began to invest in the desalination market. They installed small scale BWRO plants with different capacities to desalinate low brackish water wells in various areas in the Gaza strip [20].

Small desalination plants in the Gaza strip are owned privately, which try to maintain adequate amounts of fresh water for the population. The vast majority of these plants were established since 1998. The companies use the RO desalination system to produce desalinated water. They distribute this water by tankers . The small private desalination plants have a production capacity of about 20 m3/day to 120 m3/day, and brine water rejection ranges from 30 m3/day to 240 m^3/day depending on the inlet characteristics (Table 3-2). Brine from these commercial desalination plants is disposed of in the sewer system, irrigation and Wadi Gaza. The quality of produced water is in the range of the WHO standard guidelines. After the chemical and bacteriological examination, the water was observed to have the following characteristics [21].

Table (3-1): Comparison of physico-chemical properties of inlet and product (RO) water samples with drinking water standards [21].

Parameter	Unit	Type of water	Range from collected sample	WHO	PWA
PH		Inlet	6.5 – 7.7	6.5 – 8.5	6.5 – 9.5
		Product	4.8 – 7.1		
TDS	mg/l	Inlet	460 – 2295	1000 mg/l	1500 mg/l
		Product	39 – 142		
Mg^{2+}	mg/l	Inlet	16.6 – 172.6	60 mg/l	150 mg/l
		Product	1.8 – 10.4		
Ca^{2+}	mg/l	Inlet	10.8 – 179.6	100 mg/l	100 – 200 mg/l
		Product	3.2 – 14.5		
Na^{+}	mg/l	Inlet	35.5 – 619.3	200 mg/l	200 mg/l
		Product	6.9 – 27.6		
K^{+}	mg/l	Inlet	2.3 – 7.5	5 mg/l	12 mg/l
		Product	0.1 – 1.6		
Cl^{-}	mg/l	Inlet	77.5 – 1148.9	250 mg/l	600 mg/l
NO_3^{-}	mg/l	Inlet	28.7 – 227.4	45 mg/l	70 mg/l
		Product	4 – 31.5		
SO_4^{2-}	mg/l	Inlet	9.8 – 218.9	250 mg/l	400 mg/l
		Product	0.1 – 2.9		

3.2.2 Public plants in the Gaza strip

Table (3.2): The current status of the BWRO desalination projects in the Gaza Strip [22].

Plant name	**Date establisher**	**Quality, TDS (mg/l)**	**Capacity (m3/hr)**	**Desalination productivity (m3/hr)**	**Usage**
Deir El Balah Desalination	1991, Israel	3100	78	45	Municipal Demands
Khan Younis, Al-Sharqi	1997, Italian development cooperation program	2500	60	50	Municipal Demands
Khan Younis, Al-Sa'ada	1998, Italian development cooperation program	2000	80	65	Municipal Demands
Aqua Company	1999, private investor	1500	70	50	Sold in water trucks

Al-Braij Company	1999, private investor	1600	60	40	Sold in water trucks
Gaza industrial zone	2000, USAID	1400	95	75	Industrial Demands
Middle area plant	1998, Austrian Government	35000 (Seawater)	30	25	Pumped through 13 water shops

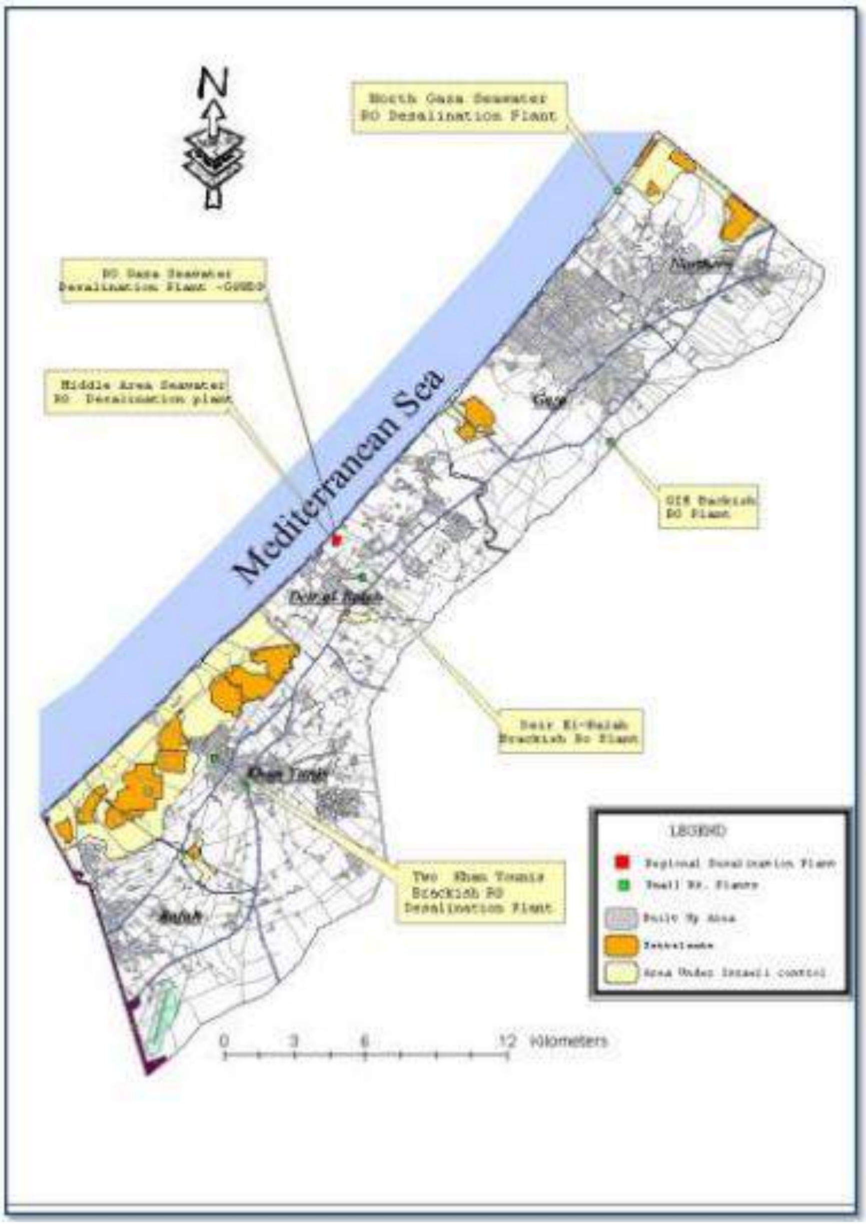


Figure (3-2): Desalination plants in the Gaza strip

3.3 Case Study (Deir El-Balah SWRO Desalination Plant):

By 1998, Palestinian National Authority has received a fund from Austrian Government for design and construction of seawater desalination plant to serve people in Middle area in general and Deir El Balah and Zwaydah in particular. The design capacity is to produce 600 m^3/day for phase (I) and to be increased up to 1200 m^3/day in phase II. The function of the project is to pump the produced water from the plant to about 13 water shops covering two intensive residential areas through a separate water network. In addition, extend the service to other far areas that are in bad need for potable water. The source of seawater comes from two existing beach wells close to the shore. The brine is discharged to the sea. The construction of the plant had been launched in July 2000, and the elementary handover was in December 2002 (Site visit, December 2012).

3.3.1 General information and design criteria

Because of the capability of the private sector to operate the water distribution by tankers, a Reverse Osmosis Water Treatment Plant (RO-WTP) will be erected in two steps (current step covers a capacity of 600 m^3/d) [23].

A future extension shall be possible at the plant site, therefore the contractor shall make his arrangement layout in a way, that the second stage maybe easily implemented within the same hall as for stage # 1, whereby most probably a 1 x 600m^3/d extension should be considered.

At the first stage two beach wells and basic infrastructure will be proposed and constructed for the desalination of seawater for a total capacity of appr. 1.200 m^3/d potable water.

The operation of the wells will be switched according to the operation time of the pumps. So the wells will be constructed for the delivery of 65 m^3/h raw water each (max. quantity 1.500 m^3/d each), and the pumps and the electromechanical equipment was also be designed for 75 m^3/h raw water per well. According to this, the infrastructure of the well and the feed line was designed for a maximum capacity of 1.200 m^3/d potable water (130 m^3/h resp. 3.000 m^3/d raw water).

The mechanical and electromechanical equipment of the reversed osmosis unit itself was designed for a max. capacity of 600 m^3/d potable water at a first stage.

If the private sector will be able to organize a water distribution of another 600 m^3/d by tankers and this way of water distribution is confirmed as an acceptable and save way to supply people with desalinated water, an extension of the desalination unit with a capacity of 600 m^3/d can be easily added to the proposed plant.

So the capacity of the projected water treatment plant can be easily increased to a capacity of 1.200 m^3/d drinking water. If enough area remains available at the proposed location an extension of the plant capacity up to 2.400 m^3/d is possible.

3.3.2 Process Description

The Seawater Desalination Plant consists in general of following process units:

- Seawater intake (beach wells),
- Seawater pretreatment plant,
- Reverse Osmosis Desalination Plant,
- Post treatment Plant, and
- Potable water storage and distribution.

The following figure show RO schematic Diagram:

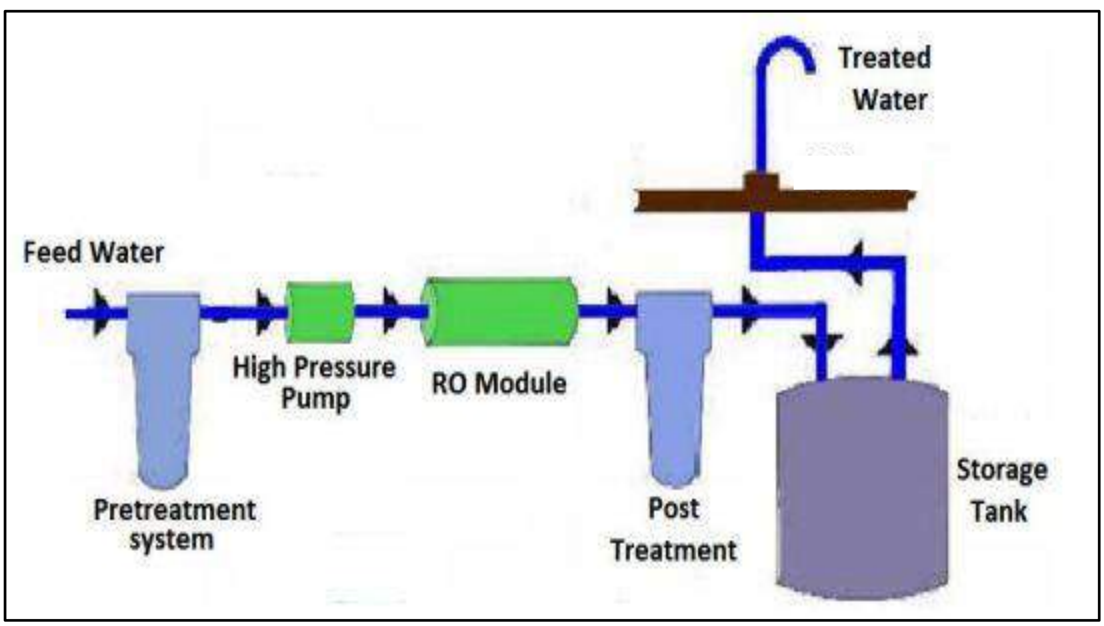


Figure (3-3): Schematic diagram shows RO system components

3.3.3 Reverse Osmosis Desalination plant

- **Cartridge filter**

Before entering the RO units the water is filtered by a 5 micron cartridge filter F-20A to protect the RO element from particles. The cartridge filter is equipped with a difference pressure transmitter if this reaches max. 1.5 bar the cartridge has to be changed to new cartridges.

- **High pressure pump & Reverse Osmosis unit**

After the water has passed the cartridge filters, the high-pressure pump pressurizes the pretreated seawater to a the required operation pressure of 65 to 70 bar and feeds the seawater into the RO unit [23].

The Reverse Osmosis consists of one unit X-20A with a design capacity of 600 m^3/day.

The RO unit are equipped with spiral wound Thin Film Composite RO membrane elements of 8 inch diameter and 40 inch length. Six pieces of this RO membrane elements may be installed in the pressure vessels.

In total 9 pcs of this pressure vessels are arranged in parallel RO block to achieve the required output.

About 40 % of the feed water is recovered as permeate (desalted water) and the remaining 60 % brine stream is discharged.

The high pressure feed pump system consist of the pumps connected in series. The first pump is connected with a pelton turbine to recover the energy form the high pressure brine stream. The second pump is equipped with a speed controlled electric motor to increase the pressure to the above mentioned operation pressure. With this system an energy saving of 30 % are achieved.

The feed booster pump is equipped with speed controlled motor to increase slowly the pressure and adjust the required feed pressure.

In order to adjust the recovery ratio and to handle pressure differences due to temperature changes the speed controlled motor and a flow adjustment valve before the turbine is provided.

An automatic flushing of the pressure vessel, the RO elements, high-pressure pump and pipe work is performed at every plant stop with permeate with flushing pump P-26A. By displacing the brine solution inside the RO modules as well in the high pressure pump and turbine pump with permeate scaling and corrosion shall be prevented during stop period.

- **RO Membrane Elements**

In the RO desalination process the salts are retained by a semi-permeable membrane which holds back the salt molecules and let pure water pass.

