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Water Desalination Using Renewable Energy Resources Based on a Cogeneration Principle

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ABSTRACT
Water scarcity and the shortage of potable water in most world regions are considered a significant challenge to scientists and researchers, hence more efforts needed to address the problem. The sole available solution today is using desalination technologies, which work to extracts freshwater or distillate water from seawater or brackish water. Applied desalination technologies can be divided into two main groups, thermal and membrane-based desalination technologies. Membrane technologies today are performing well against the thermal desalination and have registered higher thermal efficiency recently. The reverse osmosis (RO) technology is the most common among membrane-based desalination processes, which is considered the most predominant in the desalination market worldwide. Cogeneration or combined the reverses osmosis desalination and renewable power plants offer a promising prospect for covering the fundamental needs of power and water in remote regions such as grid-limited villages or isolated islands that have access to the sea or brackish water. However, cogeneration plants based on the reverse osmosis and renewable power plants is an exciting area for scientific researchers and an attractive solution to achieve sustainable development and secure availability of clean water.
Keywords; desalination, reverses osmosis,renewable energy, cogeneration plants, steam turbine, Intercooled Gas Turbine Engine.

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I. INTRODUCTION

As population increase water demand increase this clear demand gap should be secured by desalination, saline water constitutes a fundamental element for reproduction in urban, remote and arid areas these are energy, materials, money and other economic factors. Efficient desalination plants technologies were used to provide safe and sustainable drinking water it should have low cost energy, high performance and environment protection to be suitable for production.

In this study, a six - model of desalination systems will be discussed. And comparing between them to find which one have high heating rate with low economic cost. First, conventional power plant which consist of three modules for powering a reverse osmosis system by steam turbine, gas turbine and combined cycle power plant. Second, renewable power plant which consist of three modules for powering a reverse osmosis system by concentrated solar power (CSP), photovoltaic cells and wind turbine. Saline waterwas an essential need for people, animals and agriculture also in manufactures water was a demand.

In these days reverse osmosis system technologies are performing well against the thermal

Nomenclator

AD	adsorption cycle
CCPP	combined cycle power plant
CSP	concentrated solar power
DAF	dissolved air flotation
ED	electrodialysis
FFP	filter feed pumps
HPC	high-pressure compressor
HPP	high-pressure pump
HTF	Heat transfer fluid
ICGT	intercooled gas turbine engine
LPEC	low-pressure economizer
LPEV	low-pressureevaporator
LPC	low-pressure compressor
LPSH	low-pressure superheater
MgO	magnesium oxide
Mg (OH)2	magnesium hydroxide
MED	multi-effect desalination system
MEDAD	multi-effect desalination adsorption
MSF	multi-stage flash
NF	nanofiltration
PV	photovoltaic cell
RO	reverse osmosis
RO-PV	reverse osmosis- photovoltaic
TMED	multiple-effect solar distiller
TVC	thermo vapor compressor
VC	vapor compression
WHO	world health organization

heat is provided. Wind-RO desalination plants can produce up to (2300 L/Hr.) at (225 kW) nominal wind turbine power. Tidal energy-RO desalination using hydraulic turbine could reduce water desalination cost by (31%–41.7%) compared with the conventional RO system. This causes renewable energy systems more efficient and economical.

Shahzad, et al., reported a comparative study says that renewable energy such as solar and wind not commercialized due to intermittent nature, they proposed highly efficient energy storage material to compensate intermittent, magnesium oxide (MgO) system integrated with innovative hybrid desalination cycle for future sustainable water supplies. They pointed out that magnesium hydroxide (Mg(OH)2) dehydration vapor condensation produces (120 °C) and (MgO) hydration exothermic reaction produces (140 °C) heat during day and night operation, respectively, corresponding to energy storage of (81 kJ/mol and 41 kJ/mol), the produced energy can be utilized to operate desalination cycle to reduce (CO2) emission and It was showed that MgO + MEDAD (Multi-effect Desalination adsorption) cycle can achieve performance over Universal Performance Ratio (UPR) = 200, one of the highest reported ever[4].

Calise, et al., conduct an economic and sensitivity analysis for reverse osmosis located in Pantelleria Island (South Italy)), Special control strategies are implemented to maximize the system profitability both capital and operating costs[5]. The results achieved in this work reducing the dependency of the Island from the water transported by the tank ships, Low pay-back periods for specific costs of the water higher than 7 €/m³, to increase the performance, reducing the minimum and the maximum value of pressure for the activation of the reverse osmosis unit and adopting a solar field area equal to 6436 m².

Carballo, et al., reported a comparative study between multi-effect desalination system (MED) and multi-stage flash (MSF) when improving the process operation and analyze the influence of the variations of the operational parameters which system consume less energy cost[6]. The results of this study show that Thermal energy consumption (kJ/kg) equal to (190–280),(145–230) for MSF, MED, respectively, It is obvious that MED has less consuming energy cost, Also, to improve theprocess performance forward osmosis or nanofiltration (NF) coupled to MED as a pretreatment, allows working at higher temperatures with higher efficiencies of MEDMoreover, hybrid MED with adsorption cycle (AD) can operate below ambient conditions this increasing, even more, the operation temperature range and the overall performance. Finally, the use of solar energy desalination and have registered higher heating rate. The reverse osmosis technology is the most common among membrane-based desalination processes, which is considered the most predominant in the desalination market worldwide.

II. LITERATURE REVIEW

Water desalination using renewable energy resources based on a cogeneration principle many researchers write in this field, but all results should be related to energy cost, environment impact (reducing emission of co2) and efficiency performance.

Binamer developed a mathematical model to optimize the performance of the ME-TVC-MED desalination plant. The optimal design is compared with three actual ME-TVC plants having the same energy input, the first in Alba (Bahrain), the second in Tripoli (Libya), and the third in Mirfa (UAE). The GR of the optimal design is 10% greater than the Mirfa and Alba plants and 22% greater than the Tripoli plant[1]. The ME-TVC-MED unit has 130% higher production concerning the Alba plant and the entrainment ratio is lower than any of the three actual plants.

Al-Zahrani, et al., conducted thermodynamic analysis on a RO desalination unit with energy recovery devices fitted. Three configurations were introduced into the desalination unit; a throttling valve in the rejection section, a hydraulic turbine, and a pressure exchange (PX) system as an ERD. The results showed that plant performance was greatly affected by applied pressure, feed water salinity, and temperature. The PX system reduced the energy consumed by the RO unit by 50%, especially at high feed salinity[2]. The applied pressure was directly proportional to feed mass flow rate, permeate mass flow rate, and recovery ratio. The PX system demonstrated high performance compared with the others.

