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Feasibility and Possibilities of Renewable Energy in Desalination With Closer look to GCC Countries

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ABSTRACT
The use of renewable energy in various fields is not a new trend and studies covered many aspects of this subject but it is still open for further discussions and studies . And as the middle east region (specially Gulf Cooperation Council countries GCC) climate conditions make the usage of solar and wind energy techniquesa possible and feasible alternative of fossil fuelssources . And as the potable water source for GCC countries is mainly through desalination which consumes considerable amount of energy beside its environmental effect , this study directs a closer look to different methodology and techniques of water desalination systems widely used and their economic and environmental factors .Also will detail the possible alternatives of renewable energy sources and theirfeasibility to drive desalination systems .
Key Words: Renewable energy – Desalination – Solar energy – Wind energy

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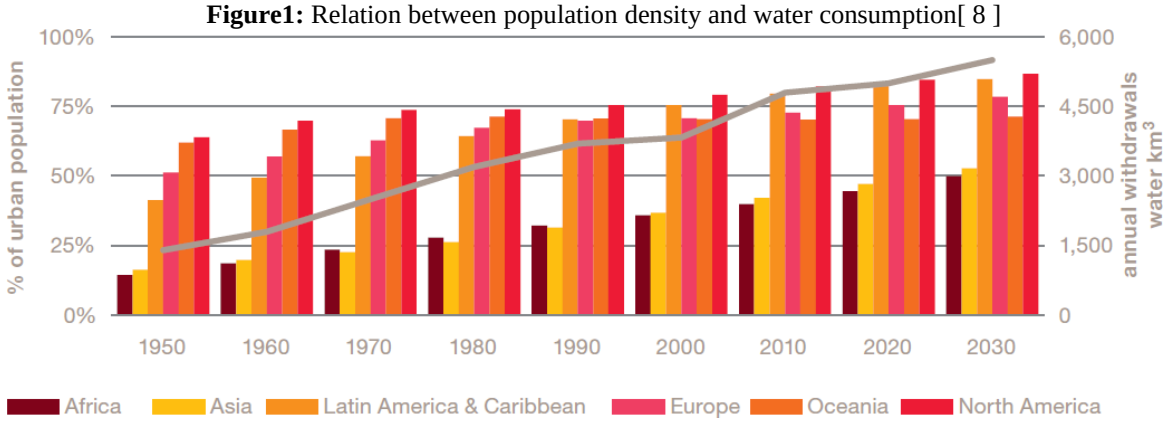
I. INTRODUCTION :

Water scarcity is considered one of the most challenging problems for many countries around the world,. As it can be extracted from figure 1 , the expected demand will be increasing in the future while the sources will remain the same or maybe reduced this will surely lead to shortage of water in many regions .

Figure1: Relation between population density and water consumption[8]



Recent study for different parts of the world showed the percentage of each region population thatwillbe subjected to watershortage or stress in the future which is shown in figure 2 [8] , unfortunately this study clearly show that the middle east and many Arab countries will be among the most affected areas in the near future which necessitates urgent and serious actions to face the crises .