- **Operating Pressure**

To force the water through the membrane a certain pressure is required, which results from the osmotic pressure of the water and the required net driving pressure (NDP) of the membrane. In our case we operate with a pressure of 65 to 25 bars. The water temperature has also a big impact on the operating pressure.

- **Water Recovery**

From water flow rate to RO unit (Feed water) a certain amount which passes the membrane is recovered as desalted water (Permeate) while the other stream which contains the retains salts is discharged as concentrated solution (Brine).

The ratio of the Permeate flow to the Feed water flow rate is called the Water recovery (Y) and multiplied by 100 expressed in percent.

In our case the feed water flow rate to the RO unit is 65 m3/hr, the permeate flow rate is 26 m^3/h and the brine flow rate is 39 m^3/h, the water recovery is therefore 40 % [23].

- **Technical terms in a Reverse Osmosis Plant**

Table (3-3) Technical terms in RO Plant

RO membrane element		Defines the commercial available RO membrane Spiral wound membrane element with 8 inch diameter and 40 inch length
Pressure vessel		Holds the above mentioned membrane

		elements. Made of Fiberglass FRP with 8 inch diameter and length to hold max. 6 elements.
Feed water flow	Qf [m3/h]	Raw water inlet flow rate to RO unit ~ 65 m3/h
Brine flow	Qb [m3/h]	Concentrated flow rate from the RO unit ~ 39 m3/h
Permeate flow	Qp [m3/h]	Flow rate of the desalted water = 26 m3/h
Water recovery: Y= (Qp/Qf)x100	Y [%]	The percentage amount (yield) of water Recovered from the feed water Y =(26/65) x100 = 40 %
Salt concentration factor CF: a) Theoretic concentration CF = 100/(100-Y) b) Practical concentration CF= (Cb/Cf) Cf = Conc. Feed (TDS mg/l) Cb= Conc. Brine (TDS mg/l)		Number of times of the brine is concen-trated in relation to the feed water CF = 100/(100-40) = 1.67 times
Salt passage Sp= (Cp/Cf) x 100 Cp.. Conc. Permeate (TDS or conductivity) Cf .. Conc. feed water (TDS Or onductivity)	Sp [%]	The percentage of salts which pass into the permeate in relation to the feed water Cp = 495 uS/cm Cp = 52 000 uS/cm Sp =(495 uS/cm/52 000 uS/cm) x100 = 0,95 %
Salt rejection:	Sp [%]	The percentage of salts which are rejected by

Sr= 100 – [(Cp/Cf) x 100] Cp.. Conc. Permeate (TDS) Cf .. Conc. feed water (TDS)		the membrane in relation to the feed water Sp =100-[(495/52 000) x100] = 99,05 %
Net driving pressure: NDPave = Pf – Po – (dp/2)- Bp Pf .. Feed pressure (bar) Po.. Osmotic pressure (bar) Dp.. Differential pressure Bp ..Permeate back pressure	NDP [bar]	Effective available pressure to force the water through the membrane. The NDP is reduced from the 1st stage front membrane elements to the 2nd stage end elements.
Flux rate F= (Q/A) x 24 Qp.. Permeate flow rate (l/h) A .. Membrane area (m2)	F= [l/m2.h]	Permeate flow rate per m2 membrane area and day

- **Required Feed Water Quality to the RO Plant**

The feed water (entering the RO unit) should be within the following limits as indicated in the following table (3-4) [23]:

Analysis		**Normal range**	**Min/ Max. Values**
Water temperature during operation		18 - 28	15 – 30

Water temperature during cleaning		40	Max. 45
pH value operation		6,7 – 7,0	6,5 – 7,3
pH value for cleaning		--	3 – 11
Langlier Saturation Index	S&DI	< + 1,0 with antiscalant	Max. + 1,5 with antiscalant
TDS, max	mg/l	41 000	42 000
Turbidity	NTU	< 0,5	< 1
Silt Density Index	SDI	< 3,0	4 , peaks max. 5
Free chlorine	mg/l	0	0
Total chlorine	mg/l	0	0
Sulfite content	mg/l	2 – 3	
Oxidation- Reduction Potential ORP	mV	< + 250	Max. + 350
Manganese	mg/l	< 0,02	< 0,05
Silica as SiO2	Mg/l	< 15	Max. 20
Total Organic Carbon TOC	mg/l as C	< 3	Max. 5
Total bacteria count	CFU/ml	preferable < 100	< 1000 depends on site

- **Power Consumption**

The below expected power consumption is based on seawater with a feed TDS of 40.000 ppm and a plant recovery of 40 %, as the following table (3-5) [23]:

Description	Required unit operation power	Specific power Consumption
Well pumps for water supply	14,0 kWh/h	0,65 kWh/m3 Desalted water
Pretreatment and RO Plant	105 kWh/h	4,00 kWh/m3 Desalted water
Water filling and distribution station	27 kWh/h max.	0,50 kWh/m3 Desalted water

3.3.4 Membrane cleaning system

In case of fouling and scaling on the membranes this residuals can be removed with certain chemicals. The membrane cleaning system serves for the cleaning of the RO membranes in the pressure vessels. The cleaning system maybe also used for the desinfection of the membranes.

In the cleaning tank T-25A the required amount and concentration of the cleaning solution is prepared. The cleaning pumps P-25A/B are required for the circulation of the cleaning solution over the tank and over the RO-block.

The cleaning solution can be heated up to 40 deg C with the cleaning solution heater W-25A to improve the cleaning efficiency of the solution.

The cleaning solution is filtered in cartridge filter F-25A before the cleaning solution enters the pressure vessels [23].

4 ECONOMIC FEASIBILITY MODEL

4.1 Introduction

Proposed capital projects can be evaluated by economic feasibility study that may also include an economic analysis of the project. The purpose of economic analysis is to determine whether there is an economic case for the investment decision. This assessment goes beyond the items typically included in a financial analysis. Economic feasibility is interested in:

- The economic benefits from the project
- The economic costs of the project
- The balance of these expressed in present value terms (the net economic benefit)

Economic costs and benefits are not always the same as financial cost and benefits. Economic analysis includes project impacts. Therefore, it is in this way that economic analysis casts a broader net than a financial assessment.

When look at the outcome of a feasibility analysis we look at the key metrics to judge the project's merit. What should be included in the key metrics depends on the type of project, funding strategy and legal structure. The most common metrics include Net Present Value (NPV), Internal Rate of Return (IRR), Developer's Margin and Return on Equity (RoE).

In this Study, IRR Method was used as an economical indicator to compare the feasibility of establishing a SWRO desalination plant with a capacity of 600 m^3/d in Deir El-Balah based on the best energy sources. The available options of energy sources for the proposed desalination Plant are follows:

1- Electricity Energy System (EES)
2- Solar Energy System (Off Grid System)
3- Combined Energy System (On Grid System)

4.2 Using Internal Rate of Return (IRR) Method

The internal rate of return (IRR) is the rate of return promised by an investment project over its useful life. It is some time referred to simply as yield on project. The internal rate of return is computed by finding the discount rate that equates the present value of a project's cash out flow with the present value of its cash inflow. In other words, the internal rate of return is that discount rate that will cause the net present value of a project to be equal to zero.

4.2.1 Internal Rate of Return Calculation

This method refers to the percentage rate of return implicit in the flows of benefits and costs of projects A. Margin defines the internal rate of return IRR “as the discount rate at which the present value of return minus costs is zero”. In other words, the discount rate which equates the present value of project with zero, is known as IRR.

Thus, IRR is the discounted rate which equates the present value of cash inflows with the present value of cash outflows. IRR is also based on discount technique like Net Present Value NPV method. Under this technique, the future cash inflows are discounted in such a way that their total present value is just equal to the present value of total cash outflows. It is assumed that the management has knowledge of the time schedule of occurrence of future cash flows but not of the rate of discount. IRR can be measured as [24]:

$$IRR = \frac{A_1}{(1+r)^1} + \frac{A_2}{(1+r)^2} \ldots\ldots + \frac{A_n}{(1+r)^n} - C = 0$$

Where, A**1**, A2 are the cash inflows at the end of the first and second years respectively. And the rate of return is computed as follows.

$$C = \frac{A_1}{(1+r)^n}$$

Where, 1 is the cash outflow or initial capital investment, A1 is the cash inflow at the end of first year, r is the rate of return from investment.

4.2.2 Interest Rate in Palestine

In the absence of a national currency, the calculated of the debit and credit interest rates on major currencies in circulation in Palestine: Jordanian dinar, the U.S. dollar and the Israeli shekel, periodically depending on data supplied by banks to the Palestine Monetary Authority PMA on the basis of the mean weighted average.

PMA does not issue a national currency, consequently:

- Main currencies that circulate in Palestine are US Dollar, Jordanian Dinar, New Israeli Shekel (NIS);
- Interest rates on deposits and loans are affected by the policies of the central banks issuing the mentioned currencies;
- The debtor and creditor rates on foreign currencies are those of the international market majored by few basis points based on the conditions in the local market (competition between banks, risk exposure, etc.).

The weighted average lending and deposit rates applied by banks are calculated quarterly by currency, on the basis of information provided by banks on the rates and volumes of various types of deposits and loans. Show table (4-1) from PMA.

Average Interest Rates on Deposits and Loans for Banks Operating in Palestine %						
Period	Deposits			Loans		
	JD	$ US	NIS	JD	$ US	NIS
2001	3.62	1.48	2.78	9.82	8.36	16.37
2002	2.74	2.74	5.55	9.41	7.97	15.47
2003	2.53	0.78	4.25	8.74	7.56	13.66
2004	1.61	1.12	2.59	8.47	6.92	13.46
2005	1.84	2.24	2.01	8.94	7.34	13.50
2006	2.72	2.98	2.48	9.08	7.81	13.23
2007	3.51	3.02	2.51	9.18	7.98	12.72
2008	1.98	0.80	1.04	9.04	7.47	12.04
2009	1.91	0.41	0.24	7.45	6.19	10.99
2010	1.15	0.29	0.30	7.54	6.33	10.93
2011	1.22	0.33	1.01	7.59	6.79	11.72
Mean	**2.26**	**1.47**	**2.25**	**8.66**	**6.43**	**13.10**

Table (4-1) Average Interest Rates in Palestine %

For economic analysis of project has taken interest rate 6.43 % as mean value of last three years for US dollars.

4.3 SWRO Desalination Plant Investment Cost

Cost is a major factor in implementing desalination technologies. This section provides elements of desalination cost which are components of direct, indirect and operating costs.

4.3.1 Factors Affecting desalination Costs

Unit product cost is affected by several design, operational and maintenance factors, which includes the following:

1- Quality and salinity of feed water: The quality of feed water is a critical design factor. Lower feed salinity allows for higher production rates. As a result, the plant operates with lower specific power consumption and dosing of antiscalant chemicals. Also, downtime related to chemical scaling is reduced.
2- Plant capacity: Large capacity plants require high capital cost compared with low capacity plants. However, the unit production cost for large capacity plants can be lower.
3- Site conditions: Installation new units to existing site, would eliminate cost associated with facilities for feed water intake, brine disposal, and feed water pretreatment.
4- Qualified manpower: Availability of qualified operators and engineers would result in higher plant production capacity.
5- Energy cost: The energy type used at the plant site have strong impact on the unit product cost.
6- Plant life: Increasing plant life reduces the capital product cost [25].
7- Regulatory Requirements: These costs are associated with local permits and regulatory requirements [26].

4.3.2 Elements of Economic Calculations

Unit product cost calculations depend on the plant capacity, site characteristics, and design features. Plant capacity specifies sizes for various process equipment, pumping units, and membrane area. Site characteristics have a strong effect on the type of pretreatment and post-treatment equipment, and consumption rates of chemicals. In addition, design features of the process affect consumption of electric power and chemicals.

Desalination plant implementation costs can be categorized as capital costs (starting costs) and operation and maintenance costs.

1- Capital Costs

Capital costs include direct and indirect costs. The indirect capital cost is usually estimated as percentage of the total direct capital cost. Indirect costs may include insurance, construction overhead, owner's costs, and emergency costs. Below is a description of various direct and indirect costs associated with constructing a desalination plant.

- **Direct Capital Cost**

The direct capital cost covers purchasing cost of various types of equipment, auxiliary equipment, land cost, construction, and buildings. Brief description for various cost items is shown below:

1- Land Cost
2- Well Supply
3- Process Equipment.
4- Energy System

This is one of the most cost items and it depends on the process type and capacity. Item included under this category are listed below:

- Instrumentation and controls
- Pipelines and valves
- Electric wiring
- Pumps
- Process cleaning systems
- Pre and post-treatment equipment
- Seawater intake and brine discharge line
- Chlorination equipment.

5- Auxiliary Equipment

The following auxiliary equipment is included:

- Transmission piping,
- Storage tanks,
- Generators and transformers,
- Pumps, and
- Pipelines and valves.

6- Building Cost

Building cost depends on the building type. Buildings include the following:

- Control room,
- Laboratory, and
- Offices.

7- Membrane Cost

Cost of membrane modules depends on its size. Cost of SWRO Desalination Plant membranes 8 inch diameter and 40 inch length is $800/module.

- **Indirect Capital Cost**

Indirect cost items are expressed as percentage of the direct capital cost as follow:

1- Insurance: This cost is equal to 5% of total direct costs.
2- Construction Overhead: This cost is equal to 15% of direct material and
3- labor cost.
4- Owner's Costs.
5- Emergency cost

2- Operating Cost

Operating cost items include labor, energy, chemical, spare parts, and miscellaneous.

