Challenges of Fresh Water Resources Scarcity in Libya and Alternative Solutions by Renewable and Sustainable Energies

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Abstract

The current paper is to investigate the shortage problem of fresh water in Libya and to propose alternative solutions by renewable and sustainable energies. This problem is not only in Libya but it is one of the most serious social and environmental challenges facing many countries in the world, especially those countries which do not have natural resources or any types of energies. Although Libya is located in a dry and semi-arid region of Africa, it is very rich in conventional energy resources, mainly the oil, and renewable energies such as solar and wind energies. In addition to that it has about 1700 km border on sea, which is very helpful to establish many desalination plants either by conventional or renewable energies. Nowadays the shortage problem of water in Libya is solved partly by ground water resources and desalination plants which are not enough. In the other hand the quantity of oil is limited to a certain period of time with other environmental impacts of this resource Here, this paper is to study the water resources as well as conventional and energy situations in Libya and suggest the most appropriate solutions for today and future by combining solar and wind energies with desalination processes. This can be done by encouraging and supporting private and de-central solar desalination technologies and establishing central desalination units for high productivity by using solar thermal or electrical processes..

I. INTRODUCTION

Water is the fundamental and essential element in the life on the earth. It is the spirit of the life through the centuries, in which all the civilizations have grown and developed on water resources. In spite of the fact that water covers about 71 percent of the Earth's surface area, however, it is a challenge to meet all humans, animals and plants demand to freshwater. Freshwater is about 2.5% of total water quantity, most of it is as glaciers, ice caps, and groundwater, only 0.008% represents the accessible surface freshwater [1].

The scarcity of fresh water around the world is becoming more pronounced due to the tremendous increase in the population over the last few decades. The renewable water resources remained constant, if not decreasing as a result of the widely reported decrease in the annual rainfall [2].

Water is a key resource for health, human development and ecosystems, and it is vital for the eradication of poverty. However, billions of people in the world are affected by serious water-related challenges, such as scarcity, pollution, deficiency of supply and sanitation, floods, droughts, the irreversible extinction of ecosystems and the loss of ecosystems services [3].

According to many experts the regions that are the most water stressed, are in the middle east and north Africa (MENA). MENA receives less rainfall than other regions, and there is shortage in other natural fresh water resources, also its countries tend to have fast-growing, densely populated urban centers that require more water.

Libya is one of the MENA countries which suffers from the water crisis. It is a dry and arid place and the presence of freshwater and rainfall is extremely scarce. Although it contains many groundwater aquifers and many conventional desalination plants, the water crisis is still continuous.

II. GEOGRAPHY AND POPULATION OF LIBYA

Libya is located in the north of Africa between longitude 9o - 25o east and latitude18o- 33o north. It extends from the Mediterranean coast in the north to the Sahara desert in the south, with a total surface area of approximately 1.750 million km2. In mid-2020, the population of Libya was estimated to be about 6.87 million according to World Bank data [4]. In addition, increasing in population shall impose severe stresses on resources demand especially food, water and energy.

The population density varies widely from one area to another. About 70% of Libyan population lives in the coastal cities, with a population density of about 45 person per km2. This density does not exceed 0.3 person per km2 in the interior regions.

The average annual rainfall varies from zone to another according to the geographic location and topography . In general, the rainfall in the northern part of the country ranges between 100 and 500 mm/year, whereas the south receives as little as 10 mm and some areas such as Al-Kufrah and Murzuq are rainless [5].

III. Availability of Fresh Water Resources in Libya

Libya is considered one of the poorest countries in fresh water resources compared with other countries have natural resources. Despite of this bad situation the available resources in the current time are classified conventional and non-conventional resources.

A. Conventional Natural Resources

These resources are surface and ground resources.

Surface water: Surface water resources in Libya are very limited and contribute less than 3% of the current water resources in use. Libya has constructed 18 major dams to harvest rainwater and for soil conservation with a total capacity of 389.9 Mm^3 and an average annual storage capacity of 61 Mm^3 . Water stored behind these major dams is used for agricultural water supply, industrial projects, and, in a few cases, for domestic use [6].