Abdelkareem, et al., reported a comparative study for desalination plants powered by renewable energy systems (solar, geothermal, wind, and ocean energy) and Conventional fossil-fuel energy systems. It finds that renewable energy systems are butter because it is abundant, cheap, and clean[3]. Results show that the efficiency of solar thermal desalination techniques such as water stills that improved by nanofluids increased the water evaporation rate to 250% in water stills with corrugated base and side mirror reflectors when both capillary and plasmonic effects were combined as in a plasmonic membrane. The energy recovery efficiency reached to 85%. Geothermal-desalination plants produce high-quality freshwater, but it depends on the geographic location where excess optimal number of effects should be 11 based on annual productivity and manufacturing cost.

Rajesh and Choudary, carried out a feasibility study on solar energy powered desalination plants this system consists of a solar chimney, solar collector, evaporation system, and passive condenser it called A solar chimney desalination system, Heated air that comes from collector released at the bottom of the chimney. By draughted force, dry air goes upward. The air is humidified by spraying salt water into the hot air stream by an amistifier in the middle of the chimney[10]. Vapors that mixed with the air are condensed in the passive condenser to give desalinated water. Results show that the performance of the integrated system including power and potable water production was estimated and the results give at 3.4m height in the chimney evaporating 3.77L of saltwater daily can condensing 2.3L of distilled water.

Raphael, et al., introduced a thermodynamic study of multi-effect desalination with Thermo vapor compressor (MED-TVC) system which designed for particular pressure and flow rate. These observations where be found. First, a buffer storage (steam accumulators) system is needed in solar MED-TVC system to adjust the differences between the steam production and the consumption rates. Second, any increase in accumulator volume causes a reduction in the maximum pressure done by the accumulator for the same solar field capacity[11]. Third, (12 m³) capacity constant pressure type accumulator can meet the (30 min.) steam demand during the cloud cover for the specified solar field condition.

Shatat and Riffat reported a comparative study used renewable energy and Conventional fossil-fuel systems connecting a thermal and membrane water desalination. Thermal processes include the multiple effects, multistage flash boiling and vapor compression, solar and cogeneration distillation, while the membrane processes include electrodialysis, reverse osmosis, and membrane distillation[12]. This study confirms that coupling desalination plants with clean environment-friendly energy resources (solar energy, wind, and geothermal energy) are a pressing issue due to the dramatic increase in fossil fuel prices and the harmful impacts of burning fossil fuels (carbon dioxide emissions). Also; the use of solar energy for water desalination was economical due to the abundance of solar sources with low prices, solar-MED is recommended for large-scale solar desalination because it requires little maintenance and waste heat source. In remote areas where water and electricity infrastructure are currently lacking. (photovoltaic and thermal) for desalination processes can reduce energetic cost and environmental impact, chiefly for MED desalination due to its greater compatibility with solar energy and the electrical and thermal energy consumption.

Shouman, et al., a comparative study illustrates a technical and an economical feature for reverse osmosis- Photovoltaic (RO-PV) system compared to MSF and MED systems. The dominant competing technology is reverse osmosis (RO), the reported production cost range for large scale conventional desalination is ($1 - $2/m³). RO has lower energy consumption when compared to MSF and MED[7]. The numerical results indicate that the estimated water cost for desalination plant with (1000 m³ /d) capacity for (PV/ SW-RO) system is about $(1.25/ m³) while ranging between $(1.22-1.59)/m³ for (SW-RO) powered with conventional generator powered with fossil fuel. Besides, the technical and economical features, the (RO-PV) system is characterized by being a friend to the environment (with no gaseous emission).

Heihsel, et al., carried out a feasibility study on a desalination plant powered by renewable energy there study focusses on two global challenges global areas of arid regions are growing due to climate and to prevent desalination becoming a driver of greenhouse gases which raise global temperature by 1.5°C, First, analyses the quantity of water and determine locations for seawater desalination plants and pipelines to distribute the water into existing storages then design a pipeline system and calculate the electricity needed to pump the water from the plants to the storages. finally, A combined renewable energy load-shifting model was used[8]. This minimizes the total cost of energy. Numerical results indicate that the unused spilled electricity can be reduced by at least 27 TWh. The electricity system's installed capacity and consumption cost of electricity can be reduced by up to 29%, and 43% respectively.

Lim, et al., perform numerical analysis on the performance of multiple-effect solar distiller (TMED) The distiller consists of a glass cover, several parallel plates, and seawater-soaked wicks placed in contact with the plates this numerical analysis was conducted in each of the four seasons at E127° and N30°. Their numerical results indicate that the TMED can produce freshwater of (16.6 kg/m2) with a performance ratio of (1.44), which is (2.8) times more than that of a basin-type still, to increase productivity decrease the inclination angle of the distiller to be (40–50°) and Feeding (6 cm³) flowrate to all effects was recommended for convenient and reliable operation[9]. Finally, the while total water shortage will grow to 199km3 yr−1 in 2050, The analysis shows that 22% of the water shortage can be attributed to climate change and 78% to changes in socioeconomic factors.

Ghaffour (2012), et al., do a techno-economic evaluation study on desalination plants many desalination plants built recently have greater desalinated water delivery costs caused by special circumstances, such as plant remediation or upgrades, local variation in energy costs, and site-specific issues in raw materials costs and Environmental regulations that cause a significant increase in capital cost as a solution suggest using hybrid systems such as adsorption desalination occurring in RO technology which can contribute in cost reduction as well as the reduction in energy consumption[16].

Lattemann and Höpner analyzed that (24.5 million m3 /day) of desalination seawater from the Arabian Gulf and other places in the world can harm the environment issues, they are a concentrate and chemical discharges to the marine environment, emissions of air pollutants and height energy demand for the processes[17]. The main observation was that the desalination process to be safe on the environment should follow Guidance Document of World Health Organization (WHO) which including technological, health, nutritional, microbiological, sanitary, and environmental aspects relevant to desalination projects.

Power Plant Technologies

Power plant technologies consists of two designs conventional power plant and renewable power plant

I-Conventional Power Plant

I1-Steam Power Plant

Steam power plan using steam turbine to generate power. A steam turbine is a device that extracts thermal energy from pressurized steam and uses it to do mechanical work on a rotating output shaft. Its modern manifestation was invented by Sir Charles Parsons in 1884. What is a turbine? A turbine is a spinning wheel that gets its energy from a gas or liquid moving past it. A windmill or a wind turbine takes energy from the wind, while a waterwheel or water turbine is usually driven by a river flowing over, under, or around it. Steam turbines Fig (1.1) has spinning bladesthat turn when steam blows past them, use high-pressure steam to turn electricity generators at incredibly high speeds, so they rotate much faster than either wind or water turbines. (A typical power plant steam turbine rotates at 1800–3600 rpm—about 100–200 times faster than the blades spin on a typical wind turbine**.**

Tomaszewskaa, et al., carried out a technical and economic feasibility study that demonstrates that effective use of geothermal resources can include direct utilization of geothermal energy in the heating system and the use of the cooled water as a source of fresh water obtained in a desalination unit. They introduced a useful information approach of this research is the coupling of two mature, well-proven, technologies (geothermal and membrane)[13]. Also, they discover that feed water quality and quality of the geothermal resource can potentially influence concentrate utilization and the cost of freshwater production.