The following gives brief description of each item and current cost estimates:

1- Energy: The average consumption is 105 kW/hr.
2- Labor: SWRO Desalination Plant staff and their salaries are:
   - Plant Manager:$1800
   - Electrician:$800
   - Mechanic:$800
   - Two workers: $600 for each
   - Three guards:$350 for each
3- Membrane Replacement: Replacement rate may vary between 5%-20% per year.
4- Maintenance and Spares: This cost item can be assigned a value lower than 3% of the total capital cost yearly.
5- Chemicals
   The chemicals used in feed treatment and cleaning include hydrochloric acid, caustic soda, antiscalant, Sodiumbisulfite, Ferric chloride and chlorine. Cost of these items may be affected by political situation in the Gaza Strip.

Table (4.2): Estimates of chemical cost and dosing rates

Chemical	Unit Cost
Hydrochloric acid (33% Conc.)	**600 $/ton**
Caustic soda (50% conc.)	**700 $/ton**
Antiscalant	**2,800 $/ton**
Chlorine (10% conc.)	**550 $/ton**
Sodiumbisulfite	**500 $/ton**
Ferric chloride	**600 $/ton**

Table (4.3): Cost estimate of SWDP [23].

item	Cost
power	**52.00%**

operation	**8.60%**
chemical	**8.10%**
Staff	**10.30%**
maintenance	**3.00%**
Fuel	**18.00%**

For SWRO Desalination Plant 26m^3/hr with pressurizing system with energy saving system 4 NIS/m3. Total Cost = 801,703 NIS/Year

4.4 Modeling Economic Feasibility By IRR Method

The IRR function, which is available as a financial function within Excel tool, can be used to build the economic feasibility model for three scenarios. Figure (4-1) shows an example of the application. In Microsoft Excel, the IRR function returns the internal rate of return for a series of cash flows

The cash flows must occur at regular intervals, but do not have to be the same amounts for each interval. In other words, IRR is a function that takes a series of cash flows and works out the effective rate of return if they were to be annually invested.

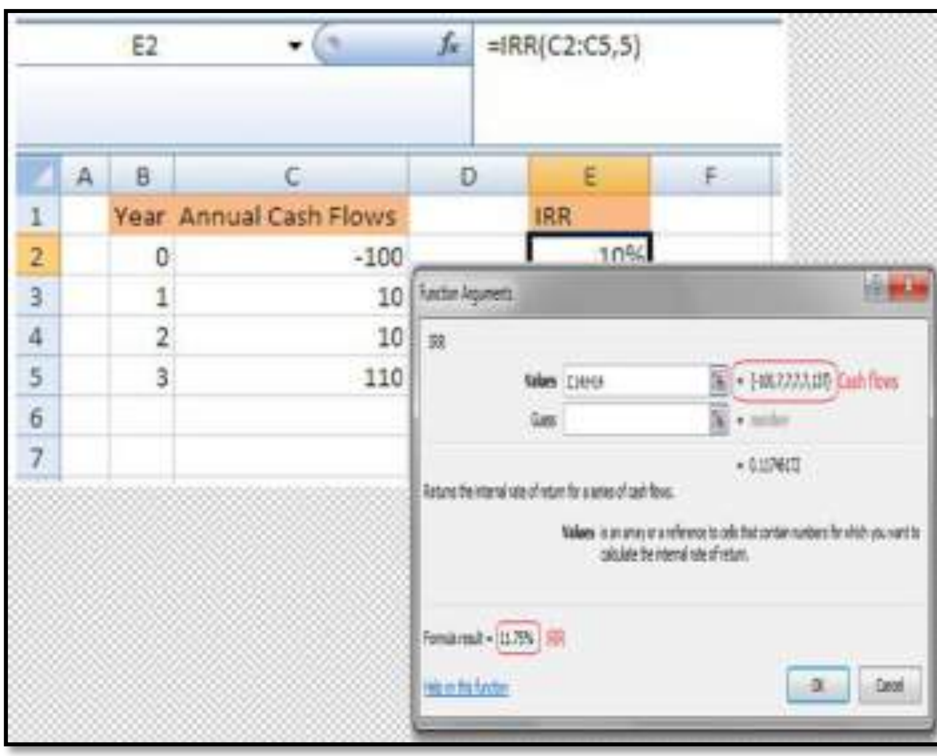


Figure (4-1) IRR function in Excel Tool

The annual cash flow of SWRO plant with series time (lifespan) that is 22 years is as the same age as any Solar System age. The investment costs was calculated as presented in figure (4-2). Some costs are the same in different scenarios such as the costs of the plant establishment and land costs. But the profits of the project was estimated based on the sale price and production unit of the plant ($ per one Cubic meter of desalted water), that is 1.7 $/m^3.

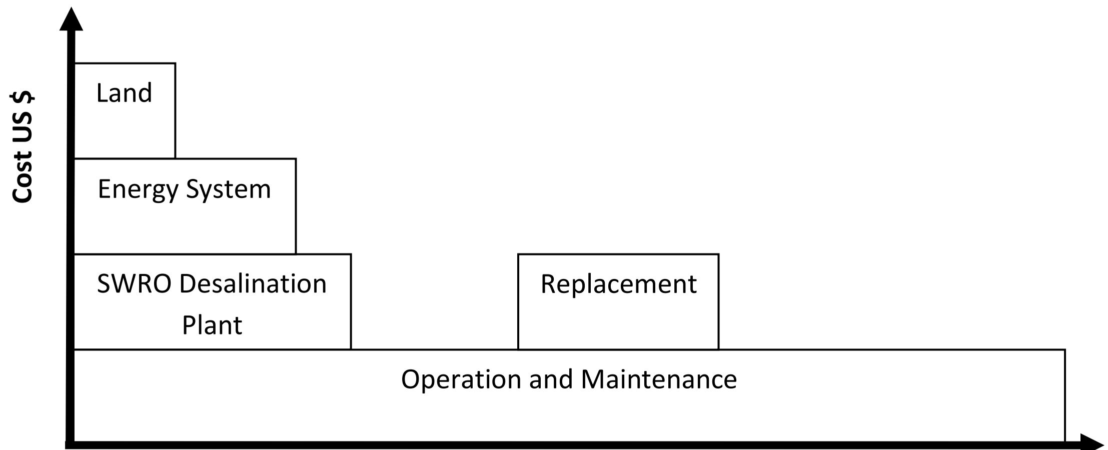


Figure (4-2) Costs of Plant with time

4.4.1 Desalination Plant Using EES (Electric Utility)

Figure (4-3), represents the first scenario of the proposed plant, which depends on local electricity network. The required energy of desalination plant is 105 kwh, while the commercial price of one kilowatt of electricity is estimated at 0.172 $/kwh. Estimating the other costs has been done by referring to the experts at the Coastal Municipalities Water Utility (CMWU), Palestinian Energy and Natural Resources Authority (PENRA), Palestinian Land Authority (PLA). Table (4-4) shows these estimations. In meanwhile the profits of the project were estimated based on the sale price and production unit of the plant ($ per one Cubic meter of desalted water) as following:

1.7 $/m^3 * 600 m^3/d * 365 d = 372,300 $/y.

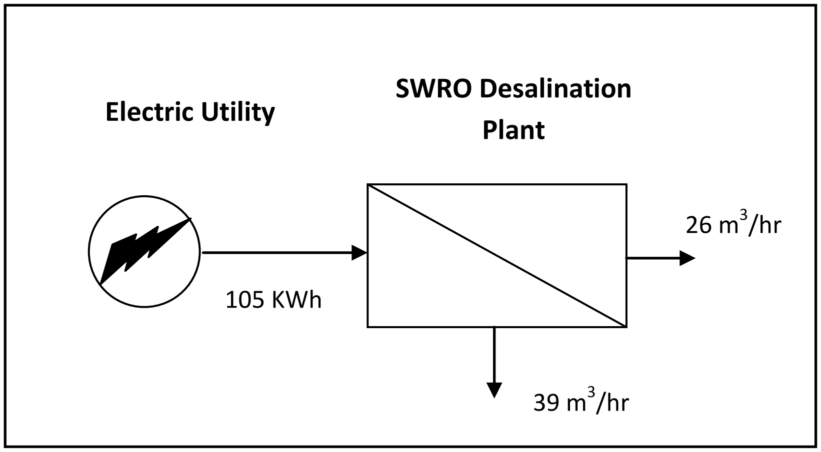


Figure (4-3) SWRO Plant depend on Electricity Source

Table (4-4) Costs Elements for SWRO Plant

Cost Type	Cost Element	Unit	Cost $	Details
Fixed	SWRO Desalination Plant	Unit	1,000,000	Intake, RO, Storage, Distribution and Facilities
	Land	m2	1,000,000	Industrial Land 7000 m2
Variables	Energy System	kw/Y	158,410	Demand fee
	Operation & Maintenance (annual)	LS	222,000	Electricity, Labors, Maintenance, Spares and Chemical
	Replacement	Unit	204,000	High Pressure and Membranes

Can be representing income and expenses over a time interval of 22 year by Cash flow diagrams (CFD) that are illustrated in chart (4-1).

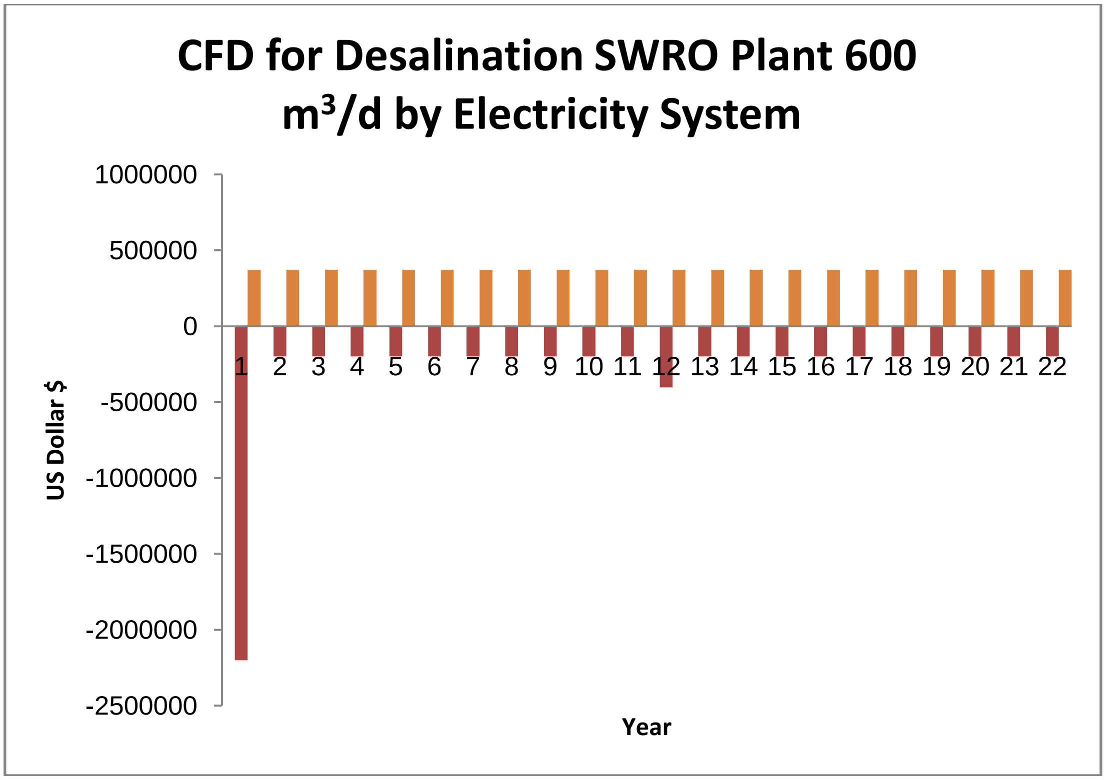


Chart (4-1) CFD for SWRO Plant depend on Electricity Source

Finally, to estimate the IRR value of project, the appropriate discount rate should be determined by Net Present Value (NPV) to properly valuing future cash flows, whether they will be earnings or obligations. Show table (4-5).

Table (4-5) NPV for SWRO Plant depend on Electricity Source

Year	1	2	---	22	Total US $
Investment Cost	2,000,000		---		
O&M Cost	200,000	200,000	---	200,000	
Cost	2,200,000	200,000	---	200,000	6,604,000
NPVc	2,200,000	187,619	---	52,267	4,539,786
Revenues	372,300	372,300	---	372,300	8,190,600
NPVr	372,300	349,253	---	97,296	4,539,786
Net Cash Flow	1,827,700	172,300	---	172,300	1,586,600

The internal rate of return is 6.6 %, When the discount rate that will cause the net present value of the project to be equal to zero. Show table (4-6) and chart (4-2).