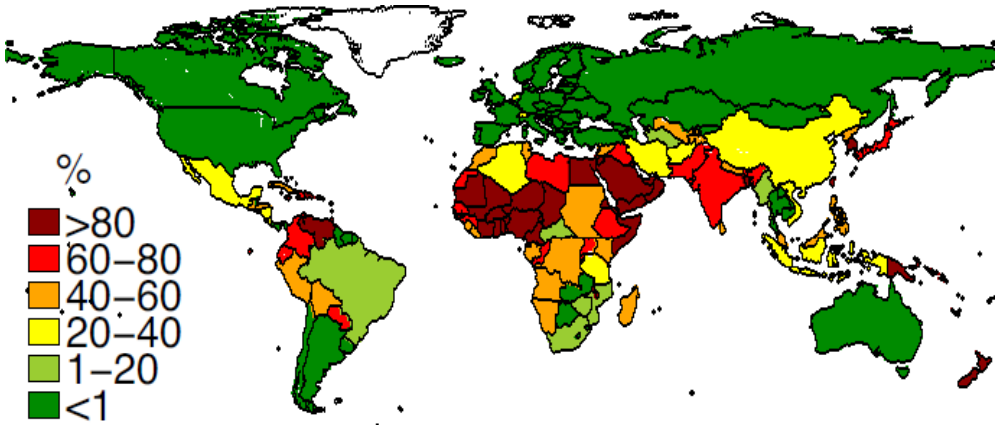
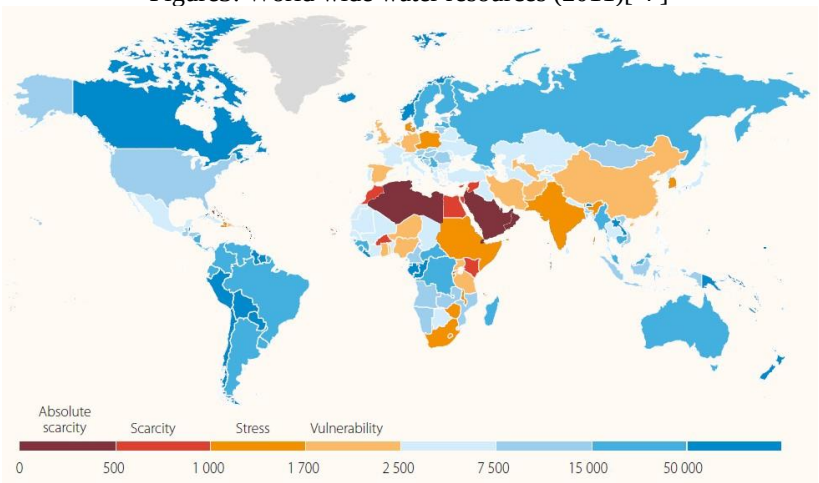


Figure2: Expected populations under water stress

The water needs have to be fulfilled through either natural sources as rivers or ground water , or through different water production techniques such as desalination , and as said the demand will surely increase meaning the need for desalination will also increase . This increased demand for desalination process will consequently lead to increased demand on energy needed for desalination systems .

Figure 3below show the actual Renewable water resources, it is defined that renewable water is the total resources surface water and resources of groundwater in certain region . While it is defined that Nonrenewable resources are the water resources existing in deep aquifers and this non renewable resources are not recharged in rates sufficient to be part of future water resources in most regions .[1]

Figure3: World wide water resources (2011)[4]



In closer look to GCC countries and Kuwait as an example , it is well known that For decades Kuwait depends on the desalination plants to fulfill the fresh water demands as the sources of fresh water is extremely low compared to actual population demands . and as the desalination process is considered expensive and energy intensive it is more than any period represent economic , technical and environmentally problem .

The recent statistics show that the current production of energy and water in Kuwait consumes around 12% of its total oil production and the portion of water production through desalination consumes at least 4% of the total production of Kuwait and as the future demand will normally increase with the increase of population it is estimated that water demand will increase with around 3% annually and that will again impose significant pressure in the economy in the coming years .

Economic Impact :

Table 1. Global oil reserves in %.

Middle East region	Parts of Central and South America	NorthAmerica region	African region	Eurasia	Asia and Oceania region	Europe
49	20	13	8	7	3	1

Looking on the world oil reserves , the middle east region have around half of the international oil reserves while other regions on the world doesn't have or have limited reserves . low reserve means that there will be problems to meet the future energy demand and necessitate the search for other energy sources rather than oil . Renewable energy sources used worldwide doesn't exceeds 7 to 14% of the energy demands and if including the hydropower sources it can be said it covers around 20% to 23 % of electricity generation worldwide but the use of hydropower plants is limited to regions where natural resources are available . [3]

And to concentrate more on GCC countries , the rate of consumption of energy vary from other parts of the world based on region population needsand taking into consideration the climate conditions, and for many years the energy tariff in GCC was considerably low and did not raise for decades , but due to world economic fluctuations and changes in oil price the rise in energy tariff occurred already in many GCC countries such as KSA and other GCC countries is most likely will follow shortly .

