Using Solar Energy Technology in Sea Water Desalination in North Sinai According to the Egyptian Sustainable Development Plan 2030

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Abstract

Due to a lack of increase in the use of renewable energy, Egypt is having problems attaining sustainable development and safeguarding the environment. Egypt is one of the solar energy-rich countries, with an average direct vertical solar radiation of 2000-3200 kWh/m^2/year and 9-11 hours of sunshine per day, indicating the availability of investment potential in solar energy applications, particularly in seawater desalination technologies. Egypt's economic development, like that of all countries in the twenty-first century, is intertwined with the water resources sector. Despite Egypt's promise in terms of solar energy availability, the use of solar energy was confined to its use in heating water, and even this use of solar energy is still constrained, if not entirely limited, to its use in home water heating. In addition to the foregoing, Egypt faces an issue with institutional building preparation, resulting in a delay in the process of replacing traditional energy with solar energy. Furthermore, demonstrating the impact of desalination technology and sanitation on boosting water supplies to meet current and future conditions, as well as ongoing efforts to sustain development and deliver resources.

Keywords

Sea water desalination, Renewable sources, Solar energy, Sustainable development, North Sinai

I. Introduction

Water stress is becoming more prevalent in more and more regions of the planet. Water scarcity affects 3.7

billion people worldwide, according to the UN World Water Development Report. This population could rise to as high as 5.7 billion by 2050 [1]. Currently, 3.5 million people die each year as a result of insufficient water supply and sanitation, highlighting the importance of water as a worldwide resource. Fig. 1 depicts expected water stress at the country level in 2040 [2]. Desalination as a means of meeting global water demand has never been more important, with dwindling fresh water sources posing a serious concern. The key drivers for the worldwide desalination industry have been described as the expansion in population and, as a result, the demand for consumable water. To give you an idea, the global desalination industry is expected to increase at a rate of 9% from 2018 to 2022, with Europe, the Middle East, and Africa (EMEA) accounting for 74% of that growth [3].

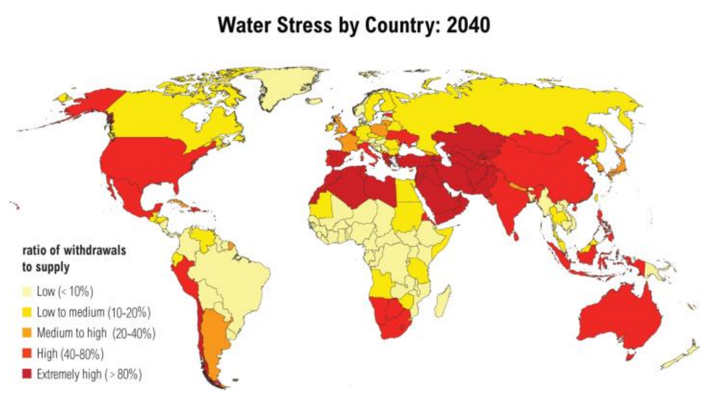

Figure 1. Projected water stress in 2040 [2].

II. Desalination Technologies

Desalination is a process in which salinity-rich water is supplied into a unit that uses electrical or thermal energy to produce two product streams, one with reduced salt concentration (freshwater stream) and the other with a higher salt concentration (salt stream). This process can transform both seawater and brackish water into fresh water.

Various desalination systems are currently commercialized, and all of them require energy. Desalination technologies are always being improved in order to increase productivity, save energy, and lower costs. The unit cost of fresh water was around 10 US$/m3 in the 1960s, and it is now less than 0.6 US$/$m^3$ [4]. Desalination systems, on the other hand, consume a substantial amount of energy, either directly from fossil fuels or indirectly through electricity.

For heating, thermal desalination systems require between 40 and 80 kWh/m3 of equivalent electrical energy. Meanwhile, its ancillary equipment consumes 2.5 kWh/m3 to 5 kWh/m3 of electricity. The most widely used RO desalination process uses about 100 TWh of energy per year on average. This results in CO_2 emissions of 60–100 Mt [5]. As a result, a robust solution/technology/design is required to reduce its energy consumption and emissions. One of the proven technologies for optimising an existing system is process integration (i.e. cogeneration/polygeneration) [6–9]. Desalination's future raises concerns about the environment and long-term development. Innovative design, process integration, waste heat utilisation, and renewable energy source coupling are all examples of innovative design.