Table (4-6) IRR for SWRO Plant depend on Electricity Source

IRR	3.00%	4.00%	5.00%	6.60%	7.00%	8.00%	9.00%
NPVc	5,430,379	5,138,346	4,883,505	4,539,786	4,464,024	4,290,853	4,137,505
NPVr	6,111,313	5,595,356	5,145,615	4,539,786	4,406,367	4,101,556	3,831,802

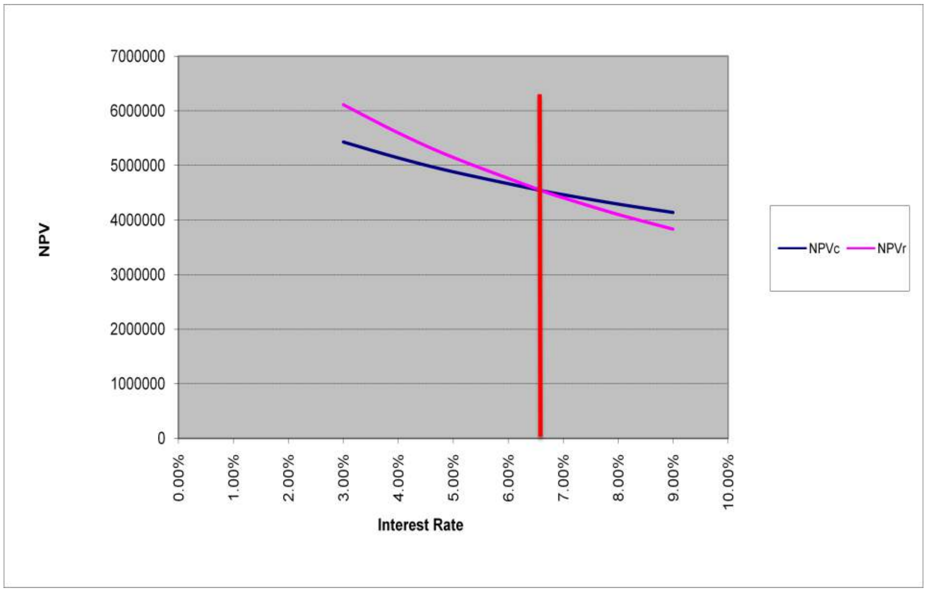


Chart (4-2) IRR for SWRO Plant depend on Electricity Source

From the previous analysis, we can note that the IRR value of project equals to 6.60 %. The IRR value of project is higher than the interest rate in Palestine that equals 6.43 %. So the value is feasible from the standpoint of investors.

4.4.2 Desalination Plant Using SES (Off Grid)

Figure (4-4), representing of Second scenario of the proposed plant, that depend on Solar energy System only that know as (Off Grid System).

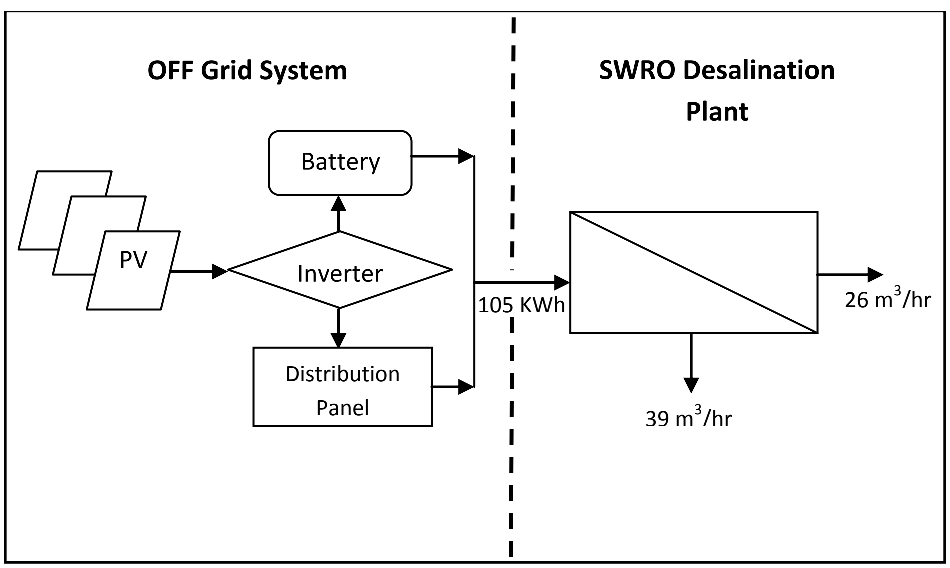


Figure (4-4) SWRO Plant depend on Off Grid System

Off-grid systems are not connected to the electricity grid. The output of the off-grid system is entirely dependent upon the intensity of the sun. The more intense the sun exposure, the greater the output., show figure (4-5).

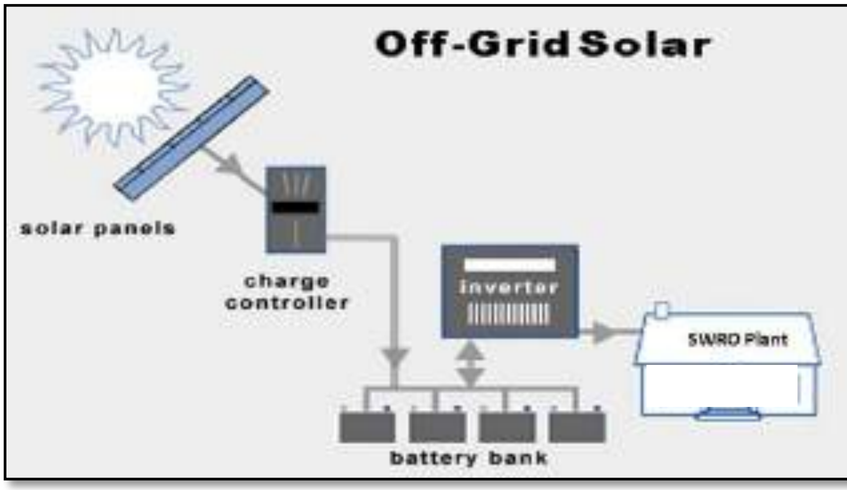


Figure (4-5) Off Grid Solar System

Table (4-7) shows the estimated investment costs which was computed based on the experts in the CMWU, PENRA, PLA and other company. The profits of the project were estimated based on the sale price and the production unit of the plant ($ per one Cubic meter of desalted water), The annual profits as following:

$1.7\ \$/m^3 * 600\ m^3/d * 365\ d = 372{,}300\ \$/year.$

Table (4-7) Costs Elements for SWRO Plant

Cost Type	Cost Element	Unit	Cost $	Details
Fixed	SWRO Desalination Plant	Unit	1,000,000	Intake, RO, Storage, Distribution and Facilities
	Land	m2	1,000,000	Industrial Land 7000 m2
Variables	Energy System	Kw	2,416,490	PV Panels and Batteries
	Operation & Maintenance (annual)	LS	25,000	Labors, Maintenance, Spares and Chemical
	Replacement	Unit	1,160,119	High Pressure, Membranes and Batteries

Can be representing income and expenses over a time interval of 22 year by Cash flow diagrams (CFD) that are illustrated in chart (4-3).

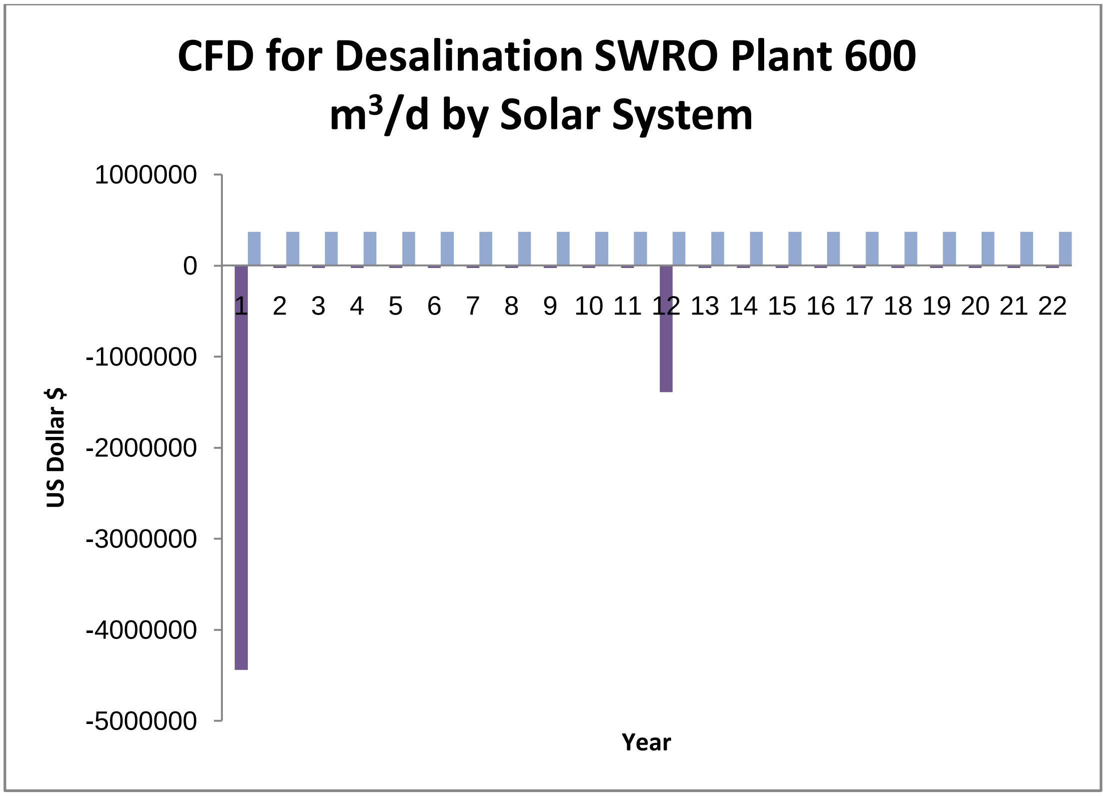


Chart (4-3) CFD for SWRO Plant depend on Off Grid System

Finally, to know the IRR value of the project, we should determine the appropriate discount rate by Net Present Value (NPV) to properly valuing future cash flows, whether they will be earnings or obligations. Show table (4-8).

Table (4-8) NPV for SWRO Plant depend on Off Grid System

Year	**1**	**2**	**3**	**---**	**22**	**Total US $**
Investment Cost	2,000,000			---		
O&M Cost	25,000	25,000	25,000	---	25,000	
Solar System Cost	2,416,490			---		
Cost	4,441,490	25,000	25,000	---	25,000	6,330,405
NPVc	4441489.92	24,092	23,216	---	11,492	5,707,519
Revenues	372,300	372300	372,300	---	372,300	8,190,600
NPVr	372,300	358,773	345,737	---	171,136	5,707,519
Net Cash Flow	4,069,190	347,300	347,300	---	347,300	1,860,195

The internal rate of return is 3.8 %, When the discount rate that will cause the net present value of the project to be equal to zero. Show table (4-9) and chart (4-4).

Table (4-9) IRR for SWRO Plant depend on Off Grid System

IRR	**1.0%**	**2.0%**	**3.0%**	**3.8%**	**5.0%**	**6.0%**	**7.0%**
NPVc	6,135,424	5,963,717	5,812,187	5,707,519	5,559,472	5,454,085	5,360,364
NPVr	7,392,755	6,705,573	6,111,313	5,707,519	5,145,615	4,752,066	4,406,367

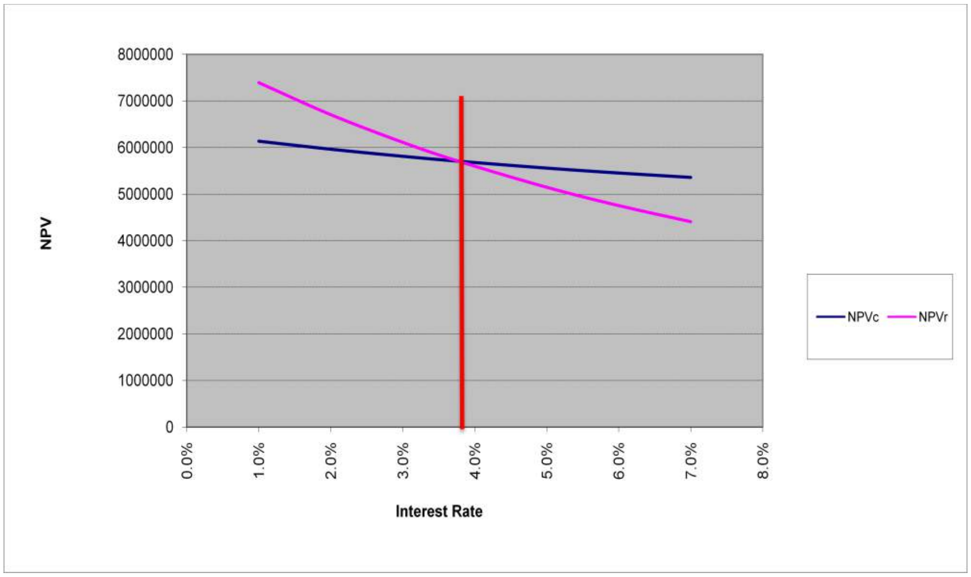


Chart (4-4) IRR for SWRO Plant depend on Off Grid System

From the previous analysis, we can note that the IRR value of project equals 3.80 %. The IRR value of project is lower than the interest rate in Palestine that equals 6.43 %. So the value is not feasible from the standpoint of investors.

4.4.3 Desalination Plant Using CED (On Grid)

Figure (4-6), represents the third scenario of the proposed plant, that depend on solar energy system only (ON Grid System).