Groundwater: Since Libya is an arid zone country, so it depends heavily on groundwater, which accounts for more than 97% of the water used. In the past, groundwater was easily extracted through large-diameter wells, dug using traditional tools, since water levels were very near to the surface. Groundwater resources are divided into two major categories: renewable and nonrenewable. The renewable groundwater resources are those retained in the northern aquifers of the Gefara plain, Jabal Akhdar and parts of the Hamada and central zone area. The non-renewable groundwater resources are those belonging to the great sedimentary basins of the Kufra, Murzuk, Sarir, and the Hamada regions, see Fig. 1. These basins underlie the southern part of the country, which portrays severely arid conditions. Rare events of heavy showers producing local runoff do take place, especially in the Haruj Mountains in the center of the country, in the Tibesti Mountains in the south and in the Aweinat Mountains in the west. These events may cause local recharge, but it is of minor importance in comparison with total storage values and aquifer losses [6].

Figure 1. Main groundwater basins in Libya [5].

B. Non-conventional Resources

These resources are man-made river, desalination plants and waste water treatment.

Man-Made River Project (MMRP): This project is considered to be the largest and most expensive groundwater pumping and conveyance project. This project was undertaken to meet the Libyan population's water needs by drawing water from aquifers beneath the Sahara—mainly the Nubian Sandstone Aquifer System—and conveying it along a network of huge underground pipes to the Northern coastal cities where most of the Libyan population live and fresh water is considered scarce, see Fig. 2. As this project considered to be one of the largest water conveyance systems it was classified as one of the non-conventional water resources, although the transported water is groundwater [7].

Figure 2. Man-made river pipeline network

Desalination: Desalination has been used in Libya since the early 1960s as an important source of non-conventional water [8].Two technologies (thermal and membrane) were implemented to bridge the gap between water availability and industrial demand [6]. Currently, there are 21 desalination plants operated by different authorities , even though all of them are owned by the government [9].

Wastewater Treatment Plants: Wastewater systems including collection, transport, treatment, effluent reuse and disposal works have been constructed in parallel with water supply networks with the major objective of protecting public health and the environment, providing a supplemental renewable source of water, and hence, freeing the over-mined groundwater aquifers [9].

IV. Water Deficiency in Libya

The rates of renewable water and surface water per capita in Libya are considered very low compared with others. Population growth in Libya has been accompanied by a growth of irrigated agricultural areas, making an increase in the volume of water used in agriculture inevitable, as well as increasing domestic and industrial water consumption [10].

So in general the deficiency of water in Libya can be referred to the following reasons: excessive groundwater exploitation, decreased annual average of rainfall, intensive agricultural activities in the coastal plains, seawater intrusion, low water tariffs, lack of institutional framework, lack of clear strategy related to the local water sector, lack of awareness in the public of the need for the rational use and management of water resources, poor management in the General Water Authority (GWA) [11].

V. Situation of Energy Resources in Libya

Libya is a member of the Organization of the Petroleum Exporting Countries (OPEC), the holder of Africa's largest proved crude oil reserves, and the fifth-largest holder of Africa’s proved natural gas reserves, see Fig. 3. Libya’s economy is heavily dependent on hydrocarbon production. According to the International Monetary Fund (IMF), oil and natural gas accounted for nearly 96% of total government revenue and 98% of export revenue in 2012 [12].

A. Oil

Libya holds 48,363,000,000 barrels of proven oil reserves as of 2016, ranking 9th in the world and accounting for about 2.9% of the world's total oil reserves of 1,650,585,140,000 barrels. Libya has proven reserves equivalent to 594.2 times its annual consumption. This means that, without Net Exports, there would be about 594 years of oil left (at current consumption levels and excluding unproven reserves [13].

Figure 3. Map of Libya’s oil and natural gas infrastructure

B. Natural Gases

Libya holds 53 trillion cubic feet (Tcf) of proven gas reserves as of 2017, ranking 21st in the world and accounting for about 1% of the world's total natural gas reserves of 6,923 Tcf [14]. Libya’s natural gas production and exports increased considerably after 2003 with the development of the Western Libya Gas Project and with the opening of the Green stream pipeline to Italy. Italy is currently the sole recipient of Libya’s natural gas exports.