The following are the basic types of desalination methods:

- Techniques of thermal desalination

- Membrane-based desalination techniques
- Techniques of hybrid desalination

Thermal and membrane-based categories can be further categorized as follows:

- Thermal technologies:
  - Multi-stage flash distillation (MSF)
  - Vapor compression distillation (VCD)
  - Multi-Effect distillation (MED)
- Membrane technologies:
  - Reverse Osmosis (RO)
  - Electrodialysis (ED)

The two subsections that follow present the state-of-the-art for the two primary categories (thermal and membrane-based).

Thermal Technologies

Thermal technology involves the evaporation of water, which leaves behind the salt content, resulting in salt-free potable water after condensation. The next sections go into greater detail about the various techniques that are regularly used.

Multi-Stage Flash Distillation (MSF)

MSF (multi-stage flash) is a desalination process that has been around since the 1960s. The functioning principle of an MSF unit is shown in Figure 2. The equipment consists of a brine heater with various stages (as designed) that heats the supply water to 90-115 degrees Celsius.

The water then rushes into the ejector chamber at a high velocity, generating a vacuum that forces the rest of the fluid inside.

The water is then delivered into the first stage, where it is transformed to steam at a pressure slightly lower than the saturation vapour pressure. To condense steam, each stage is coupled to a condenser unit, which produces a purified water stream. Each stage's condensed liquid is collected in a tray collector, which is subsequently pumped to the storage tank.

To lower the system's heating demand even more, the condenser's latent heat is used to warm the feed stream. As a result, the evaporator's load will be reduced. To reduce the entrainment of salty water droplets, mist eliminators are also fitted near the steam outflow. As the water passes through a succession of steps, the procedure is repeated multiple times. In each subsequent level, the pressure decreases in comparison to the prior one. In the last stage, some of the brine is recycled, while the rest is discarded. MSF achieves an average recovery of 19 to 28 percent, with each step accounting for about 1% of the total recovery [10].

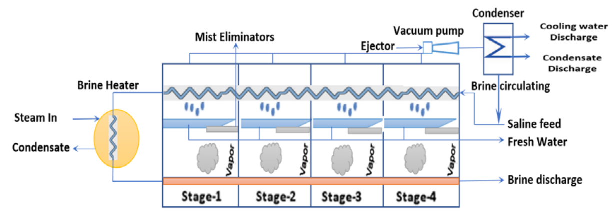

Figure 2. How multi-stage flash desalination works [10].

Multiple Effect Distillation (MED)

Multiple effect distillation (MED) is a type of thermal desalination in which input water is sprayed onto a heat exchanger for evaporation, resulting in the production of steam. Feed water is blasted with various nozzles, as shown in Figure 3. The resultant droplets land on the heat exchanger, where they are converted to steam. After that, the steam travels on to the next stage. The heat from the first effect stage's steam condensation is used to heat the feed water sprayed in the next step. This procedure is repeated in each subsequent level. As a result, the overall thermal heat content of the unit is reduced. The condensed water is collected and stored in a separate tank, while the brine is discharged into the sea. They work in temperatures ranging from 62 to 75 degrees Celsius [9].

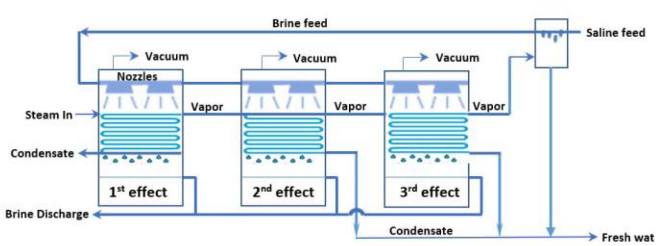

Figure 3. How a multi-effect distillation unit works [10].