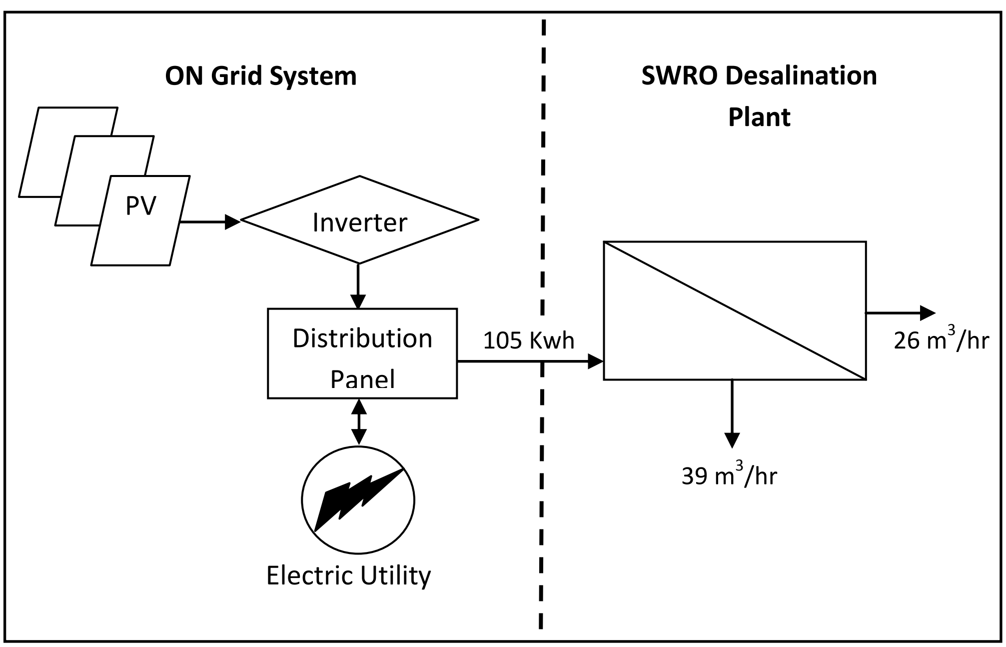


Figure (4-6) SWRO Plant depend on ON Grid System

The prime advantage of this type of system is the ability to balance the system production and plant power requirements. When a grid inter-tied system is producing more power than the Plant is consuming, the excess can be sold back to the utility in a practice known as net metering. When the system is not producing sufficient power, the Plant can draw power from the utility grid, show figure (4-7).

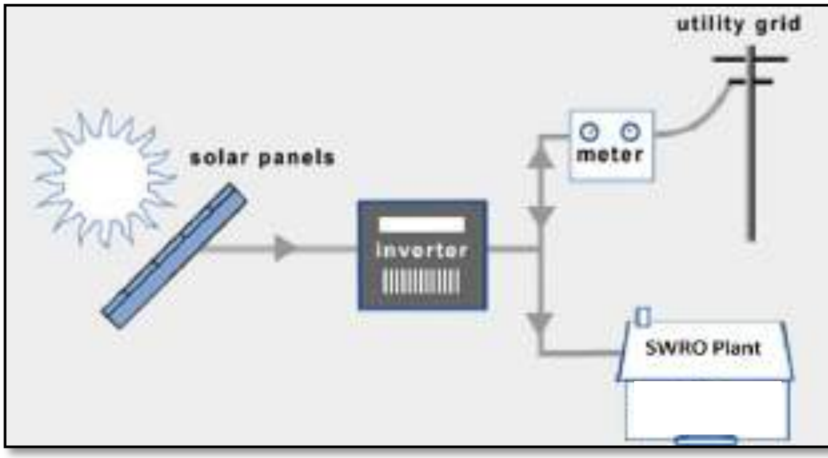


Figure (4-7) ON Grid Solar System

Table (4-10) shows the estimated investment costs. These costs have been prepared by referring to the experts in the CMWU, PENRA, PLA and other company. The profits of the project were estimated based on the sale price and production unit of the plant ($ per one Cubic meter of desalted water), The annual profits are as follows:
1.7 $/m^3 * 600 m^3/d * 365 d = 372,300 $/year.

Table (4-10) Costs Elements for SWRO Plant

Cost Type	Cost Element	Unit	Cost $	Details
Fixed	SWRO Desalination Plant	Unit	1,000,000	Intake, RO, Storage, Distribution and Facilities
	Land	m2	1,000,000	Industrial Land 7000 m2
Variables	Energy System	KW	1,256,575	All Units
	Operation & Maintenance (annual)	LS	76,090	Electricity, Labors, Maintenance, Spares and Chemical
	Replacement	Unit	204,000	High Pressure and Membranes

Can be representing income and expenses over a time interval of 22 year by Cash flow diagrams (CFD) that are illustrated in chart (4-5).

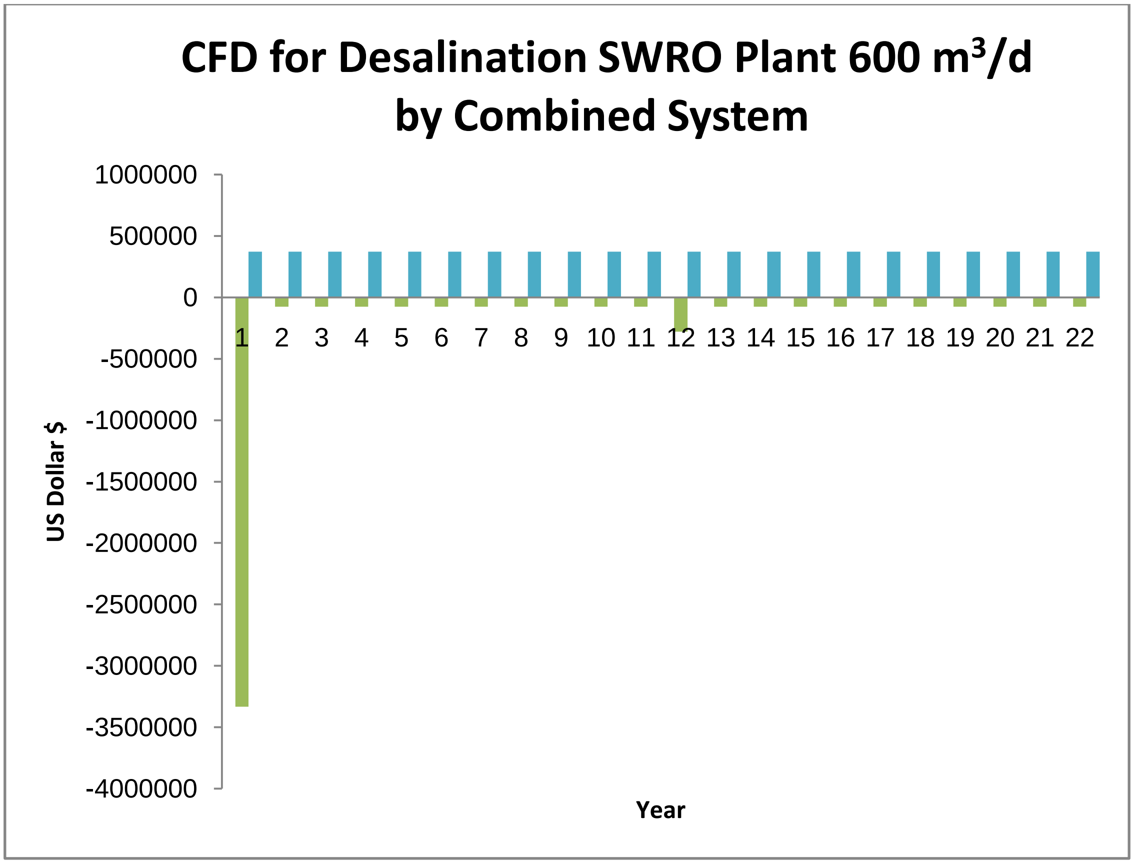


Chart (4-5) CFD for SWRO Plant depend on ON Grid System

Finally, to know the IRR value of the project, we should determine the appropriate discount rate by Net Present Value (NPV) to properly valuing future cash flows, whether they will be earnings or obligations. Show table (4-9).

Table (4-11) NPV for SWRO Plant depend on ON Grid System

Year	1	2	---	22	Total US $
Investment Cost	2,000,000		---		
O&M Cost	76,090	76,090	---	76,090	
Solar System Cost	1,256,575		---		
Cost	3,332,664	76,090	---	76,090	5,134,548
NPVc	3,332,664	70,690	---	16,216	4,207,205
Revenues	372,300	372,300	---	372,300	8,190,600
NPVr	372,300	345,878	---	79,344	4,207,205
Net Cash Flow	2,960,364	296,210	---	296,210	3,056,052

The internal rate of return is 7.64 %, When the discount rate that will cause the net present value of the project to be equal to zero. Show table (4-10) and chart (4-4).

Table (4-12) IRR for SWRO Plant depend on ON Grid System

IRR	4.00%	5.00%	6.00%	7.64%	8.00%	9.00%	10.00%
NPVc	4,532,654	4,427,497	4,335,254	4,207,205	4,182,332	4,118,765	4,062,242
NPVr	5,595,356	5,145,615	4,752,066	4,207,205	4,101,556	3,831,802	3,592,209

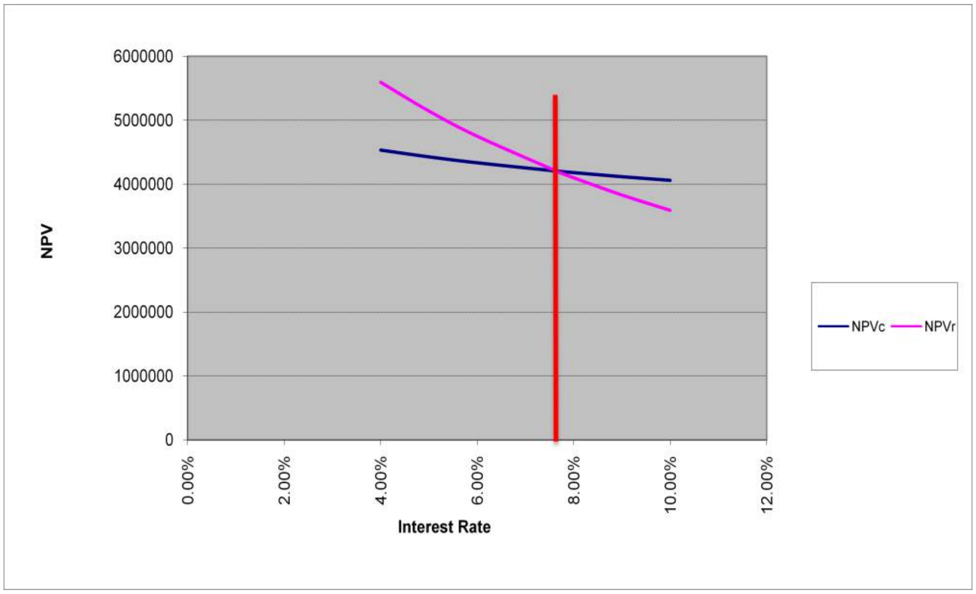


Chart (4-6) IRR for SWRO Plant depend on ON Grid System

From the previous analysis, we can note the IRR value of project equals 7.64 %. The IRR value of project is higher than the interest rate in Palestine that equals 6.43 %. So the value is feasible from the standpoint of investors.

4.5 Comparison of the Scenarios by IRR value as Economic Indicator

The cost of SWRO Desalination Plant (600m^3/d) that depends on the Combined System (On Grid Solar System) as energy source is the lowest cost between other scenarios. This is reflected positively according to the economic indicator (IRR value). Show table (4-10) and chart (4-7).

Table (4-13) Three Scenarios Cost with IRR value

Energy System		IRR	4%	5%	6%	8%	9%
NPVc of System US $	C.S (On Grid)	7.64%	5,595,356	5,145,615	4,752,066	4,101,556	3,831,802
	E.S (Electric Utility)	6.60%	5,595,356	5,145,615	4,623,585	4,101,556	3,831,802
	S.S (Off Grid)	3.80%	5,539,165	5,145,615	4,752,066	5,145,615	5,539,164

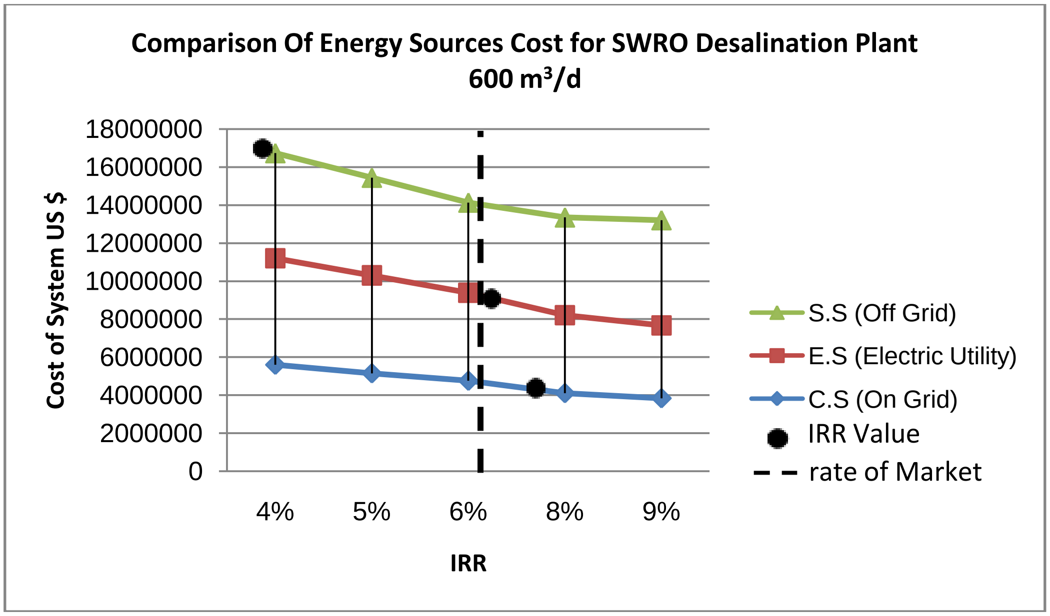


Chart (4-7) Three Scenarios Cost with IRR value

The third scenario was selected as the best economic option to optimize the cost of the desalination plant in Deir El-Balah desalination plant. The next chapter will discuss the selected system.