Ma and Lu, performed experimental studies of wind energy powered desalination plant, Renewable energy (wind) provides energy security and environmentally friendly if compared with fossil fuels. The study confirmed that the (RO) is the major desalination process connected to wind power and (MVC) is the major thermal desalination process powered by wind. On the other hand, wind energy has two important technological problems intermittent characteristics and improving energy utilizing efficiency[14]. As a solution for the intermittent characteristic of wind energy integrating the wind energy with other kinds of energy and designing flexible desalination units to fit the variation of wind, moreover, a storage reservoir aboard was used for stabilization and coping with fluctuations in energy supply and water demand. Secondly to improving the energy utilizing efficiency direct wind-thermal conversion is utilize.

El Kharraz, et al., attempts to present an overview of water scarcity and drought issues in West Asia & North Africa (WANA) countries whenever quantitative or qualitative data are available[15]. These authors claimed that to producing freshwater, distillation should be done by thermal processes (Multi-Stage Flash (MSF), Multi-Effect Distillation (MED), and Vapor Compression (VC) Distillation) or Membrane processes (Reverse Osmosis (RO) and Electrodialysis (ED)) powered by renewable energy which is a suitable solution for water supply and irrigation in remote locations especially where there is no electricity grid. For development, it needs Supply management, Demand management, Improvements.

20-Droogers Carried out a feasibility study from two-stage modeling approach (An advanced, physically based, distributed, hydrological model Subsequently with water allocation model) is used to explore the impact of climate change, population growth, economic development, and environmental considerations in the Middle East and North Africa (MENA) region[9]. Results show that total demand in the region will increase to 393km3 yr−1 in 2050, This went straight into the Guinness World Records as the most efficient at that time. As is evidenced by the rush for more efficiency, CCGT hold an advantage over simple cycle gas turbines when it comes to this area. Efficiency of this power plant is expressed in heat rates (Btu/kWh). the CCGT appears to be the most efficient power plant type. The rise in efficiency is simply from the Waste Heat Recovery section of the unit. The efficiency of combined cycle power plant has already surpassed the 60% mark. This is how the industry calculates this efficiency:

$h_{cc} = h_{c1} + h_{c2} - h_{c1}h_{c2}$

Where;

- h_{cc}= Combined Efficiency
- h_{c1}= Efficiency of Cycle 1
- h_{c2}= Efficiency of Cycle 2

Assuming the first cycle efficiency is 40% and the second cycle efficiency is 35%, the efficiency for the combined cycle comes to 0.40 + 0.35 – 0.40*0.35 = 0.61. This makes the CC efficiency much higher than individual cycles.

II-Renewable Power Plant

II1- Concentrated solar power (CSP)

Concentrated solar power (also called concentrating solar power, concentrated solar thermal, and CSP) systems generate solar power by using mirrors or lenses to concentrate a large area of sunlight onto a small area. Electricity is generated when the concentrated light is converted to heat (solar thermal energy), which drives a heat engine (usually a steam turbine) connected to an electrical power generator or powers a thermochemical reaction (experimental as of 2013).CSP had a world's total installed capacity of 5,500 MW in 2018, up from 354 MW in 2005.

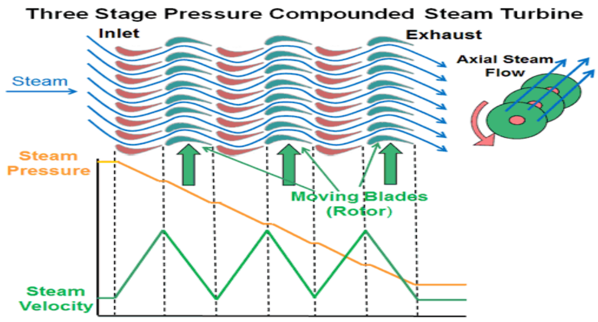
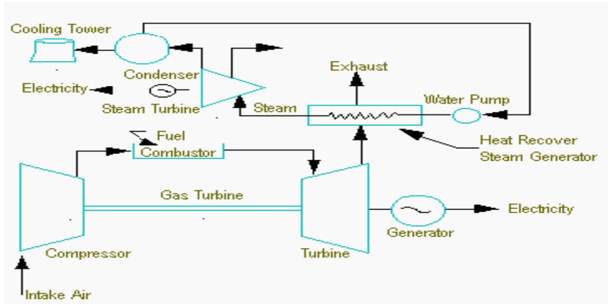


Fig (1-1) steam turbine blades



I2-Combined Cycle Power Plant

Combined cycle power plant, this type of power plant comprises of a combination of both gas and steam power production technologies. A combined cycle power plant relies on the simple fact that a gas turbine produces both power and hot exhaust gases. As the power is channeled to a generator, the hot gases are used to heat water until it reaches boiling point to produce steam. This steam runs a steam turbine to produce extra power.Fig (1,2) show schematic diagram for a Combined Cycle Power Plant

In 2016, GE manufactured a combined cycle power plant with an efficiency of 62.22%.

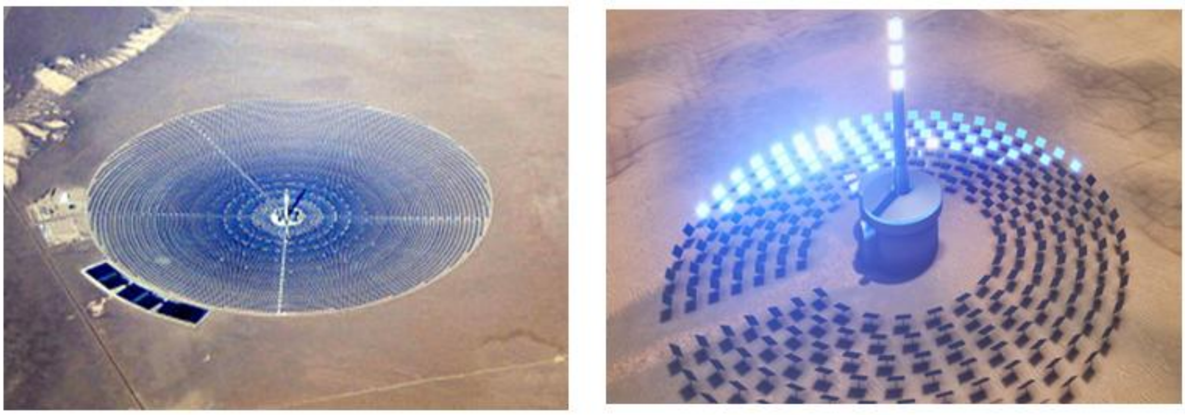


Fig (1-3)Crescent Dunes Solar Energy Project the creation of voltage and electric current in a material upon exposure to light. It is a physical and chemical phenomenon). In most photovoltaic applications the radiation is sunlight, and the devices are called solar cellsIndividual solar cell devices can be combined to form modules, otherwise known as solar panelsfig (1-4). The operation of a photovoltaic (PV) cell requires three basic attributes:

- The absorption of light, generating either electron-hole pairs or excitons.
- The separation of charge carriers of opposite types.
- The separate extraction of those carriers to an external circuit.