The recent fluctuations and drop in oil prices affected stability the economy of GCC countries and most of them had to take serious actions to overcome the negative fiscal balance indicated in the international monetary fund reports for the region and to cut spending. GCC countries started recovery plans including increasing the interest in expanding the use of different renewable energy sources and re evaluating energy production , usage and consumption policies [4] .

Environmental Impacts

Desalination process as energy consuming process utilizing fossil fuel contributes with considerable percentage on the CO2 emissions crisis , In the Middle east region, it is expected by 2050 that producing the required water quantities by desalination would produce yearly aroundto 360 million tons of CO2 equivalent emissions [11]. Such figures would necessitate implementing renewable energy sources to reduce the emission and energy requirement of the desalination process [12].

One of the important points to be taken into consideration when studying the desalination process is how this process will affect the environment , it is known that environmental effect of desalination process exists regardless how the desalination plant is powered and even it is powered by renewable energy sources desalination it will still have environmental impacts . As desalination process depends mainly on sea or ocean water desalination process will have negative impacts and also indirect influence or impact on the marine life , this impact will grow with the increasing demand on water and thus on using more desalination systems [13] .

In an attempt to get most possible benefits of desalination process outcomes, recent studies discussed the feasibility of using the salt and chemicals contained in brine to produce some products such as ink , fertilizers ,fillers , soil conditioners and other products [14] .Such way of thinking would contributes in reducing the environmental negative contribution of desalination and open doors for similar projects .

Different Desalination techniques and systems :

Generally speaking we can say that Desalinationis theprocessesthataims to separatedissolvedminerals such as salts, from seawater or brackish water to produce water withacceptable percentage of total dissolved solids

Desalination techniques widely used now days are thermal desalination and membrane desalination . Thermal desalination can be divided intoMulti Stage flash distillationMSF ,Multiple Effect Distillation MED and Vapor Compression VC. On the other hand membrane desalination systems includes Membrane Distillation MD , Reverse Osmosis ROand Electrodialysis ED .

Worldwide RO is considered the most installed systems while MSF comes second .,From Energy point of view Multi Stage Flash needs thermal energy to heat the feed-brine and alsofor ejector's medium-pressure steam used to generate vacuum in the desalinationunit different sections. Waste heat can be used to increase the temperature of the inlet seawater, it is also used withordinary boilers and also utilizing the backpressure steam from turbines in power stations, increasing its cost effectiveness and efficiency and MED daily capacity 11is up to 35.000 m^3 [11].

In desalination systems MED ,vapour from certainstage is condensed in the subsequent stage and then it is vaporized again at lower pressure. At the first stage with lower temperatures , heat is required to increase the brine temperature. The vapour is then transferred to the second stage vessel and the process is repeated ,.MEDdaily production capacity is up to 30.000 m^3 or higher [17].

In the Vapour Compressionprocess VC , Vapour's temperature is increased by compression meaning that source for the evaporator direct heating is replaced by compression. When vapour is generated in the evaporators it is compressed mechanically in what is called MVC or thermally TVC . VC daily production capacity is in the range of 100 and 3000 m3,while the daily production capacity of

MVC may reach 10.000 and it can reach 30.000 m3daily for TVC.To improve overall efficiency ,Vapour Compression is often combined with other processes such as MED.

Using membrane technologiesfor desalination , three main techniques are widely used :Reverse OsmosisRO systems , Electrodialysis ED systems , and Membrane Distillation MD systems .

Electrodialysis technique ED uses the electrical energy to push salt over special membrane separating it from freshwater that is left behind. Its capacitymay reach between 2 to 145.000 m^3/day [11].