C. Renewable Energies

Renewable energy can be defined as the ‘energy obtained from natural and persistent flows of energy occurring in the immediate environment’, which includes wind, solar, biomass energy, geothermal, and hydropower energy…etc, but the most applicable now and more interesting is the solar and wind energies. The flows of energy passing continuously as renewable energies through the Earth are shown in Fig. 4 .

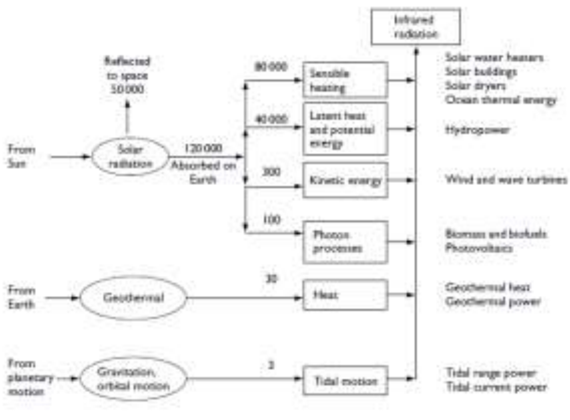

Figure 4. Natural energy currents on earth, showing renewable energy system [15]. (Units terawatts =10^{12}W).

Like other countries, Libya suffered from high conventional energy prices, environmental issues, rapid demand growth and high energy consumption [16]. It is worth noting that Libya

has a high potential of renewable energies, especially wind energy and solar energy, which can create local jobs, drive local economies and reduce carbon pollution. The government therefore plans to utilize the renewable energy sources to their full potentiality by the year 2050 in order to satisfy the energy requirements of the country and still export the excess energy [17].
The location of Libya on the high centered radiation area as well as its long coastal line on the Mediterranean make it one of the countries that have very high potential for solar and wind energy in addition to other renewable sources such as geothermal, biomass and tidal waves, however, at the moment all these sources have not yet utilized in proper and efficient ways [18].

Solar Energy In Libya: The solar energy is the most important renewable energy resource compared with other resources, and fortunately Libya is considered one of the countries which has abundant of energy from this resource. Based on data acquired from The Centre for Solar Energy Research and Studies, the average annual solar radiation in some areas in Libya is summarized in Fig. 5. Solar energy could be considered one of the primary resources due to Libya's location on the cancer orbit line with exposure to the sun's rays throughout the year and with extended hours during the day. The daily average solar radiation on a horizontal plane is about 7.1kWh/m ^{2} /day on the coastal region in the north and 8.1kWh/m ^{2} /day in the South region, with the average annual sun duration more than 3500 hours per annum.

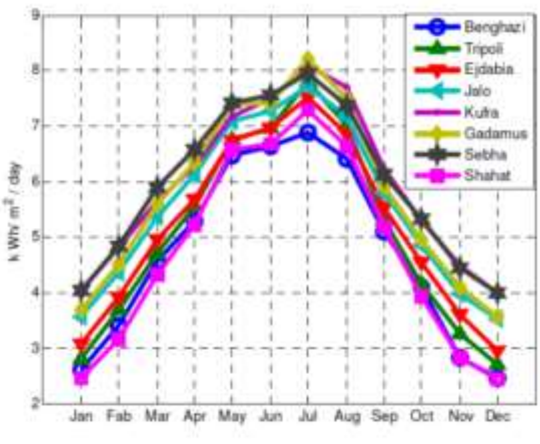

Figure 5. The monthly solar radiation in different cities in Libya

Wind Energy In Libya: Wind energy is considered the second important resource of renewable energy in Libya. Although the interest of this resource is not new, where it has been used in many oasis to pump water since 1940, it has not been developed on a large scale , because of the availability of the traditional energy sources such as oil and natural gas. However it has been emanated in the last decades to be another important renewable resource with solar energy, where there are many local studies from the researchers and encouragements from the authorities about wind energy [19]. However, Fig. 6 illustrates NASA's mean monthly wind speed for all regions between 1982 and 2019 [20]. It is noticed that Darnah has a maximum monthly wind speed, which occurred in January with a value of 6.177 m/s followed by Benghazi with a value of 6.006 m/s recorded in February. The lowest wind speed value of 3.351 m/s was recorded in December for Al-Kufrah.