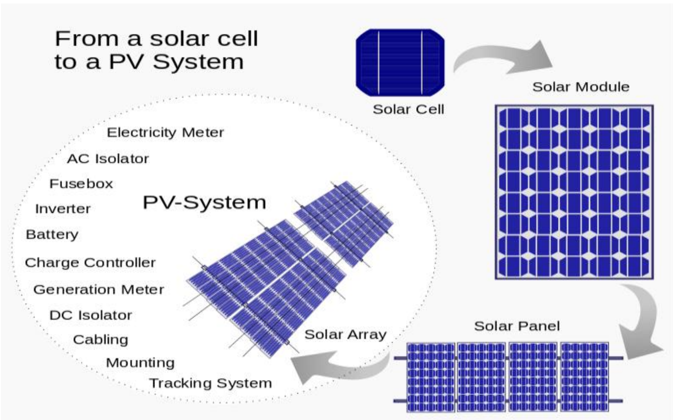
The main source of light on Earth is the Sun, Historically, another important source of light for humans has been fire. Light is electromagnetic radiation within a certain portion of the electromagnetic spectrum fig (1-5). Fig (1-4) solar panels

In 2017, CSP represented less than 2% of worldwide installed capacity of solar electricity plants. However, in recent years the falling prices of CSP plants are making this technology competitive with other base-load power plants using fossil and nuclear fuel even in high moisture and dusty atmosphere at sea level, such as the United Arab Emirates. Baseload CSP tariff in the extremely dry Atacama region of Chile reached below ¢5.0/kWh in 2017 auctions. How Does CSP Work?

In steam turbine CSP installations mirrors reflect sunlight to focus on a liquid which then turns to steam. This steam is then directed and used to power a steam turbine, which generates electricity. In engine based CSP installations, the principle is the same, but the steam is used to drive an engine, which in turn produces electricity.There are three steam turbine types of CSP installations: Parabolic Through, Linear Fresnel Reflector and Power Tower.

II2- Photovoltaic Cells

A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect(is



The word usually refers to visible light, which is the visible spectrum that is visible to the human eye and is responsible for the sense of sight. Visible light is usually defined as having wavelengths in the range of 400–700 nanometers (nm), or 4.00×10^{-7} to 7.00×10^{-7} m, between

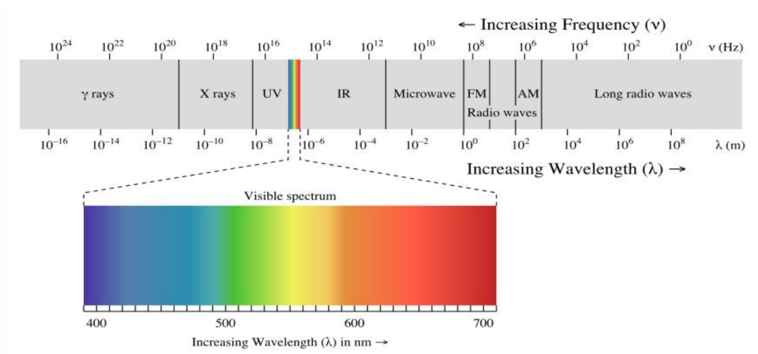


Fig (1-5) Electromagnetic spectrum and visible light

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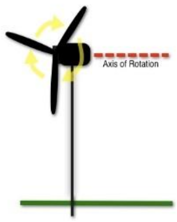


There are two general types of wind turbines:
1- Horizontal axis wind turbine (HAWT) fig (1-8).
2- Vertical axis wind turbine (VAWT) fig (1-9).Fig (1-8)

The most used type of wind turbine today is the horizontal-axis wind turbine. In a HAWT the axis of the rotating turbine is horizontal, or parallel to the ground, and it is the type of wind turbine that one would usually see on a wind farm.

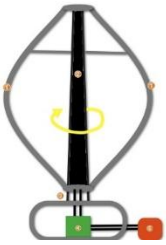
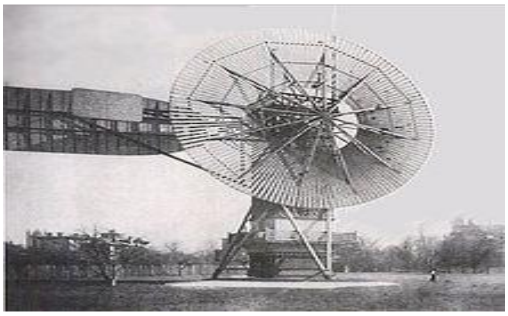


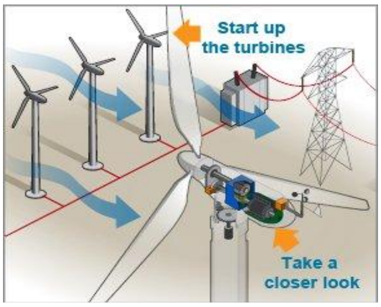
Fig (1-9)

Desalination Plant Technology
7- R.O Desalination Plant

The RO desalination plant driven by several energy systems since part of generated power directly consume and the remaining power export to the electrical network. The intake area of the Shuwaikh RO desalination plant is located on the coast of the Arabian Gulf at high salinity reach to 45,000 ppm, as illustrated in Figure 5. The design capacity of inlet condition is about 17,716 m^3/h. The seawater supply pumps (SSP) draw the seawater from the intake area and deliver it into dissolved air flotation (DAF) system. The feed water treated physically and chemically in the DAF system to remove or separate the colloidal solids, oils and greases. The feed water moves forward to strainers and static mixer via filter feed pumps (FFP). Next, the feed water directs to the ultrafiltration system where the large macromolecules, colloids, bacteria and proteins are removed. The UF system has a membrane with a large pore sizes compared to membrane modules in the RO unit. The treaded feed water mixed with brackish water, which is produce from the second pass RO unit, in static mixture then moves to high-pressure pump (HPP). After that the the infrared (with longer wavelengths)and the ultraviolet (with shorter wavelengths).This wavelength means a frequency range of roughly 430–750 terahertz (THz).The speed of light in a vacuum is defined to be exactly 299,792,458 m/s (approx. 186,282 miles per second).