Membrane distillationsystem MD is considered as combination of thermal distillation system combined with membrane desalination. Due to difference in pressure caused by differences in temperature and the membrane characteristics , only water vapour move through the membrane. The temperature difference between membrane sidescause the vapour to diffuse from the high temperature side of the membrane to lower temperature side .

Reverse osmosis techniqueRO uses semi-permeable membranes and through increase the pressure of the feed water higher than the osmotic pressure, the desalinated water passes through the membranes and the salt is left behind.

Water – Energy Relation

Water and energy have a strong ties and directrelationship. Energy production plants andprocesses require considerable amounts of water and on the other hand producing fresh water and handling it from treatment to distribution requires significant amount of energy. This fact leads to a conclusion that dealing with issues related to water production is closely related to energy production and consumption . To explain we can take some figures, some of the water treatment processes will consume small amount of energy like ultraviolet light which may consume up to 0.04 kWh/m^3while other techniques like RO would require considerable amount of energy up to 4 kWh/m^3 .

It is estimated that electrical energy cost may reach a percentage of 5 to 40% of water utilities ruining cost and as the water demand will normally increase with increased population the cost will surely get higher affecting the availability and affordability of water supply [5] .

Energy Requirements

In general it can be said that desalination process is an energy consuming process and the required energy amount depends on many factors such as the technique itself , system design , system efficiency and characteristics of feed water among other parameters .

The statistics and range of electrical , thermal and total energy requirement of different desalination systems are summarized in Table 3

	MSF	**MED**	**MVC**	**TVC**	**SWRO**	**BWRO**	**ED**
Electrical Energy consumption (kWh/m^3)	2.5 - 5	2 – 2.5	7 – 12	1.8 – 1.6	3 - 6	1.5 – 2.5	0.8 – 5.5
Thermal Energy consumption (MJ/m^3)	190 - 282	145-230	-	227	-	-	-
Equivalent electrical to thermal energy (kWh/m^3)	15.83 - 23.5	12.2 - 19.1	-	14.5	-	-	-
Total energy consumption (kWh/m^3)	19.58-27.25	14.45-21.35	7-12	16.26	3 - 6	1.5 – 2.5	0.8 – 5.5

Table 3: Energy consumption of Desalination techniques [11] , [18]

Renewable Energy and Desalination

The need for desalination as main source of potable water is expected to continue for decades as many regions worldwide have no other alternative or natural resources of water . And as discussed the environmental impact of desalination is divided into two categories , one related to the need to use fossil fuel and its effect on emissions and the second is the impact on the marine life . Here we will concentrate on the energy side of the impact as it is the main point of the study and as an obvious solution of the impact of using ordinary fuel and oil

to operate desalination plants the clear idea would be using renewable energy instead of oil or other ordinary energy sources .

The use of renewable energy as main source of energy for desalination depends on the expected advance in industrial and technology development in renewable energy filed which my lead to reducing the entail costs , running costs and improving the efficiency and increase the produced amount of energy .

Studies showed that very low share of RE powered desalination on the world's desalination capacity not exceeding 1 to 2 % [19]. The main technology in this minor share is for RO systems with around 62% of the total RE desalination systems. While solar photovoltaic PV represents about 43% of renewable energy source for water desalination with less share for solar thermal and wind energy [19] .

RE resources in GCC

Climate conditions of GCC countries are so similar from many aspects on different countries , and as the desert covers vast area of the GCC region the solar irradiation is existing most of the day with high rates specially in summer months beside high wind power utilizing possibilities [6] .