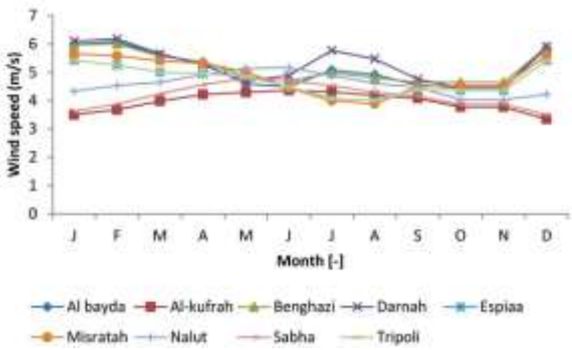

Figure 6. NASA mean monthly wind speed for all selected regions in Libya .

VI. MATCHING OF DESALINATION AND RENEWABLE TECHNIQUES

Desalination is an industrial process which needs a type of energy which could be thermal, electrical or mechanical, depending on the desalination process itself. The application of the renewable energies (RE) in desalination processes is widely considered due to environmental and economic impacts. Coupling of renewable-energy technologies with desalination processes is the most appropriate option for supplying water and electricity to locations where no grid electricity is available and where the water scarcity is severe [21].
Selecting the most suitable RE-driven desalination technology depends on several factors such as size of the plant, salinity of the feed water and required product, remoteness, existence of access to an electricity grid, technical infrastructure and the RE source and its availability, potential and exploitation cost. There are several combinations of desalination and RE technologies, which are particularly promising with regard to their economic and technological feasibility. Some combinations are more suited for large-scale desalination plants, whereas others are more appropriate for small-scale applications [22], as shown in Fig. 7.

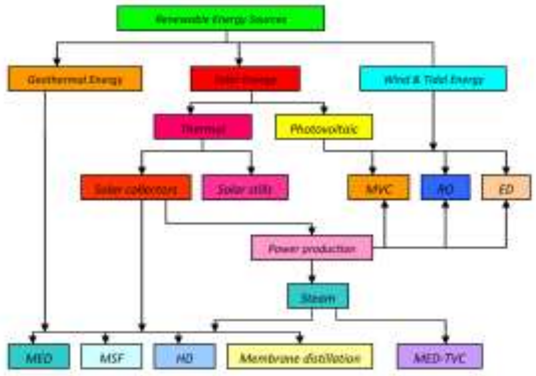

Figure 7. Feasible combination of RE and desalination technologies.

Desalination by means of solar energy is a most appropriate alternative to conventional methods because it can be used either thermally or electrically. The thermal energy can be achieved in solar stills, collectors, or solar ponds, as shown in Fig. 8. Electrical energy can be produced from solar energy directly by photo-voltaic (PV) conversion or via a solar thermal power plant [23].

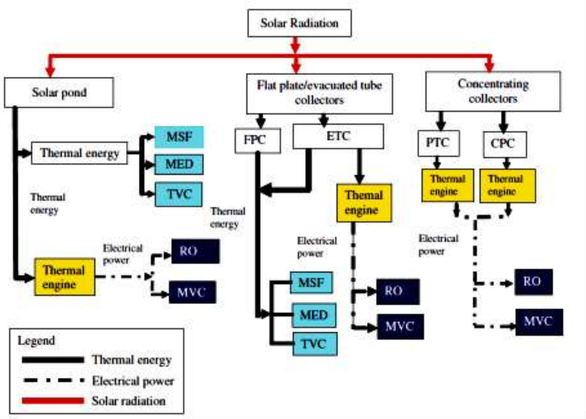

Figure 8. Possible configurations for solar thermal desalination plants

VII. Sustainable Solutions for Fresh Water Scarcity in Libya

As it has been illustrated before in the above sections about the situation of natural fresh water resources in Libya, as well as the situation of conventional energy resources which are helpful in producing water by using desalination processes, the shortage of water resources still arises as a main dilemma and challenge in development process in Libya. However, the alternative to solve this problem is by depending on the renewable energy resources, mainly solar and wind energies which are available abundantly in Libya with a reasonable history of applications in thermal or electrical processes. Here, the researcher proposes some solutions depending on the solar and wind desalination techniques which have been used widely in many countries in the world to produce fresh water. Before proposing the solution two topics have two be highlighted concerning the renewable energy desalination, the first is the addressing of the integration challenges and the second is the sustainability of desalination technologies.