II3- Wind Turbine
A wind turbine, or alternatively referredto as a wind energy converter, is a device that converts the wind's kinetic energy intoelectrical energy.
Fig (1-6) The first automatically operated wind turbine built in Cleveland in 1887 by Charles F Brush It was 60 feet (18 m) tall, weighed 4 tons (3.6 metric tons) and powered a 12 kW generator



Wind turbines work on a simple principle
see fig (1-7): Wind turns the propeller-like blades of a turbine around a rotor, which spins a generator, which creates electricity. Wind is a form of solar energy caused by a combination of three concurrent events:

1. The sun unevenly heating the atmosphereFig (1-7) wind turbine
2. Irregularities of the earth's surface
3. The rotation of the earth.

exchanger and booster pumps. The second RO unit consists of 4 stages and similarly the exiting brine water return to the mainstream and mixes with the feed water after the UF system reduces the salinity. The pressure exchanger system reduces the consumed energy in the first RO unit by about 50%, especially at high feed salinity. In the contrast, the RO desalination plant contains a sophisticated pretreatment process with respect to thermal processes. In addition, more than twenty types of chemicals are required in order to protect the RO unit during operating mode. The RO desalination plant performance data is illustrated also in Table 1.

feed water at high pressure mixed with discharge stream of ERD booster pumps then enters to the first RO unit which consists of 10 stages. The exit stream splits into two main streams with different salinity. The permeate exiting from the first unit is also divided into two streams, the first is used as a feed to the second RO unit while the second will blend with permeate stream exiting from the second RO unit and moves to the product tank by the product water pump. The product stream has a capacity of 5682 m^3/h with a salinity less than 200 ppm. The brine water of the first RO units returns to the mainstream after passing through the pressure

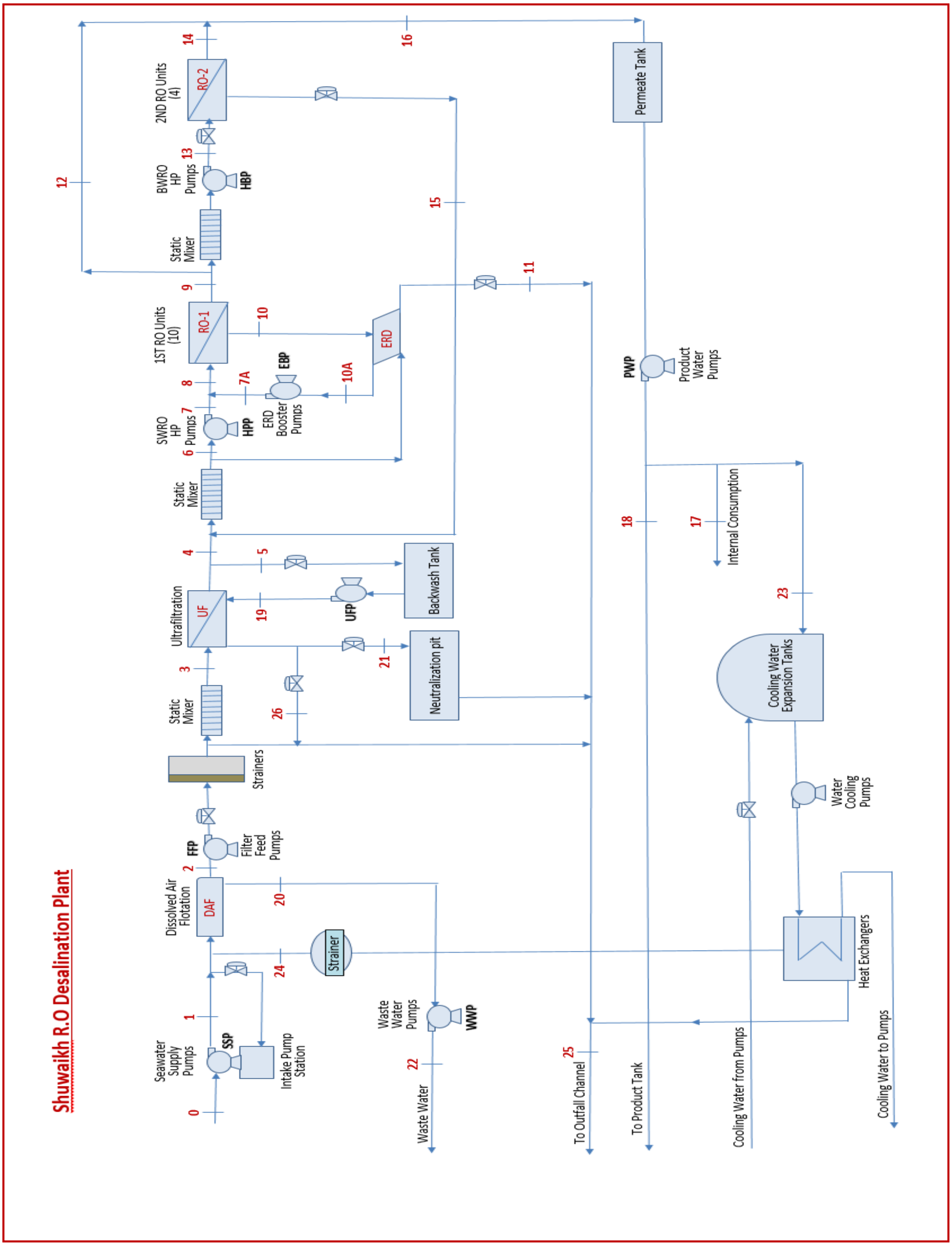


Figure 10. Schematic diagram for the Shuwaikh RO Desalination Plant

Table 1. The performance data of proposed cogeneration system.

	Description	Value	Unit
RO Desalination Plant	Number of SWRO stages	**10**	**----**
	Number of BWRO nit stages	**4**	**----**
	Seawater feed temperature	**15**	**^{o}C**
	Seawater temperature salinity	**45000**	**ppm**
	Design mass flow rate	**4921.1**	**Kg/s**
	Permeate mass flow rate	**1611.1**	**Kg/s**
	Rejected mass flow rate	**3342.8**	**Kg/s**
	SWRO permeate mass flow rate	**1750**	**Kg/s**
	SWRO bypass permeate mass flow rate	**361.1**	**Kg/s**
	SWRO permeate mass flow rate	**1250**	**Kg/s**
	BWRO rejected mass flow rate	**138.8**	**Kg/s**
	Permeate salinity	**less than 200**	**ppm**
	Brine salinity	**66279**	**ppm**
	SSP discharge pressure	**2.5**	**bar**
	FFP discharge pressure	**5.5**	**bar**
	UF Backwash discharge pressure	**4.5**	**bar**
	ERD booster pump discharge pressure	**66.7**	**bar**
	SWRO HPP discharge pressure	**66.7**	**bar**
	BWRO HPP discharge pressure	**13.7**	**bar**
	SWRO recovery ratio	**42**	**%**
	BWRO recovery ratio	**90**	**%**

located in state of Kuwait. Desalination is a technology that is used to separate dissolved salts and minerals from saline water in order to provide fresh water. The desalination technology consists of three main processes. However, the power side of the cogeneration systems are intercooled gas turbine engine, steam power plant, combined cycle power plant, photovoltaic power plant, concentrated solar power and wind turbine while the water side used RO desalination plant. The operating principles for all the proposed systems are described in brief in the following subsections.