Although that fact it is still observed that the main source of energy generation in the region is still by usingfossil fuel while the use of RE sources is very limited . In other parts of the world It was estimated in year 2015 that RE contribution is about 7.1%, it rise up to 23.1% if hydro power stations are counted. In addition to this, the use of coal in generating electricity was observed for about 39.3%, while for gas and nuclear power, it was 22.9% and 10.6% respectively [7]

Looking into GCC area , it is estimated that the contributions of the renewable energy portion of the electricity power generationin GCC countries is between 0.01% to 0.5% except for UAE where the percentage increased significantly years 2019 and 2020 reaching 7.2 % of the total electricity capacity .

%	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Bahrain	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Kuwait	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.3	0.5	0.5
Qatar	0.4	0.4	0.5	0.5	0.5	0.5	0.4	0.4	0.3	0.3
KSA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.5
UAE	0.0	0.0	0.4	0.5	0.5	0.5	1.1	1.9	5.8	7.2

Table 4. Renewable energy share in electricity capacity % [2]

Comparing the total produced RE for the GCC countries from 2011 to 2020 is listed in Table 5. Showing significant increase in the capacity in years2019 and 2020 in UAE, KSA, Kuwait and Oman.

CAP(MW)	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Bahrain	1	1	1	6	6	7	7	7	10	10
Kuwait	0	0	3	4	6	33	44	55	106	106
Oman			1	1	2	2	8	8	59	159
Qatar	39	39	40	42	42	43	43	43	43	43
KSA	3	14	22	24	24	24	37	87	413	413
UAE	13	13	128	136	136	142	356	599	1919	2540

Table 5. RE based electricity capacity in the GCC [2] .

Table 6 show the capacity of the wind energy in MW from years 2011 to 2020 and it can be noticed that the wind energy is very low in all area except for Kuwait where it started in 2013 with 2 MW then increased to 12 MW in 2017 but did not increase since then .

CAP	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Bahrain	1	1	1	1	1	1	1	1	1	1
Kuwait			2	2	2	2	12	12	12	12
KSA							3	3	3	3
UAE			1	2	2					

Table 6. Wind energy electricity capacity in GCC region (MW).

The installed capacity of solar energy is shown in Table 7 the data show significant increase in 2019 and 2020 in UAE, KSA, and Kuwait.

CAP (MW)	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Bahrain	0	1	1	5	5	6	6	6	9	10
Kuwait	0	0	0	2	3	31	32	43	93	93
Qatar	1	1	2	4	4	5	5	5	5	5
KSA	3	14	22	24	24	24	34	84	409	409
UAE	13	13	126	133	134	141	355	598	1 918	2 539

Table 7. Capacity of solar energy in the GCC inMW.[2]

In general electricalpower capacity with RE in GCC, is about 0.6% to 0.8% of the installed capacity and it can be noticed that solar energy constitution is the largest REsource .

Possible RE powered desalination systems

It is to be mentioned that using renewable energy for power generation actually would be considered easier than using it for desalination technically speaking and there are many differences in utilizing the renewable energy in both fields.The use of renewable energy to power desalination system is subjected to many factors to judge its feasibility technically and economically . The location , climate condition , feed water characteristics , stability of the energy produced and many other factors must be studied in detail .

The simplest and obvious alternatives would be using solar or wind energy to power desalination ,from the wind to electricity is almost seamless and has been proven viable using a vast range of applicable technologies. On the other hand, integrating solar or wind energy conversion technologies with desalination processes requires careful consideration to assure maximum thermodynamic synergy, which appears yet far from being adequately validated for feasibility, or even demonstrated for practicability on solid scientific and technically acceptable basis .

Table 8 belowshow some of the alternative combinations of REwith desalination technologies

	MSF	MED	VC	RO	ED	MD
Solar PV				○	○	○
Wind				○	○	○
Solar thermal	○	○	○	○	○	○
Geothermal	○	○	○	○	○	○

Table 8: alternative combinations of REwith desalination technologies

Solar Powered Desalination

In practice there are different methodologies of converting Solar energy into either thermal energy or electric energy. Solar stills can collect energy directly to water, or by another technique by using solar thermal collection and this thermal energy is then usedin desalination processes. Solar photovoltaic energy can be used to produce and collect Electrical energy which is then used in RO and ED .