Vapor Compression Distillation (VCD) Desalination

Along with any other technology, such as MED, vapor compression distillation (VCD) is often utilized in medium or small-scale desalination systems. Rather than requiring a heat exchanger, VCD generates the heat required to evaporate the supply water. The working pressure inside the unit is kept low, resulting in a decreased evaporation heat content demand. The technique is carried out using either thermal vapor compression or mechanical vapor compression. Thermal vapor compression machines have numerous stages and can produce 20,000 cubic metres of purified water per day, but mechanical vapor compression units only have one step and can only produce 3,000 cubic metres per day. Furthermore, regardless of the number of steps utilized, mechanical vapor compression devices consume the same amount of power per cubic metre of purified water. The cost of thermal vapor compression units, on the other hand, rises when more stages are added [11]. The workings of a mechanical vapor compression process are depicted in Figure 4. They are usually powered by either fuel or electricity.

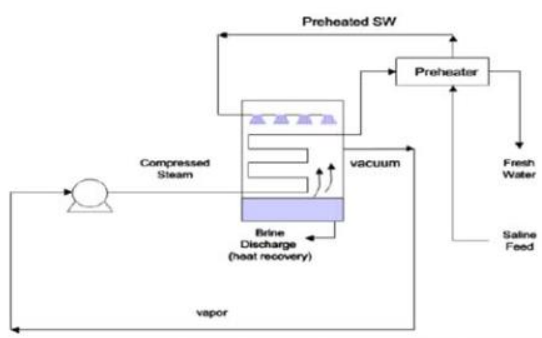

Figure 4 vapor compression distillation [10].

Membrane Technologies

Electrodialysis (ED)

Electrodialysis is a sophisticated membrane-based technique capable of providing drinking water for several years in an industrial setting [12]. As shown in Figure 5, electrical energy in the form of direct current (DC) is utilized to separate pure water from a brine solution. As DC energy flows, water ions travel from a diluted solution to a concentrated solution via a membrane wall. Cationic and anionic membranes are sandwiched between two negative and positive electrodes in this procedure. As a result, ions with the opposite charge travel towards the electrode. The dissolved solid content is thus removed as it passes through the membrane.

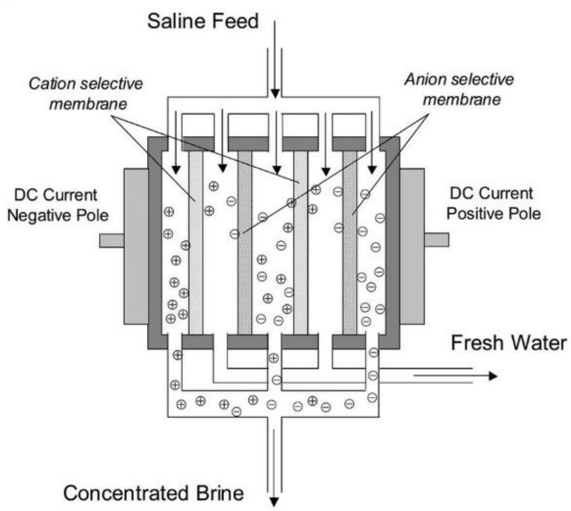

Figure 5. Working principle of an electrodialysis desalination unit [12].

Reverse Osmosis (RO)

The natural osmotic process, in which a water selective membrane is utilized to separate water, produces a reversed effect in reverse osmosis. The difference in water chemical potential on both sides influences the migration of water from a solution with a greater salt content toward a solution with a lower salt concentration. The operation is repeated until the desired osmotic pressure is reached.

Figure 6 depicts the functioning arrangement of RO. Water is forced to pass from the feed side to the freshwater side through a semipermeable membrane at a pressure greater than the relevant osmotic pressure. As a result, water travels to the permeate, leaving all salts in the feed side behind, resulting in a brine that is highly concentrated.

Depending on the charge and size of the solute particles, the membrane either inhibits or enables movement. This method can be used to remove dissolved salts as well as other contaminants. The bigger particles, on the other hand, gradually accumulate on the membrane's surface, resulting in fouling. This is why, in order to avoid membrane fouling, a pre-treatment step is incorporated to remove suspended solid content. Furthermore, depending on the ultimate use of purified water, a post-treatment step, such as a mineralization stage in the case of drinking water [10], may be used.