2.1 Intercooled Gas Turbine Engine

The ICGT engine is distinguished by the intercooling modification of the gas turbine system, and it has the highest power output as well as

System Descriptions

Co-Generation Power and Desalination Plant

A cogeneration system is a power system that utilizes waste heat energy or extracts energy to achieve high efficiency with low cost investment and responsible emissions. The same energy source ends up with two useful resulting energies. Cogeneration systems have several forms, where the primary generation is electricity along with the best practical utilization of the heat energy or energy. The proposed systems are considered a cogeneration system based on a several energy systems used a renewable and non- renewable resource, which is widely used nowadays, and integrated with a RO desalination plant. The desalination plant is inspired by Al Shuwaikh RO desalination plant, which is combustor, which increases the fuel consumption in the engine. The overall pressure ratio in the LPC and HPC compressors is 42. There are two scroll cases, one at the exit of the LPC before the intercooler, and the second at the inlet of the HPC, to reduce pressure loss. The high-pressure compressed air moves forward to the annular combustor and mixed with fuel to result in a hot gas. Then, directed into turbine section and expanded through the high-pressure turbine (HPT), intermediate-pressure turbine (IPT), and low-pressure turbine (LPT) or power turbine (PT). The HPT and IPT are derived HPC and LPC whereas the LPT produce the power output. The thermal efficiency and capacity of ICGT engine is about 45% and 100 MW at International Standards Organization [ISO] condition. The exhaust gases stream exit from the stack at an atmospheric pressure and temperature of 685 K. However; the ICGT performance data is illustrated in Table 2.

efficiency for simple cycles in the market today. Intercooling is an essential technique that results in increased power by reduction of compressor power consumption. With the intercooling system, the power consumption of the HPC is reduced; this results in a high-pressure ratio and subsequently increases efficiency. The ICGT system consists of three shafts, as illustrated in Figure (1),the first is connected to the low-pressure components; the second, to the high-pressure components; and the third, to the power turbine. The cold section consistsfrom theLow-pressure compressor (LPC), high-pressure compressor (HPC) and the intercooler lying between them. The compressed air is delivered from the LPC to the intercooler to reduce the inlet temperature of the HPC by extracting heat. The work required to HPC will reduce and lead to increase the engine output power. There is one negative impact on the intercooling process related to the lower temperature being delivered to the

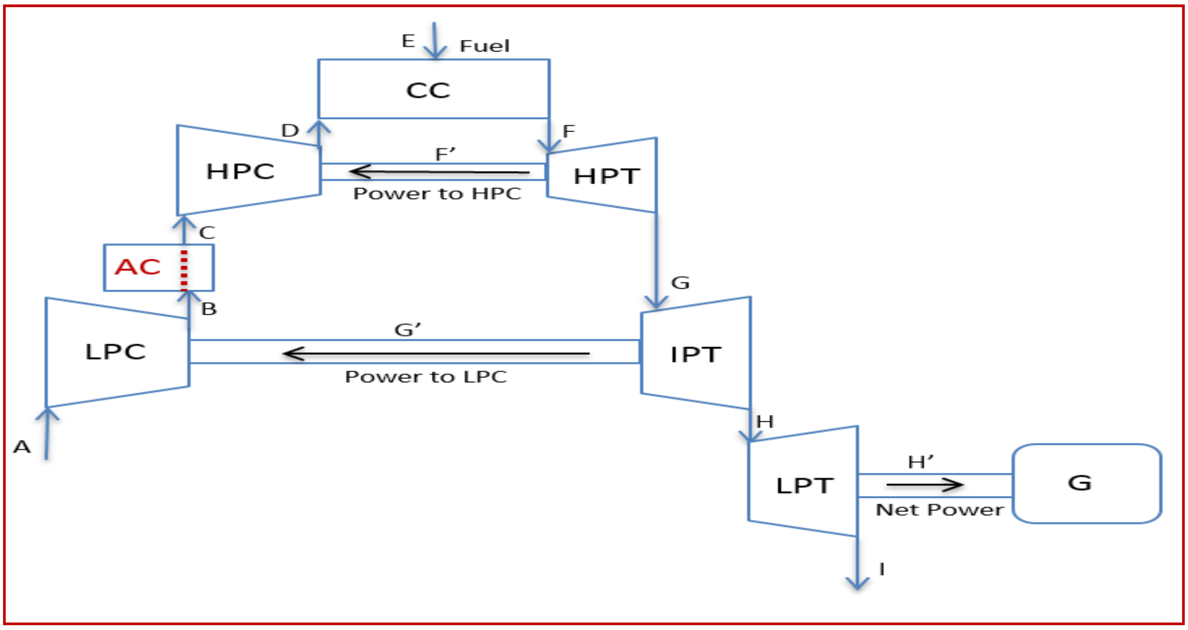


Figure 1. Schematic diagram for the intercooled gas turbine engine.

Fig (1)

Description		Value	Unit
ICGT	GT Power output	**98.70**	**MW**
	Thermal efficiency	**45**	**%**
	Heat rate	**7921.00**	**kJ/kWh**
	Compressor Pressure ratio	**42**	**----**
	Exhaust Mass flow	**222**	**Kg/s**
	Exhaust Temperature	**412**	**^{o}C**

Table 2. The performance data of intercooled gas turbine engine.

boiler. The boiler comprises two sections the furnace and heat recover section. The later has three superheaters (SH) as well as two reheaters (RH-1&2) with one economizer. The steam required is generated from fossil fuels through the boiler. As seen in Figure 2, the steam turbine consists of three sections which are the high pressure turbine (HP), intermediate pressure turbine (IP) and low-pressure turbine (LP) . The steam inlet temperatures for the high pressure (HP) and intermediate pressure (IP) steam turbine are the same, due to the reheat effect, which is equal to 535 ^{o}C. The exit steam from the low-pressure turbine is condensate in the condenser then directed to the condensate pump, to convey the feed water through six heaters to raise its temperature before reaching to the boiler.

2. Al-Zour South Power Plant

Al-Zour south power plant located in Al-Zour area south of Kuwait. Established in 1988, its production of electric power is estimated at 2400 MW. Al-Zour south consists of eight steam turbines each with 300 MW. Steam power plants play a key role in supplying electrical energy. In a steam power plant, the steam turbine converts the thermal energy to rotating mechanical energy, and the generator to convert the mechanical energy to electrical energy. Typically, the turbine is directly coupled to the generator. The boiler is essentially a closed vessel inside which water is stored. Fuel is burnt in a furnace and hot gasses are produced. These hot gasses come in contact with water vessel where the heat of these hot gases transfer to the water and consequently steam is produced in the