One of the production systems are Solar Stills , it is used to capture the solar irradiance that passes through its transparent surface reaching the salty water , and as the water temperature increase

the water is evaporated and the vapour then condensate on glass or other suitable material surfaces . This technique is considered suitable for low production ranging 3 to 4 l/day/m^2 or 200 m^3/day [11] . Such low productivity show that large area to install the solar collections maybe needed to achieve larger production rates this will lead to be more costely than other systems [17],[19].

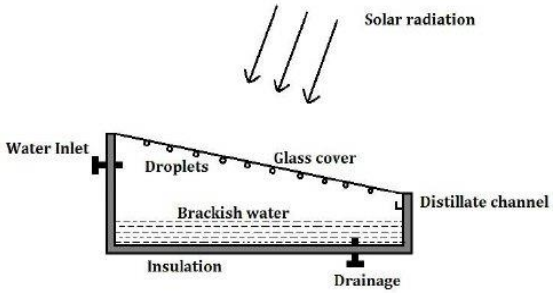


Fig 4: Diagram of a conventional solar still

Another system of collecting and storing thermal energy is Solar ponds .Solar pond consists of three layers upper convection zone,non-convection zone or salinity gradient and storage zone or lower convection .

Solar Ponds are considered of high storage capacity and suitable for coupling with MED, TVC and MSF desalination plants and solar pond operation in MED is more feasible than in MSF due to less temperature requirement , [17].The main advantage of solar ponds are the large capacity and the ability to store heat allowing continues operation [11] .

Solar thermal collectors are another solution , they absorb the solar radiation and they can be integrated with different systems such as membrane units and multiple stage basin stills that have several compartments used to recover part of the condensing heat to be used to heats the water in upper compartment.

concentrated solar power (CSP) power plants can produce thermal energy through concentrating the direct solar irradiation and the heat can be directly used with different types of desalination systems beside generating electric power for auxiliary systems .The parabolic system is considered one of the best option with Concentrated solar power system to be coupled with desalination systems specially with RO systems or MED system [11].

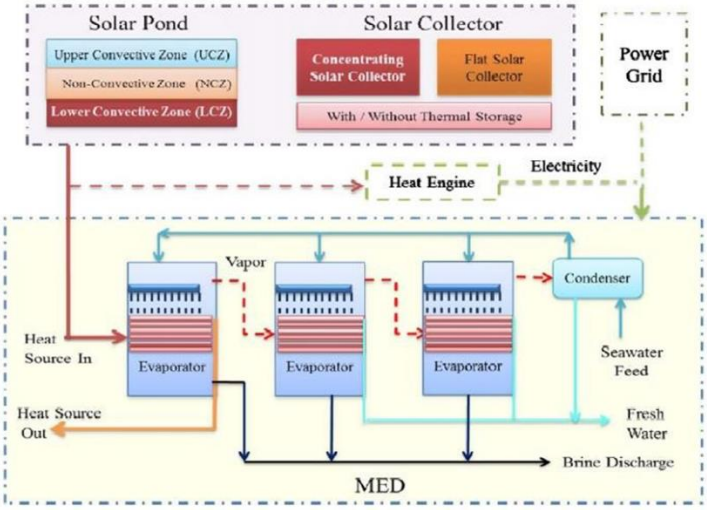


Figure5 : MED-CSPwith SolarPond[17]