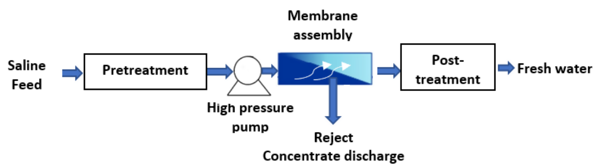

Figure 6. Diagram showing the main components of a typical RO plant.

III. Renewable Energy and Egypt's vision 2030

The Sustainable Development Strategy (SDS): Egypt Vision 2030 is a step toward inclusive development, inspired by the achievements of ancient Egyptian culture and linking the present to the future. As a result, a path to prosperity is being cultivated via economic and social fairness, and Egypt's role in regional leadership is being resurrected. SDS is a road plan for maximizing competitive advantage in order to realize Egyptians' ambitions and aspirations for a dignified and decent living.

SDS was created using a participatory strategic planning process, in which representatives from civil society, national and international development partners, and government agencies collaborated to identify broad objectives for the country's many pillars and sectors. The SDS focuses on three key dimensions: economic, social, and environmental, in order to consider subsequent generations' rights to a prosperous existence.

Egypt's Vision 2030 relies on the use of renewable energy sources to reduce CO_2

emissions and so mitigate the effects of global warming [13]. Outside of OPEC (Organization of Petroleum Exporting Countries), Egypt is Africa's third largest producer of oil and third greatest producer of natural gas. In addition, the Suez Canal is a major player in the global energy market [14].

IV. North Sinai Governorate

The county is located north of the Sinai in the northeastern Arab Republic of Egypt, between longitudes 32.34 E and latitudes 29.31 N, and is bounded to the north by the Mediterranean Sea for 220 kilometres, while the south line runs from the south corridor, for example, even the head of the Negev, and is bordered to the east to reduce the political to Egypt with Occupied Palestine. The province has a land area of roughly 27 thousand km^2 and a population of 486,242 people in 2021 [15].

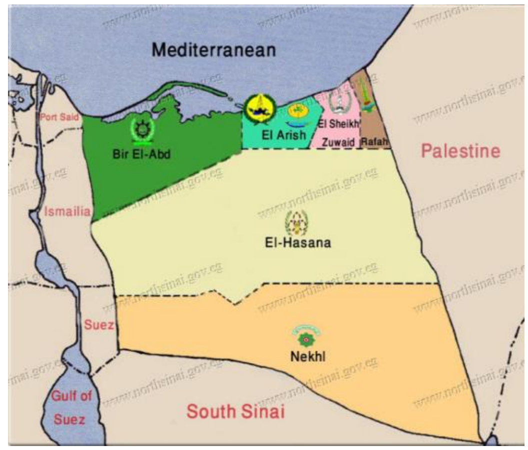

Figure 7. North Sinai Governorate map.

V. Solar Energy In North Sinai Governorate

Figure 8 shows the solar atlas map for the North Sinai Governorate and Table 1 lists the map-data.

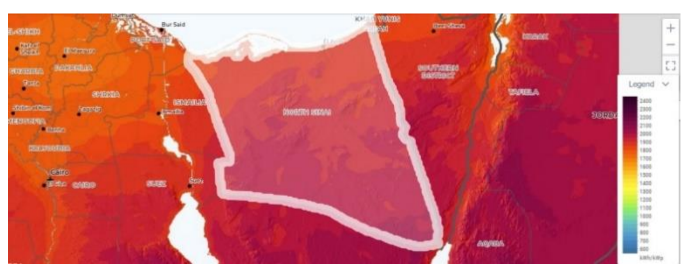

Figure 8. Solar atlas of North Sinai Governorate (https://globalsolaratlas.info/)