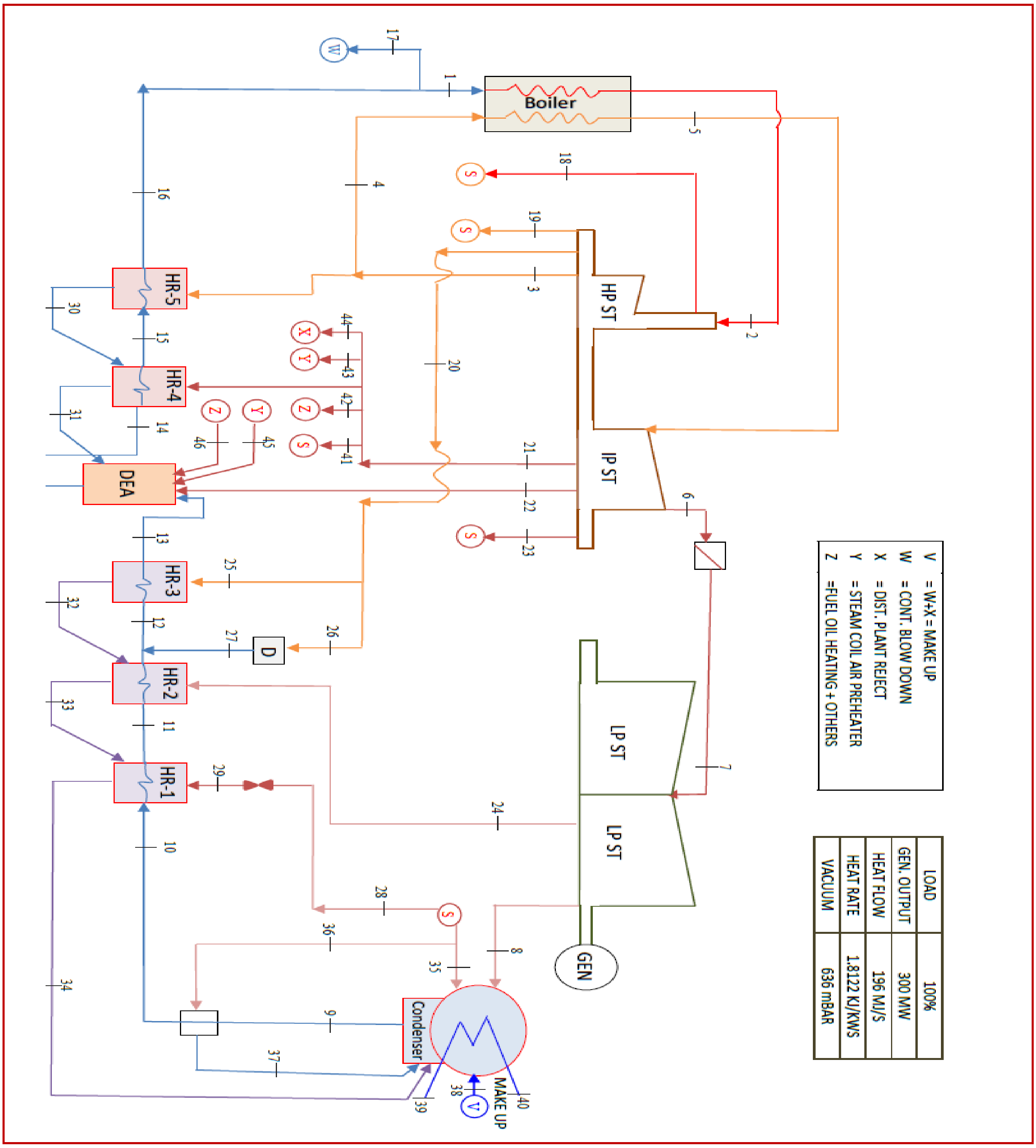


Figure 2. Schematic diagram for the Az-Zour thermal power plant [15].

Figure 11. Schematic diagram for a Al-Zour south thermal power plant

4. Sabiya Power Combined Cycle Power Plant

The Sabiya CCPP consists of three blocks. Each containing two GE gas turbine frame 9FAs, with two triple pressure reheat HRSGs, and one steam turbine. A typical block is illustrated in Figure (12). The plant's power output and efficiency are more than 2000 MW at local conditions, and 54.5%, respectively. The exhaust gases' stream passes through 14 heat exchangers in each HRSG before it reaches the stack. The pressure and a temperature at the exit of stack are 101.325 kPa and 107 °C respectively. In the steam cycles there are three levels of steam pressures on each evaporator. Which are at 131.8, 28.78, and 5.208 bars. The steam inlet temperatures for the high pressure (HP) and intermediate pressure (IP) steam turbine are equal to 565 °C. They are identical and this is a consequence of the reheat effect. As seen in Figure 1, there are two high pressure superheaters (HP SH) as well as two reheaters (RH-1&2). Between both the two superheaters and reheaters there are two attemperators, which help to adjust the steam temperature. The intermediate pressure steam stream exits from the superheater (IP SH) and mixes with the reheat stream, before entering reheater-1. The low-pressure superheater (LP SH) before entering the (LP) low pressure steam turbine mixes with the exit stream coming from the intermediate steam turbine. The low pressure stream expands to 0.1 bar, before entering the deaerating condenser, which is the more preferable equipment in the combined cycle power plant, rather than the separating one, due to its smaller size, which saves equipment space and is easy to deaerate makeup water. The steam condensate is then directed to the condensate pump, to convey the feed water to the low-pressure economizer (LPEC). In the low-pressureevaporator (LP EV), the flow is divided into three streams, based on the flow pressure, to continue the cycle. The operational data at different operating conditions was collected from the Ministry of Electricity and Water (MEW) and theplant manufacturer. This data includes the state of all streams and the power output at different ambient conditions and loads.