5 OPTIMAL ENERGY SYSTEM

5.1 Introduction

The third scenario was selected as the best economic option to optimize the cost of the desalination plant in Gaza. It depends on solar energy System and Electricity Energy that is known as (ON Grid Solar System) show following figure (5-1).

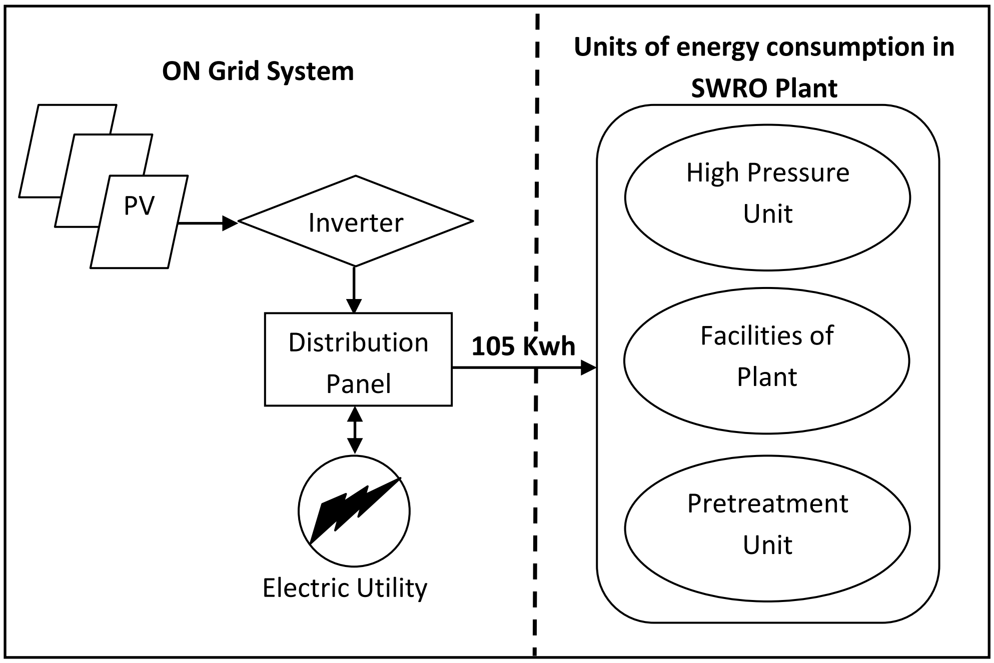


Figure (5-1) On Grid Solar System

The On Grid Solar System has the ability to balance the system production and Plant power requirements. When a grid inter-tied system is producing more power than the Plant is consuming, the excess can be sold back to the utility in a practice known as net metering. When the system is not producing sufficient power, the Plant can draw power from the utility grid. The net metering is a special metering and billing agreement between utilities and their customers, which facilitates the connection of solar systems to the power grid. These programs encourage small-scale renewable energy systems to provide substantial benefits to the electric power-generating system, the economy, and the environment.

Supporting legislations to the implementation this system based on Palestine energy law of No.13, 2009, which states that Articles of Palestine Energy and Natural Resources Authority (PENRA) laws.

5.2 Major System Components

Figure (5-2), representing of main components for solar energy system (ON Grid System), that are PV Module, Inverter and Net Meter.

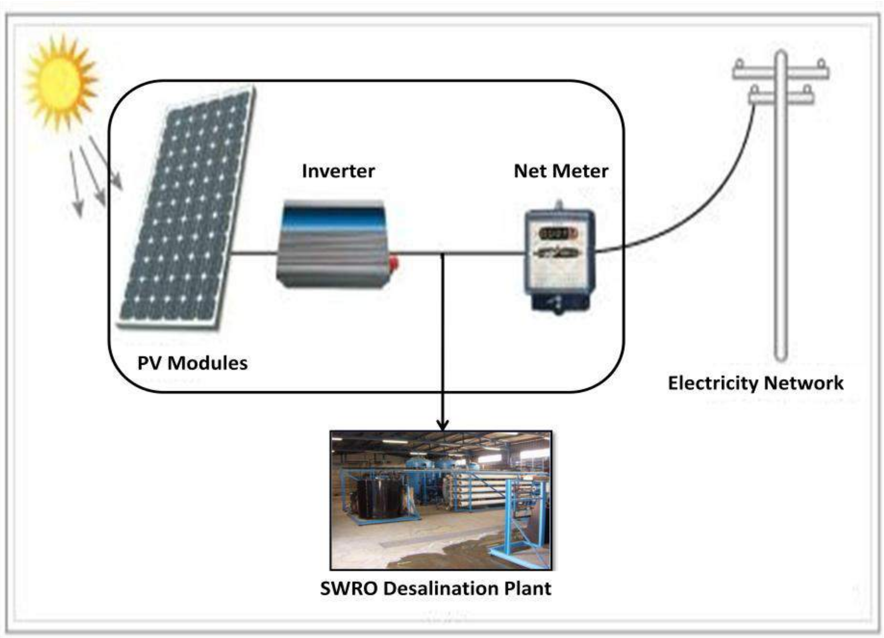


Figure (5-2) Solar Energy Components

5.2.1 PV module

The main function of PV panels is converting the sunlight into DC electricity. So, the conversion efficiency is the percentage of power converted from sunlight to electrical energy under "standard test conditions" (STC) that is selection criteria of PV module from following figure (5-3) [11].

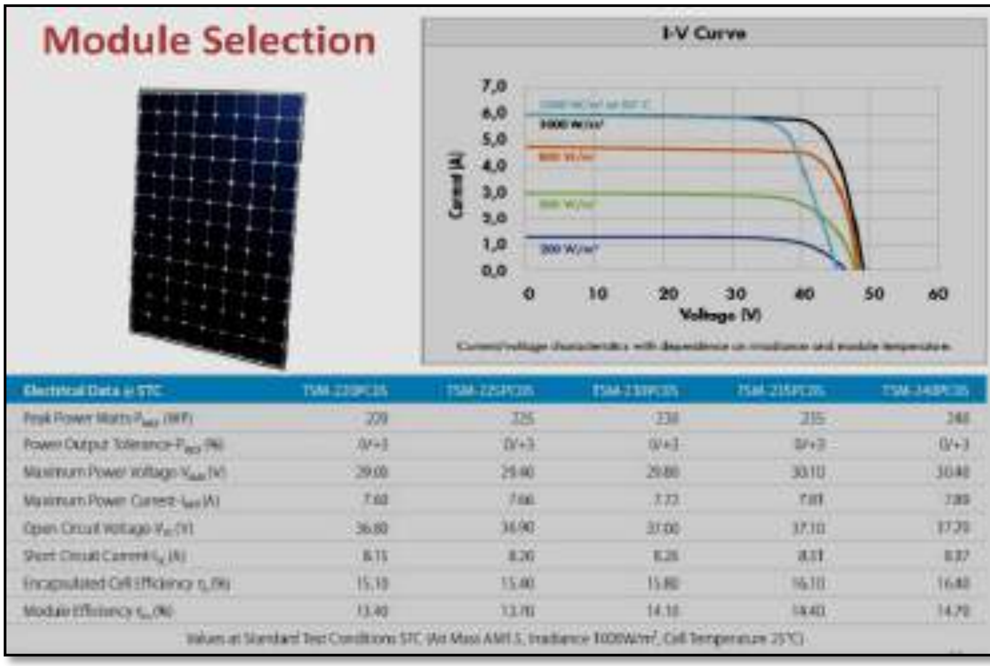


Figure (5-3) PV Module Selection

5.2.2 Inverter

Converts DC output of PV panels into AC current for AC appliances or fed back in to grid line.

5.2.3 Net Metering

Is a special metering and billing agreement between utilities and their customers, which facilitates the connection of solar systems to the power grid.

5.2.4 Load

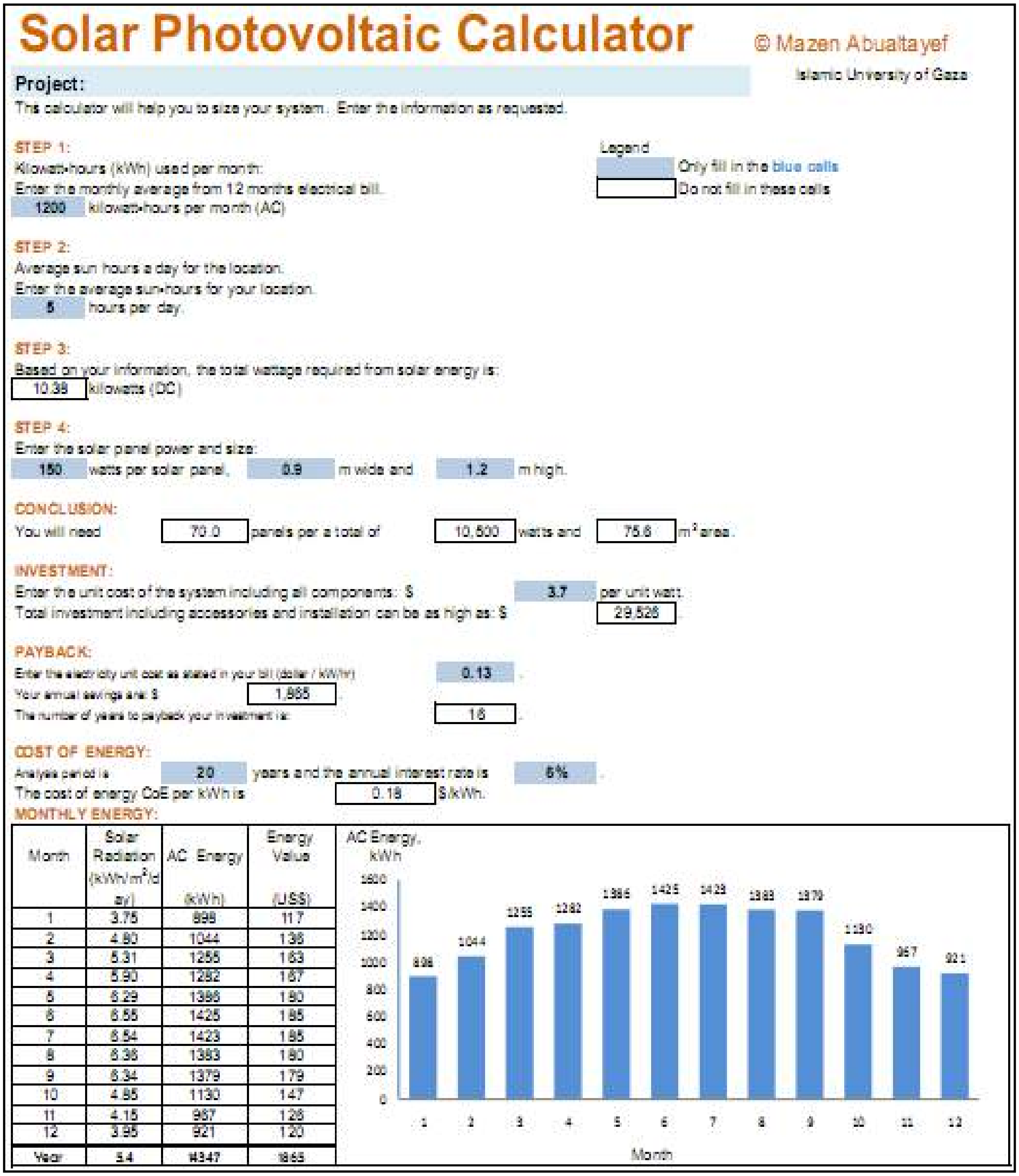
Is electrical appliances that connected to solar PV system that up to 105 kWh in SWRO Desalination Plant that consist of high pressure unit, pretreatment unit and facilities plant.

5.3 Modeling Energy System

To model the solar energy system we have used a solar photovoltaic calculator which originally developed by Abualtayef, 2012 and modified by the researcher
and can be found in following link [27].

http://site.iugaza.edu.ps/mabualtayef/files/PV-calculator.xls

The model was built using Microsoft Excel as analysis tool to determine Sizing the photovoltaic generator and system costs that are depended on some of energy and economic parameters in Gaza strip show figure (5-4).



Solar Photovoltaic Calculator © Mazen Abualtayef

Islamic University of Gaza

Project:

This calculator will help you to size your system. Enter the information as requested.

Legend

Only fill in the blue cells

Do not fill in these cells

STEP 1:

Kilowatt-hours (kWh) used per month:

Enter the monthly average from 12 months electrical bill.

1200 kilowatt-hours per month (AC)

STEP 2:

Average sun hours a day for the location.

Enter the average sun-hours for your location.

5 hours per day.

STEP 3:

Based on your information, the total wattage required from solar energy is:

10.38 kilowatts (DC)

STEP 4:

Enter the solar panel power and size:

150 watts per solar panel, 0.9 m wide and 1.2 m high.

CONCLUSION:

You will need 70.0 panels per a total of 10,500 watts and 75.6 m^2 area.

INVESTMENT:

Enter the unit cost of the system including all components: $ 3.7 per unit watt.