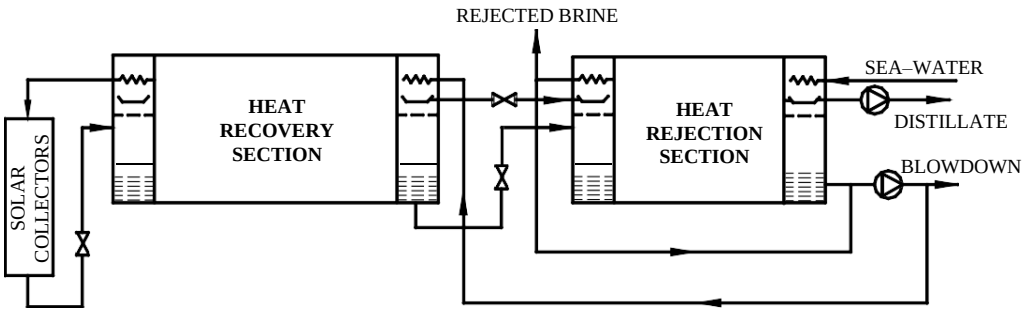


Fig. 6. Solar energy driven MSF process.

MSF desalination process is widely used due to highcapacityand performance [20] , Fig 7 shows solar energy coupled MSF process , as suggested the system would consist of two sections one for heatrecovery and the other is for heat rejection. Seawater enters the first section for heat rejectionwhere thermal energy is rejected from the system and water and brine discharges at low temperature. Thefeed is then mixed with a large amounts of water, and recirculated through the system . This mixturegoes through number of heat exchangers to rise its temperature. Then water enters the solar collector arearaising its temperature to near saturation temperature. The water enters the first stage reducing its pressureand flashes into steam, where it is condensed and drips into a distillate tray. This process is repeated through the plant as both brine and distillate streams flash as they enter subsequent stages, which are at lower pressures .

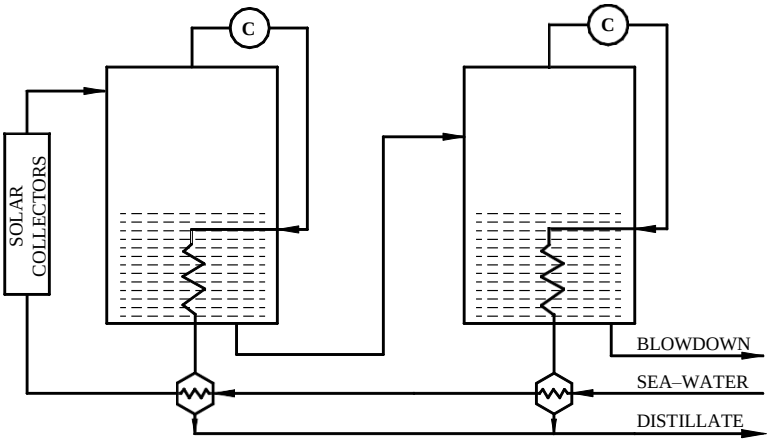


Fig. 7. Solar energy driven VC system

InFig. 15 ,showing solar energy driven vapour-compressionsystemVC , where a compressor is used to increase the vapour pressure and temperature. and the latent heat is released from the compressed vapour during the compression process and this heat can be used in the evaporation process . vapour is overheated as the pressure is dropped lower than saturation pressure it can be used to provide energy to the same stage it came from or to other stages [23 , 22].

As a summery of the referenced studies and researches that discussed both possible configuration of RE – desalination system and cost analysis ,it can be said that Solar thermal energy can be considered promising application of RE in desalination .

Generally speaking RE driven desalination methods can be divided into main two categories , one includes systems driven by heat produced by RE, while the second utilize electrical or mechanical energy produced by RE to operate the desalination plant .

Several configurations was presented and detailed in the referenced researches including proposed combination of improved design solar thermal collector with MSF plant .

Systems was developed to improve MSF ability to adopt the variation of heat sources to overcome the fact that MSF process is not able to operate with variable heat source . Powering MSF systemusing solar pond is most costeffective systems ,Thermal energy delivered by a salinitygradient solar pond has been used in seawater and brackish water RO desalination. Coupling solar thermal energy to drive RO process and to drive MVC was also presented.