TABLE 1. Solar map data of North Sinai Governorate

Map data (min-max range) — Per day

Specific photovoltaic power output	PVOUT	4.86	—	5.61	kWh/kWp
Direct normal irradiation	DNI	5.50	—	7.64	kWh/m^2
Global horizontal irradiation	GHI	5.54	—	6.30	kWh/m^2
Diffuse horizontal irradiation	DIF	1.43	—	1.98	kWh/m^2
Global tilted irradiation	GTI	6.12	—	7.09	kWh/m^2
Optimum tilt of PV modules	OPTA	27	—	32	°
Air temperature	TEMP	17.9	—	21.9	°C

VI. Water Status in North Sinai Governorate

Water demand for North Sinai Governorate is about 100,000 m^3/d. Reaching About of 70,000 m^3/d come from Nile River and about 20,000 m^3/d from desalination plants. There is a significant gap between the available water and the demand. So, it is very important to begin establishing new desalination plants to cover this gap. Table 2 lists the main desalination plants in North Sinai Governorate. All of these plants use the RO desalination technology.

There are nine main desalination plants in North Sinai Governorate with total installed capacity of 34,275 m^3/d. Three of these plants depends on wells water with total capacity of 750 m^3/d and six plants depends on seawater with total capacity of 33,525 m^3/d. Only Two of desalination plants in North Sinai Governorate powered by PV technology.

VII. Typical desalination system powered by solar PV

Photovoltaic (PV) systems are well known to directly convert sunlight into

DC electricity using cells made from silicon or other semiconductor materials.

Table 2 Main Desalination Plants in North Sinai Governorate.

Plant Name	Capacity (m^3/d)	Water Source	Desalination Technology	Solar Powered
Elreed	250	Wells	RO	√
Sadr Elhettan	250	Wells	RO	√
Abo Elglood	250	Wells	RO	X
Elmsaeid 1	4950	Seawater	RO	X
Elmsaeid 2	5000	Seawater	RO	X
Elrysa 1	9975	Seawater	RO	X
Elrysa 2	5000	Seawater	RO	X
Elskadra 1	3600	Seawater	RO	X
Elskadra 2	5000	Seawater	RO	X

The cells are connected together to form a PV module. They can then supply this electrical power to drive either RO or ED desalination technologies.

Figure 9 shows an assembly of a typical RO desalination plant coupled with a PV generator. This configuration collects (i) a set of storage battery blocks with the system to stabilize the energy input to the RO unit and to compensate for solar radiation variations and (ii) a charge controller to protect the battery block from deep discharge and overcharge, and RO desalination system.

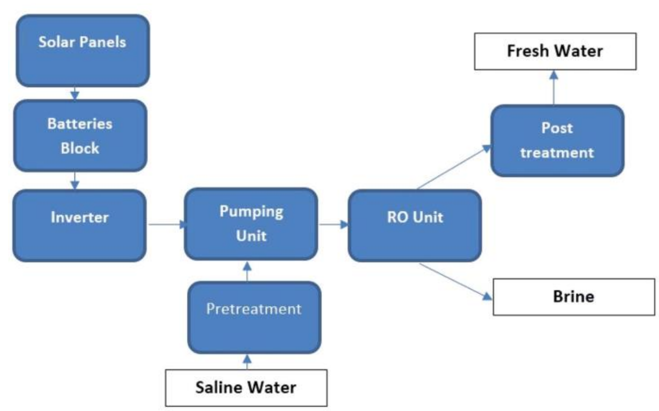

Figure. 9 A typical RO desalination plant coupled with a PV generator

The PVsol Premium 2023 program is used to design the appropriate PV system to supply a sea water desalination plant with capacity of 5000 m^3/day. Lenntech Reverse Osmosis plant with rate of 100 m^3/h, type BWRO-L 50000 has been assumed with the following specifications:

- Low energy or high rejection membranes
- All equipment mounted on stainless steel 304 skid
- Available in complete Stainless-Steel piping
- Standard control with RO micro-controller and conductivity display.
- Advanced control with flow, pressure, pH and conductivity transmitters for data monitoring, normalization and SCADA.