Total investment including accessories and installation can be as high as: $ 29,526

PAYBACK:

Enter the electricity unit cost as stated in your bill (dollar / kW/hr) 0.13 .

Your annual savings are: $ 1,865

The number of years to payback your investment is: 16 .

COST OF ENERGY:

Analysis period is 20 years and the annual interest rate is 6% .

The cost of energy CoE per kWh is 0.18 $/kWh.

MONTHLY ENERGY:

Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value (US$)
1	3.75	898	117
2	4.80	1044	136
3	5.31	1255	163
4	5.90	1282	167
5	6.29	1386	180
6	6.55	1425	185
7	6.54	1423	185
8	6.36	1383	180
9	6.34	1379	179
10	4.85	1130	147
11	4.15	967	126
12	3.95	921	120
Year	5.4	14347	1865

Figure (5-4) Modeling Energy System using Microsoft Excel

5.3.1 Calculation of Solar Energy System Sizing

System sizing is the process of evaluating the adequate voltage and current ratings for each component of the photovoltaic system to meet the electric demand at the facility and at the same time calculating the total price of the entire system from the design phase to the fully functional system including, shipment, and labor.

The more factors Affecting System Sizing are geographical location that dictates the tilt angel, panel orientation, and the average sun hours per day

- **Environmental Data**

Palestine has a high solar energy potential, where average solar energy is between 2.63 kWh/m^2 per day in December to 8.5 kWh/m^2 per day in June, and the daily average of solar radiation intensity on horizontal surface, peak sunshine hour PSSH (5.31 kWh/m^2 per day) while the total annual sun shine hours amounts to about 3000. The annual average temperature amounts to 22 C^o while it exceeds 30 C^o during summer months [28], these figures are very encouraging to use Photovoltaic generators for SWRO desalination plant.

The solar radiation data has a great effect on the performance of photovoltaic (PV) systems. Table (5-1) shows the monthly values of solar energy [28].

Table (5-1) Average of PSSH in Palestine

Month	Mean of PSSH KWh/m2/day (1989-2002)
Jan	3.36
Feb	3.97
Mar	4.33
Apr	5.19
May	6.46
Jun	7.78
Jul	7.40
Aug	6.76
Sep	5.88
Oct	4.73
Nov	4.31
Dec	3.53
Mean	5.31

Chart (5-1) shows the average monthly solar energy on horizontal surface plotted from data of table (5-1).

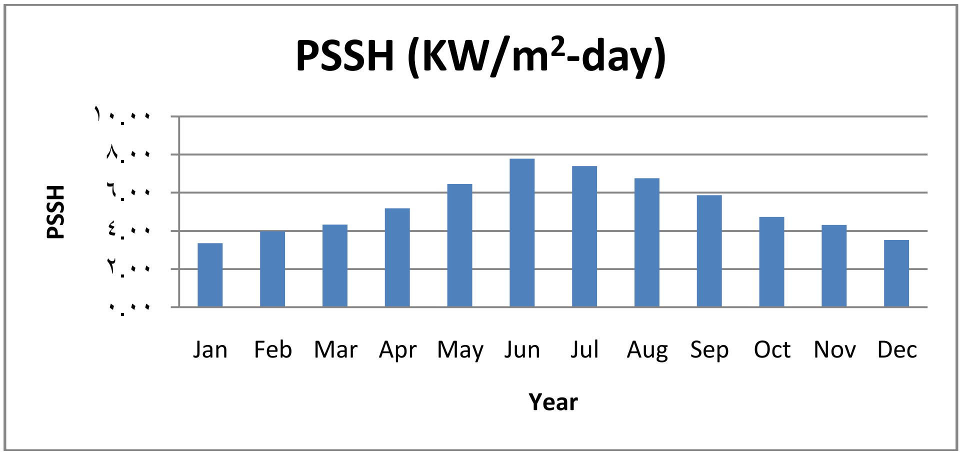


Chart (5-1) Average monthly solar energy on horizontal surface

- **Power Consumption Data**

The expected power consumption based on seawater with a feed TDS of 40.000 ppm and a plant recovery of 40 %.

The total power load required to operate the RO during 24 hours is 2520 KW/day, 90 KWh/day for High-pressure unit and 15 KWh/day for Other Units in desalination plant. Show the second description at following the table (5-2) [23].

Table (5-2) Power Consumption of SWRO Plant

Description	Required unit operation power	Specific power Consumption
Well pumps for water supply	14,0 kWh/h	0,65 kWh/m3 Desalted water
Pretreatment and RO Plant	105 kWh/h	4 kWh/m3 Desalted water
Water filling and distribution station	27 kWh/h max.	0,50 kWh/m3 Desalted water

- **Sizing the photovoltaic generator.**

To design the PV module it is important to take into consideration not only the RO unit power load but also other parameters such as inverter losses and the PV thermal losses [29].The peak power of the PV generator (Ppv) is obtained as: [30]

$$P_{pv} = \frac{E_l}{PSSH * \eta_b * \eta_{inv}} S_F$$

where PSSH is the peak sunshine hours and it was found for the Palestinian territories to be 5.31 hours [30] . rjtm,= Inverter losses, rj,= 15%, and S.F = Safety factor, for PV thermal losses for Palestinian environment =1.15% Using above values in following equation, we obtain the peak power of PV array should produce 654 W and to install this power.

A high-power module using multi-crystalline silicon cells with 14.3% module conversion efficiency and a gross area of 120cm x 90 cm rated at open circuit voltage 29 volts, and a short circuit current of 8.15 A is necessary. A peak power of Pmpp = 150Wp was selected. Then the necessary number of PV modules[30] (Npv) is 4361 that need 4710 m^2 of land.

$$N_{pv} = \frac{P_{pv}}{P_{mmp}}$$

- **Inverter sizing**

Total KiloWatt of all appliances = 105 KWh,for safety, the inverter should be consi dered 25to30% bigger size. The inverter size should be about 818 KW or greater.

5.3.2 Calculation of System Cost

From the economical point of view, photovoltaic energy system differ from conventional energy systems in that they have high initial cost and low operating costs[31]. The price of the PV system and its installation are important factors in the economics of PV systems. These include the prices of PV modules, storage batteries, the control unit, the inverter, and all other auxiliaries. The cost of installation must be taken into consideration.

For the present PV system, the life cycle cost will be estimated as follows:

1- The lifecycle of the system components will be considered as 22 years

2- The interest rate is about 6.43%. based on PMA.

The initial cost of the PV system = PV with all requirements it + inverter cost The initial cost of the PV system = 1,248,409 + 8166 = 1,256,575 US $.

The life cycle cost of PV system is obtained by drawing cash flow as in figure (5-5):

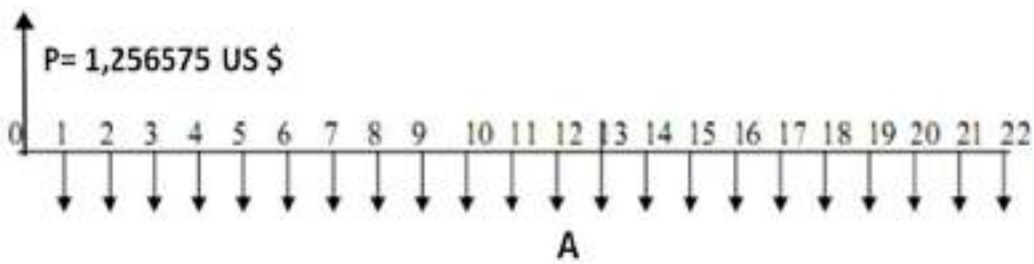


Figure (5-5) Cash Flow Diagram (CFD) of PV System

The term P (A / P i ,n), is called the capital-recovery factor, or A/P factor, yields the equivalent uniform annual worth A over n years of a given investment P when the interest rate is i ,and (A/P) factor solved by using following equation [32]:

$$A = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]$$

The cost of 1 kWh from the PV generator = 0.13 US $/kWh, and The number of years to payback your investment is 9 Years.

5.3.3 Net Metering of System

Combined system is able to balance the system production and plant power requirements. In June, The grid inter-tied system is producing more power than the Plant is consuming which is up to 23,637 KWh, the excess can be sold back to the utility. When the system is not producing sufficient power, the Plant can draw power from the utility grid which is up to 28,394 KWh in January. So it will be reading of net meter up to 12,500 $/year of plant. Shown in table (5-1).

Table (5-3) Net of Energy and Cost from Electric Utility

Mon.	PSSH	AC Energy	Electricity Cost	Energy Value	Req. Energy	Net Energy	Net Cost
	(kWh/m2/day)	(kWh)	(US$)	(US$)	(kWh)/m	(kWh)	(US$)
1	3.36	47,206	0.17	8,119	75600	-28,394	-4,884
2	3.97	50,688		8,718		-24,912	-4,285
3	4.33	60,033		10,326		-15,567	-2,677
4	5.19	66,200		11,386		-9,400	-1,617
5	6.46	83,594		14,378		7,994	1,375
6	7.78	99,237		17,069		23,637	4,065
7	7.40	94,390		16,235		18,790	3,232
8	6.76	86,226		14,831		10,626	1,828
9	5.88	75,001		12,900		-599	-103
10	4.73	64,705		11,129		-10,895	-1,874
11	4.31	58,959		10,141		-16,641	-2,862
12	3.53	48,289		8,306		-27,311	-4,697
	5.31	834,527	0.17	143,539	75600	-72,673	-12,500

The produced power by On Grid Solar System can be presented at the following chart (5-2). For each month that illustrates the variation in the monthly daily average in total insolation on horizontal surface that depend on PSSH for each month, which is up to higher value during summer season.

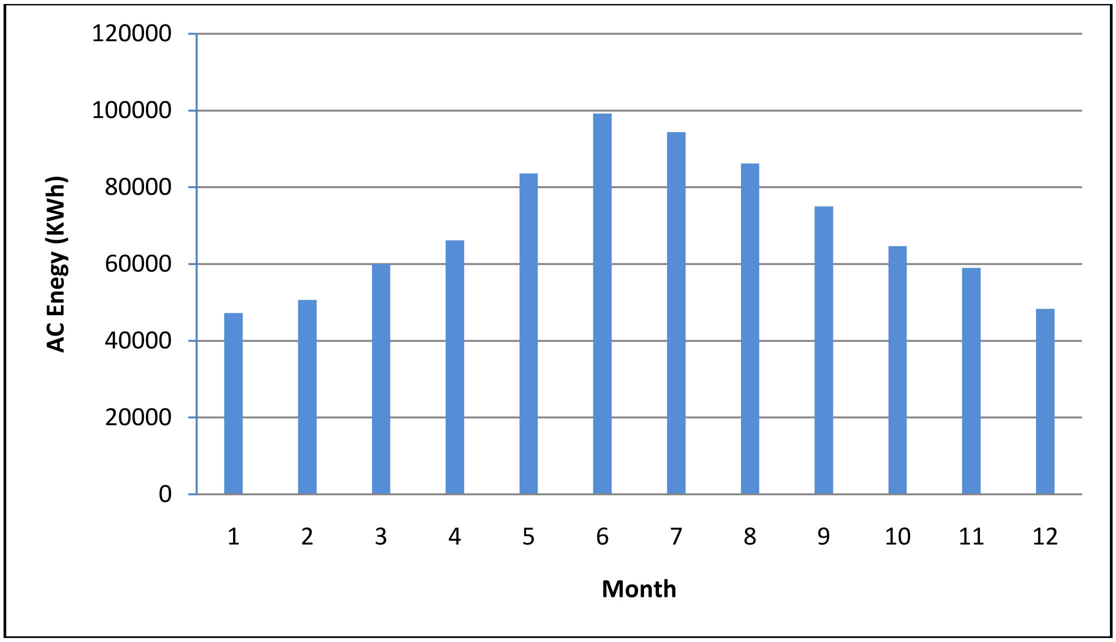


Chart (5-2) Produced Monthly Energy

6 DISCUSSION AND ANALYSIS

6.1 Energy Systems Cost

Investment cost of SWRO Desalination Plant (600m^3/d) that depends on Combined System (On Grid Solar System) as energy source is the lowest cost between other scenarios which is up to 0.13 $/KWh. This is reflected positively to economic indicator (IRR value). Show table (6-1).

Table (6-1) Comparison of Energy Systems Cost

Energy System	IRR	$/KWh
Solar Energy System (Off Grid)	3.77%	0.27
Electricity Energy System (Electric Utility)	6.6%	0.17
Combined Energy System (On Grid)	7.64%	0.13

Can be note the difference of IRR values of the project, shown in chart (6-1). The Interest rate in Palestine is 6.43 % so the IRR value should be higher than the local interest rate to consider the project as a cost effective project from the standpoint of investors.