A. Addressing Integration Challenges

A variety of options are available to address integration challenges of renewable energies with desalination technologies. Key considerations in selecting methods to address the variability and uncertainty of the renewable generation are the cost-effectiveness of the method and the characteristics of the existing grid system. Grid infrastructure, operational practices, the generation fleet, and regulatory structure all impact the types of solutions that are most economic and viable. Generally, systems need additional flexibility to be able to accommodate the additional variability of renewables. Flexibility can be achieved through institutional changes, operational practices, storage, demand-side flexibility, flexible generators, and other mechanisms [24].

B. Sustainability of desalination technologies

Sustainability of desalination technologies can be assessed by four components which comprise environmental, economic, social and technological areas. In addition to the other key components, technical feasibility becomes an important component in the evaluation of desalination processes since they are chemical-, cost and energy-intensive contributing to environmental emissions and technology has a vital role to play in their mitigation. The economic impact depends on various factors such as water source availability and its quality, type of energy source, process technology, labor, operation and maintenance costs, geographical location, and finally on the financial package. The environmental component includes the greenhouse gas emissions (global warming and acid rain potentials), brine and chemical discharges (eutrophication, water quality and ecological impacts) into the receiving environments and the ecological impacts associated with these environmental emissions. While the social factors include social acceptance, confidence in quantity and quality of the water sources and their demands and the acceptance of desalination technologies and trust in the water providers [25].

VIII. THE PROPOSED SOLUTIONS OF RENEWABLE ENERGIES – DESALINATION TECHNOLOGIES

In the previous sections it has been talked about the solar and wind energies in Libya which are available abundantly and have acceptable history of applications in some areas. In desalination processes these two types of renewable energies can be applied in decentral as a small and medium units, or central units in large plants for high productivity.

A. Decentral Units

The decentral desalination units are with low productivity and can be operated with low energy source. These units could be small sized for private or family use, or could be medium sized for small communities or industries or firms. These units are very simple in design and can be constructed easily and locally with low costs, thus make it very attractive to many researchers, where we could find many interesting studies about different designs which intend to improve its productivity and performance. According to the combination process with solar energy these units could be either solar thermal assisted systems or solar photovoltaic systems.

Solar thermal-assisted systems: Solar thermal energy can be harnessed directly or indirectly for desalination. In indirect systems, solar energy is used either to generate the heat required for desalination and/or to generate electricity used to provide the required electric power for conventional desalination plants such as MED and MSF plants. Direct solar desalination requires large land areas and has a relatively low productivity. However, it is competitive with indirect desalination plants in small-scale production due to its relatively low cost and simplicity [26].

Direct solar thermal desalination: In the direct systems the heat collection and distillation processes occur in the same equipment. This method is mainly suited for small production systems, such as solar stills, and it is used in regions where the freshwater demand is low. It has low efficiency and low water productivity due to the ineffectiveness of solar collectors to convert most of the energy they capture, and to the intermittent availability of solar radiation. These units are of different features and designs as shown in Fig. 9.

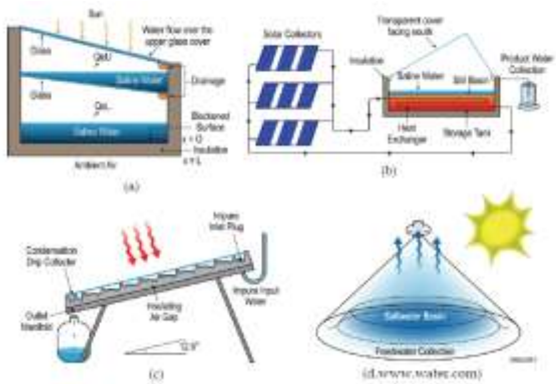

Figure 9. Diagrams of various solar stills: (a) double-basin solar still, (b) single-basin solar still coupled with flat plate collector, (c) multi-steps tilted solar still, (d) micro-solar solar still [27].