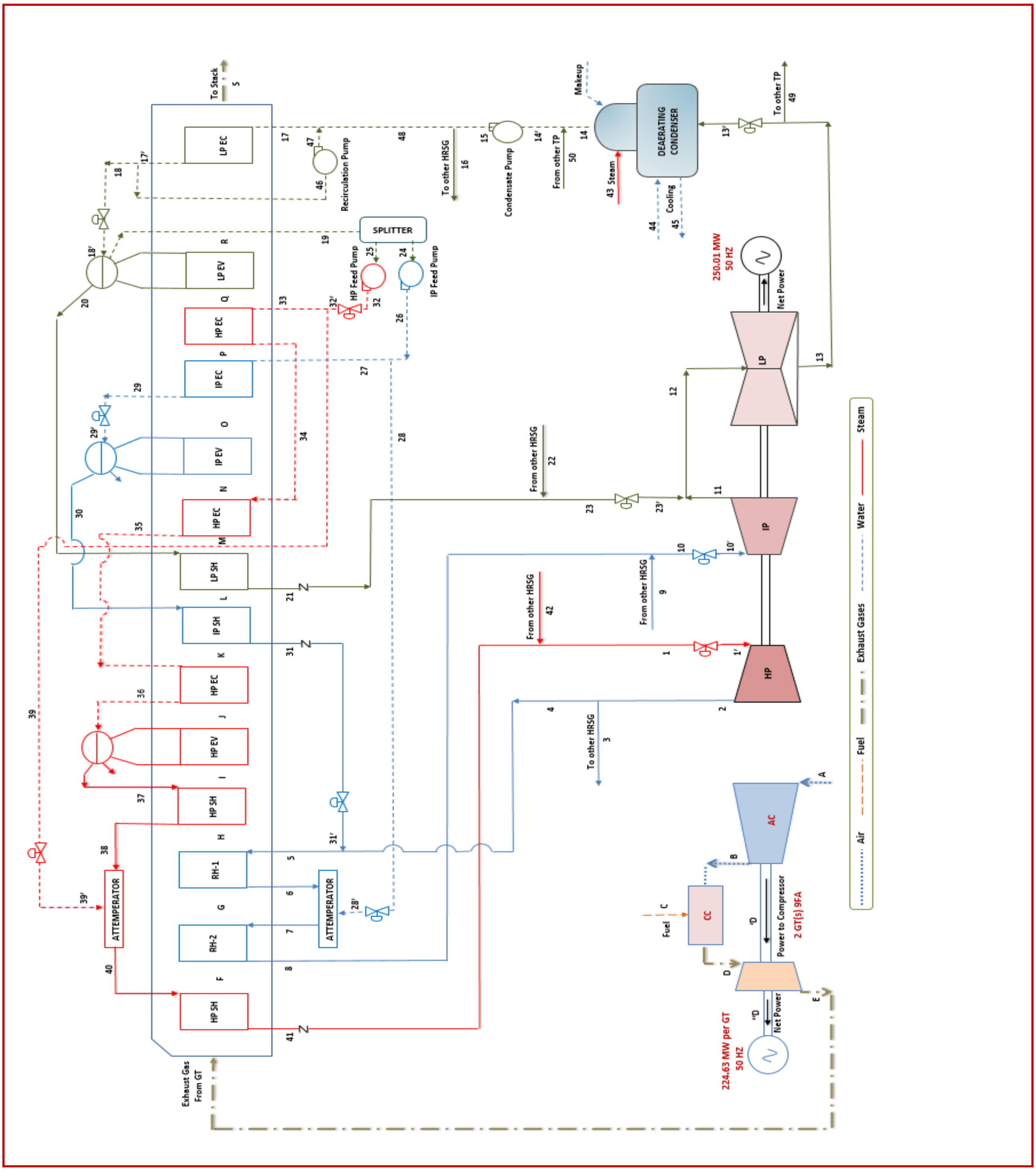


Figure 12. Schematic diagram for a Single Block of Sabiya Combined Cycle Power Plant

table(3). The wind turbine HUB height is about 79 m while Blade length 47 m. Wind turbines generate electrical power in the same way as all other generation technologies. The only difference is in the source of the mechanical power supplied to the electrical generator: wind, rather than a diesel

4-Shagaya Renewable Energy Park - Wind Farm
The Shagaya Wind Farm has a total gross installed capacity of 10 MW and consists of five (5) wind turbines placed in one row and connected in three (3) strings to the Substation at a Medium voltage level of 11 kV through an underground cable

adjust the pitch of the blades (blade angle) as wind speeds change. Typically, a gearbox connects the shaft from the blades (rotor) to the electrical generator.

engine or steam turbine, provides the energy. Blades capture energy in the wind and turn the turbines. Control mechanisms point the blades into the wind (yaw control) and, on large wind turbines,

TABLE 3. Technical Characteristics of the Shagaya Wind Farm

Characteristic	**Technical Value**
Turbines	Siemens-Gamesa G97
Rated Power per turbine	2 MWe
Number of turbines	5
Tower height	78.98 metres
Rotor diameter	97 metres
Swept area	7,390 m^2
Number of blades	3
Blades length	47.5 metres
Gearbox	1 stage planetary /2 parallel

coating a sheet of reflective material into a parabolic shape. This shape concentrates the incident solar radiation onto a central receiver tube at the focal line of the collector. The arrays of mirrors can be 100m long or more and with the curved aperture of 5m to 6m. The receiver comprises of the absorber tube, which is usually metal, inside an evacuated glass envelope. The absorber tube is typically coated with stainless steel, with a spectrally selective coating that absorbs the solar irradiation well but emits very little infrared radiation. This helps to reduce heat loss and evacuated glass tubes also help to reduce heat losses. Heat transfer fluid (HTF) is circulated through the absorber tubes where it is heated to high temperatures and is then transferred to a steam generator or a heat storage system. Synthetic oils that are stable up to 400 °C are the heat transfer fluid in most of the parabolic trough plants. The key design features for the CSP plant are summarized in table(4) below.

5-Shagaya Renewable Energy Park - Concentrated Solar Power

The Shagaya CSP Plant comprises a solar field (based on parabolic trough technology), a power block with a rated gross electric capacity of 50 MWe, and molten salt TES with a useable thermal storage capacity of 1200 MWth, and it utilises the highest number of equivalent storage hours (more than 9) in the MENA region. Shagaya CSP Plant, as illustrated in Figure (13), will be producing 180GWh/year with a total area of 250 hectares and avoiding the emission of more than 81000 tons of CO_2/year. Solar thermal technologies are based on the concept of concentrating solar radiation to produce steam or hot air which can then be used for electricity generation using conventional power cycles. The parabolic trough collector (PTC) systems consist of a series of mirrors which form the solar collectors, the combination of collectors (Solar arrays), heat receivers, tracking components, and their support structures. The parabolic mirrors are formed by

TABLE 4. Technical Characteristics of the Shagaya CSP Plant

Characteristic	**Technical Value**
Technology Type	CSP Parabolic Trough
Contracted Gross Power Capacity	50 MWe

Minimum Net Annual Energy Generation Capability	170 GWhe/year
Usable thermal capacity of TES	1200 MWth
Number of collector loops	206
Aperture/Length of Solar Collector Assemblies (SCA)	5.77 m / 148.6 m

Fig (13) Shagaya CSP Plant

6-Shagaya Renewable Energy Park - Photovoltaic

10 MW Photovoltaic (PV) plant using both thin-film and polycrystalline PV technologies. For the Shagaya PV plant a fixed structure was selected and used for 5MW of poly-crystalline panels consisting of 920 strings of Crystalline-Silicon modules, in series of 20 modules, and 5MW of thin film panels that consisted of 4320 strings of Thin Film copper-indium-selenium modules, in series of 8 modules. Key design aspects are shown in table(5) below.

TABLE 5. Technical Characteristics of the Shagaya PV Plant

Characteristic	Technical Value
Technology Type	Crystalline-Si and Thin Film
Contracted Gross Power Capacity	10 MWe
Total PV Installed Capacity	11142 kWp
Crystalline-Si module area	110000 m^2
Thin Film module area	45000 m^2
Crystalline-Si module power	305 Wp
Thin Film module power	160 Wp
Inverters	20 units
Transformers	10 units

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III. Conclusion

Renewable energy was used to generate clean power with no negative effect on the environment in Shagaya Renewable Energy Park it consist three parts wind turbine with gross power capacity (10MWe) for five turbines, concentrated solar powerwith gross power capacity (50MWe) and photovoltaicwith gross power capacity (10MWe). So total power capacity that can be taken from this station was (70MWe) clean energy.

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