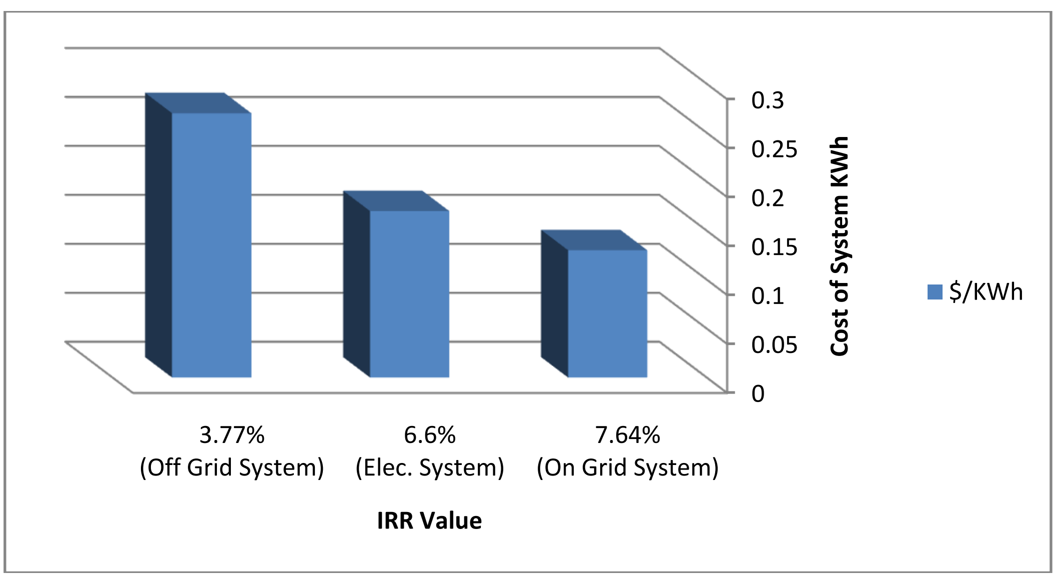


Chart (6-1) Comparison of Energy Systems Cost

6.2 Combined System Costs

On Grid solar system it is able to balance the system production and plant power requirements. In May, June, July and August, the grid inter-tied system is producing more power than the Plant is consuming, the excess can be sold back to the utility which up to 61046 $/year from plant. When the system is not producing sufficient power, the Plant can draw power from the utility grid which is estimated 133719 $/year for plant, shown in table (6-2). So will be reading of net meter with each year which up to 12500 $/year of plant. Show chart (6-2).

Table (6-2) Saving Cost of Combined System

Energy	AC Energy	Electricity Cost	Req. Energy	Net Energy	Net Cost
Mon.	(kWh)	(US$)	(kWh)/month	(kWh)	(US$)
1	47,206	0.17	75,600	-28,394	-4,884
2	50,688			-24,912	-4,285
3	60,033			-15,567	-2,677
4	66,200			-9,400	-1,617
5	83,594			7,994	1,375
6	99,237			23,637	4,065
7	94,390			18,790	3,232
8	86,226			10,626	1,828
9	75,001			-599	-103
10	64,705			-10,895	-1,874
11	58,959			-16,641	-2,862
12	48,289			-27,311	-4,697
SUM	83,4527	0.17	75,600	-72,673	-12,500

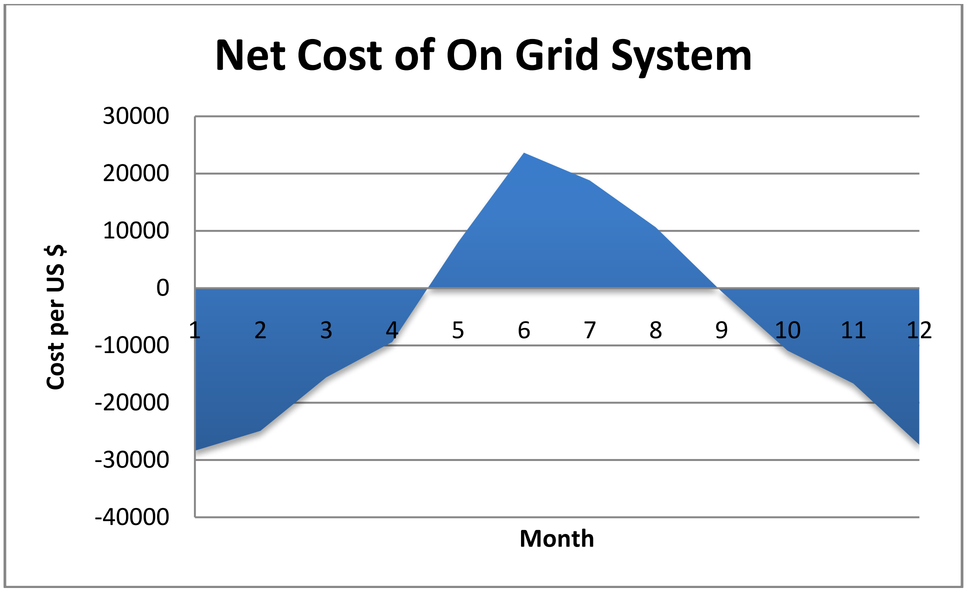


Chart (6-2) Net Cost of On Grid Solar System

6.3 Saving Values Of Optimal System

To estimate saving value, we should be take traditional power as baseline value. The cost of Electricity system during lifespan of the project is higher than the investment cost of On Grid Solar System; this reduction costs 25 % of conventional System, Shown in table (6-3).

The Net Metering process increases the Solar System Efficiency and can be saving more values, which is up to 17 % as saving value by On Grid Solar System.

Table (6-3) Saving Value of Optimal System

Element	Baseline (Elec. System)	Solar System	Net Meter	Combined System	Net Saving
NPV of Cost ($/22Year)	3,432,845	2,589,780	274,993	2,849,261	568,071
%	100%	75%	8%	83%	17%

The efficiency of Net Metering System is 92 % as illustrated of saving results. So the Net saving value is enough to operating cost during 7.5 year for SWRO Desalination Plant.

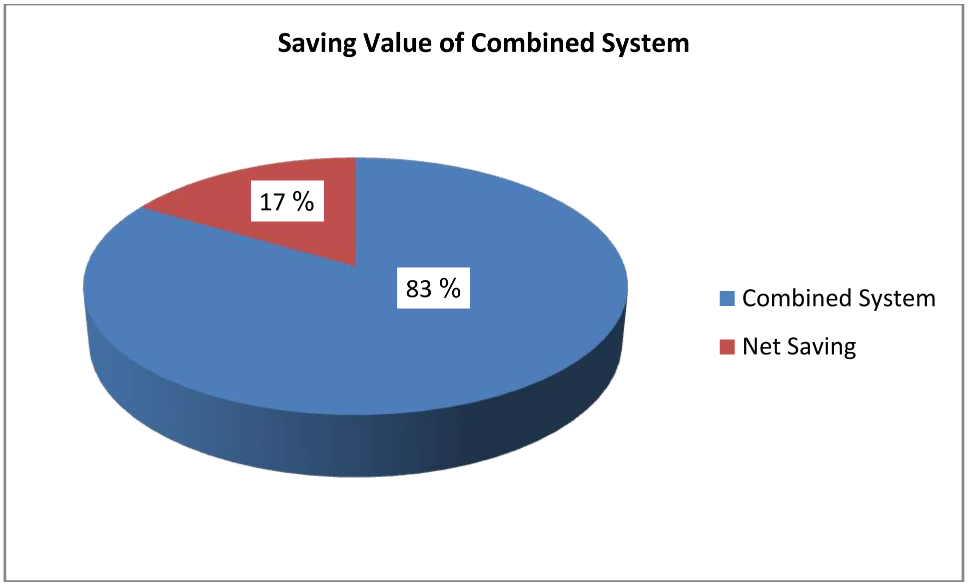


Chart (6-3) Saving Value of Combined System

6.4 Cost Reduction of Desalinated Water

When the reduction of operation and maintenance cost in the plant happens, that will decrease the production cost of desalinated water unit m^3. See following table (6-4).

Table (6-4): Cost Reduction

Energy System	NIS/m^3	Reduction
Electricity System	4	0.0%
Combined System	3.3	17%

Cost of O&M in the plant using electricity system only is 200,000 $/year, but using On Grid Solar System it will be 76,090 $/year. Hence, reflected on the cost of produced water per cubic meter. See chart (6-4)

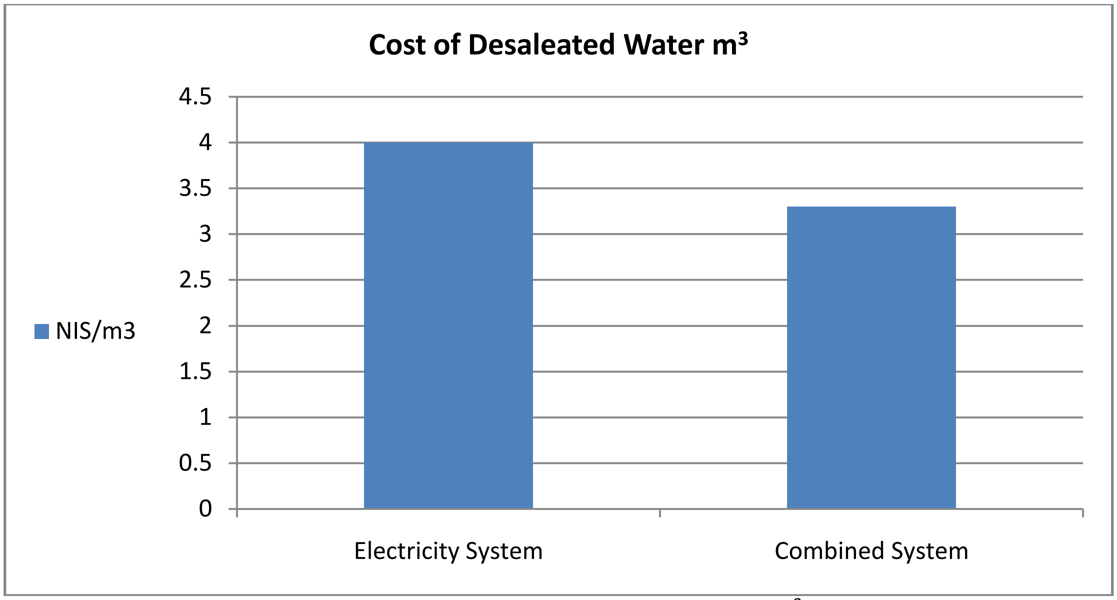


Chart (6-4) Cost of Desalinated Water m^3

6.5 Cost Reduction of PV Modules

There is a big potential for further reductions of PV system costs. Less expensive materials would allow to cut significantly the costs of PV modules. Even if it is still uncertain how fast and to what extent this potential could be tapped by the PV industry, in the project it is enough evidence to indicate that PV systems in grid-connected building-integrated applications will be able to reach the break-even price and then compete without incentives with electricity [33].

7 CONCLUSION AND RECOMMENDATION

7.1 Conclusion

The study focused on the optimal use of solar energy and selection of the most economically feasible configuration of utilizing this source either fully or partially in the SWRO process. Internal Rate of Return (IRR) has been used as an economic indicator to analyze the feasibility of establishing a SWRO desalination plant with a capacity of 600 m^3/d in Gaza based on the optimal energy sources. The available options of energy sources for the proposed desalination Plant were the following:

1- Electricity Energy System (Electric Utility) or EES
2- Solar Energy System (Off Grid System) or SES
3- Combined Energy System (On Grid System) or CES

Results differ between the three plants scenarios according to the source of energy used and the economic analysis for the project throughout its assumed period of 22 years, results are presented in more details as follows:

1- SWRO Desalination Plant Using EES

This source depends completely on the local power company, it is the traditional system present, and that will be the baseline to calculate the quantities of savings in any other system. The following is the overall results for its economic analysis:

- Net Cost Value: 4,539,786 US $
- IRR Value: 6.60%
- Cost of Energy source: 0.17 $/KWh
- Cost of Desalinated Water: 1.05 $/$m^3$
- Saving Value: 0.00 %

2- SWRO Desalination Plant Using SES

Off-grid systems are not connected to the electricity grid. The output of an off-grid system is entirely dependent upon the intensity of the sun. The more intense the sun exposure, the greater the output. And after doing economic analysis for the assumed period of this scenario, results were as follows:

- Net Cost Value: 5,707,519 US $
- IRR Value: 3.8%
- Cost of Energy source: 0.27 $/KWh

- Cost of Desalinated Water: 1.5 $/m^3$
- Saving Value: -30%

3- SWRO Desalination Plant Using CES

Combined system is able to balance the system production and plant power requirements. In June, The grid inter-tied system is producing more power than the Plant is consuming which is up to 23637 KWh, the excess can be sold back to the utility. When the system is not producing sufficient power, the Plant can draw power from the utility grid which is up to 28394 KWh in January. So it will be reading of net meter up to 12500 $/year of plant. And after doing economic analysis for the assumed period of this scenario, results were as follows:

- Net Cost Value: 4,207,205 US $
- IRR Value: 7.64%
- Cost of Energy source: 0.13 $/KWh
- Cost of Desalinated Water: 0.89 $/m^3$
- Saving Value: 17%

The third scenario will be selected as the best economic option to optimize the cost of the desalination plant in Gaza. Considering the On-Grid system, the unit cost for desalinated water will be reduced from 1.08 $/m3 to 0.89 $/m3 which is about 17% saving. and an estimated U.S. $ 568071 that is enough for the operating cost during 7.5 years for SWRO Desalination Plant.

7.2 Recommendations

- There is a big potential for further reductions of PV system costs, hence can be fully reliable in the future.

- ON Grid Solar System is most feasible between other solar systems in Gaza at now.

- Awareness campaign regarding the crises of energy situation and why we should look for alternatives energy sources.

- Promote the solar industry of all types.

- Donors must be encouraged to allocate funds for power generation projects in locations where they are found feasible.

- This study must be followed up for further research and investigation of possible technologies and sectors that are not studied here.

- Regulations and legislations for using the renewable energy sources, especially solar energy.

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الْحَمْدُ لِلَّهِ

الَّذِي بِنِعْمَتِهِ

تَتِمُّ الصَّالِحَاتُ