Indirect solar thermal desalination: In these methods the desalination process is achieved in two separate systems: the collection of solar energy by a solar collecting system, coupled to a conventional desalination unit. These methods include e humidification-dehumidification (HD), as in Fig. 10, membrane distillation (MD), as in Fig. 11 , solar pond-assisted desalination and solar thermal systems such as solar collectors, evacuated tube collectors, and concentrating collectors (CSP) systems driving conventional desalination processes such as MSF and MED. These processes can be used as medium sized units as HD, or could be used for high productivity for central units as in the other types.

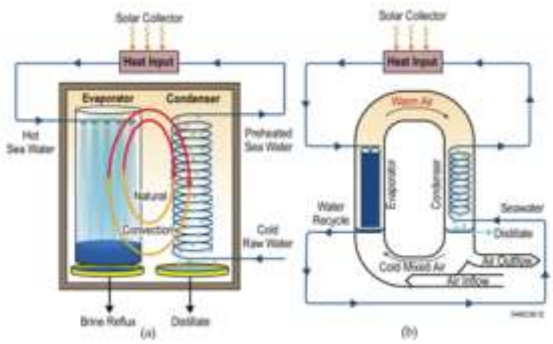

Figure 10. HD systems: (a) open-water closed-air cycle, and (b) open-air closed-water cycle.

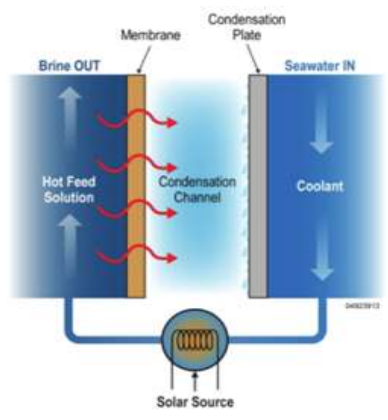

Figure 11. Schematic of the membrane distillation process [27].

B. Central Desalination Units

The second proposal is the central desalination units which have high productivity. This type can be established by depending only on renewable energy resources such as solar energy or can be constructed as a hybrid unit by using auxiliary conventional thermal energy source such as fuel burning process. The importance of this type comes due to the ability of updating the old conventional desalination plants which are operated by thermal or membrane processes to be operated also by renewable energy resources, according to the type of process and the way of matching between the desalination and renewable energy resources as illustrated before. One of these combinations is by coupling CSP systems with desalination plants or PV systems with desalination plants.

CSP systems coupled with desalination plan: The primary aim of CSP plants is to generate electricity, yet a number of configurations enable CSP to be combined with various desalination methods. When compared with photovoltaic or wind, CSP could provide a much more consistent power output when combined with either energy storage or fossil-fuel backup. There are different scenarios for using CSP technology in water desalination , and the most suitable options are parabolic trough coupled with MED desalination unit (see Fig. 12), and parabolic trough coupled with RO desalination unit (see Fig. 13).

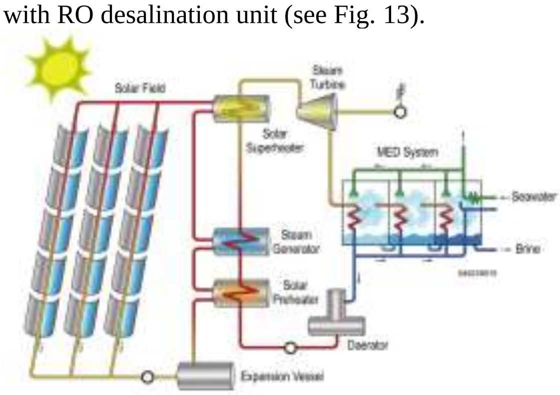

Figure 12. Parabolic trough power plant with oil steam generator and MED desalination .