Additionally, the possibilities and opportunities related to wind power was point of interest as it is expected to have soon progress in research and development of how to utilize the wind energy in different fields of power generation which will boost the use of wind energy in desalination field specially in RO systems .It was reported that using windenergy to operate RO plant from brackish water resulted in lower cost than that the using conventional diesel engines. On the same line , a study showed that combinations of wind-powered RO plant with diesel generator can provide a reliable energy system .

Mostly when there is no sun the wind becomes stronger and vise versa , this lead to the logical idea of combining both solar and wind energy on the same plant to integrate each other and produce energy continuously without interruption due to solar power cut or wind power cut this solution or combination can be considered a reliable suggestion to power a desalination system and this choice is already implemented in several projects in

different locations worldwide as detailed in recent researches .

To choose a system utilizing RE for desalination ,different parameters should be taken into consideration, starting with availability and suitability of the RE resources , the overall water resources both quality and quantity ,availability of the land area , cost analysis for both entail and running costs , sustainability of the RE resources , energy consumption , maintenance requirements , and overall system efficiency [20] .

The main disadvantage of using direct collection solar systems is that it depends upon availability of solar energy and their collection is inefficient and this situation may impose using storage device which is considerably expensive. To overcome this indirect collection disadvantage , using solar collectors with more efficiency and in the form of hot water or steam and replacing the storage device by connecting to the electric grid or back up boiler to supply energy during the night time where there is no solar energy available .

For wind energy , it is clear that energy produced using energy is variable source of supply as it depends onboth wind speed and wind frequency. Meantime generating electricity using wind energy can be efficient and this process can adapt the changes and variations by using storage batteries systems that provide power when wind energy is interrupted and this ensures continues supply for the load .

Using wind energy to power desalination system thesystemmust be designedtoadapt the variation of the wind power produced and would result in lower efficiency of the system and operation problems for RO systems because those systems requires steady power supply to achieve acceptable efficiency [10]. To ensure practical operation ,RO desalination driven by wind energybetter be operated coupled to the grid so when the system is connected to grid, the desalination plant operate continuously as a conventional plant and the wind energy acts as a substitute. [21].

II. CONCLUSION AND RECOMMENDATIONS

This paper reviewed different aspects related to using renewable energy sources to power desalination plant and discussed the renewable energy sources in GCC area and showed the importance of utilizing the RE in the desalination field .Also the paper reviewed different types of conventional desalination systems widely used and compared between them from different angles . The paper reviewed the latest proposed configuration of coupling RE with desalination and showed the advantages and disadvantage of the proposed configurations as shown in many recent researches world wide .Also discussed the selection parameters for the suitable RE – desalination plant including the availability and stability of the RE and water supply and quality together with infrastructure and other factors affecting the right selection of the combination .Several combinations would be feasible technically and cost wise more than others according to the local and regional factors .

It is highlighted that solar energy powered RO system can be considered the most applicable and feasible system specially if also combined with wind power and integrated into the grid ,

As conclusion to the comparison of different proposed techniques of desalination the least consuming energy system is the RO system utilizing energy recovery techniques noting that is more applicable on larger installations to compensate for the high cost of energy recovering turbines needed to increase the system efficiency . Meantime RO system without energy recovery would also be of relatively low cost butRO although requiring a smaller amount of energy is expensive and requires a complex seawater treatment.The Multi Effect Boiling MEB is the cheapest of all the indirect collection systems and also requires the simplest seawater treatment . From RE point , the solar still will be surely the lower in cost and direct collection system is the easier in construction and operation but it needs large land area to achieve acceptable capacity

Also wind energy showed to be a promising solution if the climatic and land condition meets the requirement of its plants .

Beside what was discussed concerning Renewable energy powered desalination , we would also recommend some general points enduring the idea and principles of utilizing renewable energy . Government and official organizations should give more attention to research centers to boost RD in renewable energy, and encourage the participation in producing and using RE for residential buildings and usage or electrical vehicles in public and private sectors to save fuel and reducing the emissions .

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