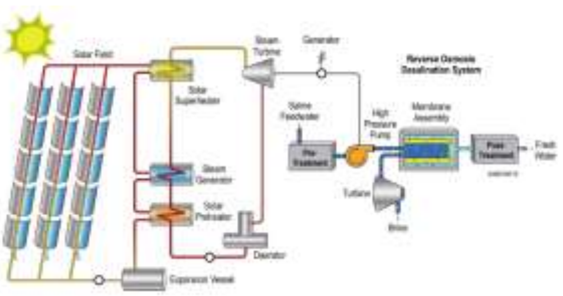

Figure 13. Parabolic trough coupled with seawater RO desalination unit.

Solar PV desalination: A photovoltaic or solar cell converts solar radiation into direct-current (DC) electricity. It is the basic building block of a PV (or solar electric) system. PV systems can be classified into two general categories: flat-plate systems and concentrating systems(CPV). CPV system have several advantages compared to flat-plate systems: CPV systems increase the power output while reducing the size or number of cells needed; and a solar cell's efficiency increases under concentrated light. PV-powered reverse osmosis is considered one of the most promising forms of renewable-energy-powered desalination, especially when it is used in remote areas, Fig. 14. Two types of PV/RO systems are available in the market: brackish-water (BWRO) and seawater (SWRO) PV/RO systems.

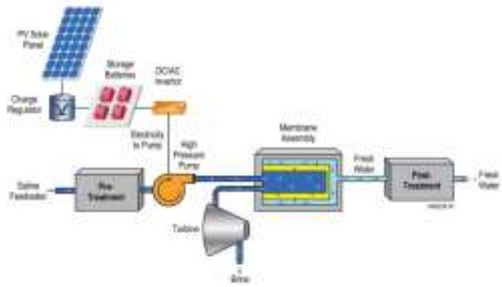

Figure 14. Schematic of a PV/RO system [27].

C. Desalination systems driven by wind

The other option for renewable desalination is by using wind energy to produce mechanical power, to be used directly for desalination process with RO technology (Fig. 15), or to produce electrical energy and then be used with any process needs this energy such as RO, ED, and VC technologies. Wind-driven desalination has particular features due to the inherent discontinuous availability of wind power. For standalone systems, the desalination unit has to be able to adapt to the energy available; otherwise, energy storage or a backup system is required.

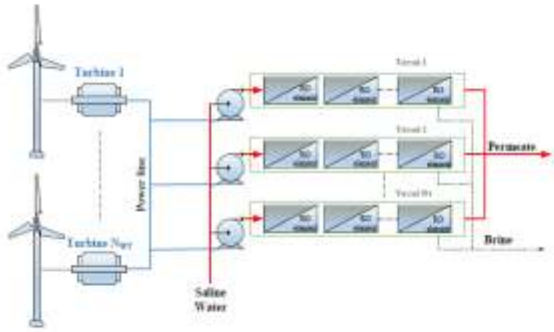

Figure 15 . Wind-driven reverse osmosis (RO) plant structure [28].

IX. CONCLUSIONS

Based on the previous explanation about the water shortage problem in Libya the following points can be concluded:

1. The water crises in many countries in the world is increasing, and especially in the countries which do not have enough natural resources such as Libya.
2. The rates of water per capita in Libya are considered very low compared with others. Population growth in Libya has been accompanied by a growth of water consumption in domestic use as well as agricultural and industrial areas.
3. Libya is considered as an arid zone country, so it depends heavily on groundwater, which accounts for more than 97% of the water used, where this resource is limited for a period of time and will not last for the future generations.
4. Currently Libya is very rich country in conventional energy resources mainly oil and gas and most of its cities are on coast, this can help in solving problem of water shortage by conventional desalination processes. Also the renewable energy resources are very abundant in Libya mainly solar and wind energies which are the promise for solving energy and water crises in future.
5. In general there are awareness from the authorities and researchers about the expectation of water crises in Libya if there are no sustainable solutions.
6. Encouraging solar and wind desalination technologies either as decentral or central units will participate effectively in solving water shortage problems nowadays and in the future.

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