The plant requires 10 ROs to satisfy the demand. Each RO needs electrical power of 45.0 kW, 400v, 50Hz. So, the total required power is 10 * 45 = 450 kW. The design has been done based on 500 kW to compensate the losses. The PV system is grid connected system as the required power is very high and it is not appropriate to use batteries here. Figure 10 shows the monthly load profile which changes with the water demand through the different seasons. Figures 11, 12 show the P-V, I-V curves for the used PV modules (Suntech power – STP275-20Wfw). Figure 13 shows the single line diagram of the designed plant. The inverter that has been used is FIMER (PVI-110.0-TL).

Table 4 lists the cost calculations of the designed PV system which need 250,000 L.E. The system as mentioned before is grid connected system, so it supplies the demand and share the surplus power with the grid. It is expected that the system will cover its cost after nine years and begin to earn. The Co_2 emissions that can be avoided is 239,183 kg / year.

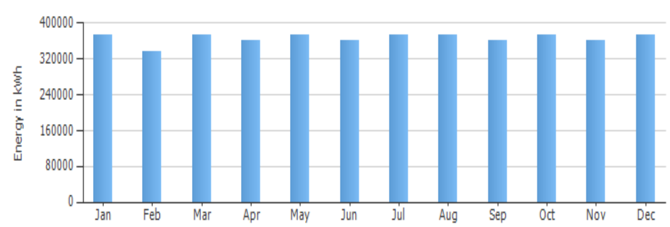

Figure 10 Monthly load profile.

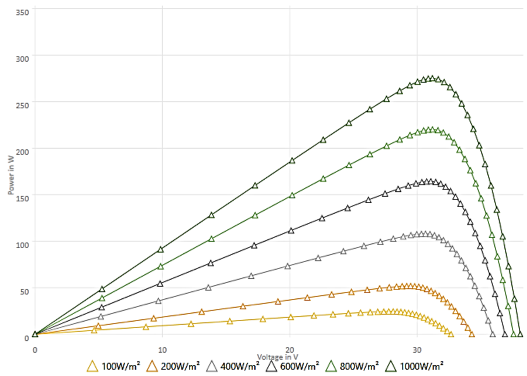

Figure 11. P-V curve of PV module.

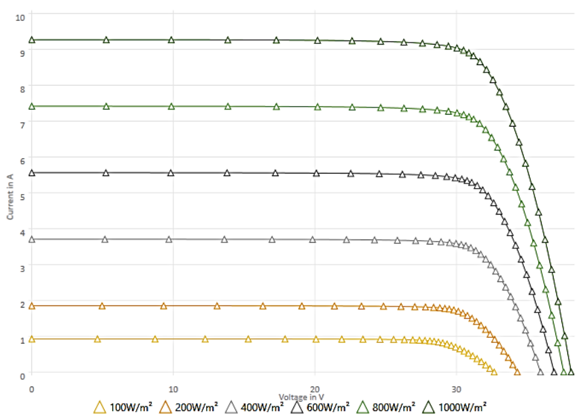

Figure 12 I-V curve of PV module.

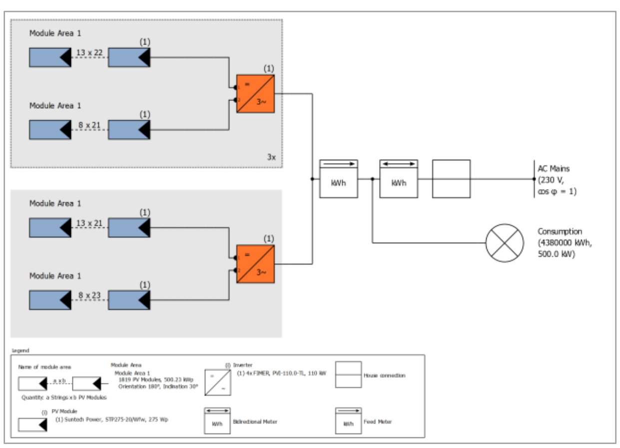

Figure 13 The single line diagram of the system.

VIII. Conclusions

The most essential aspects of the development in popularity of solar photovoltaic (PV) cells around the world, as well as the main factors for coupling PV energy with reverse osmosis (RO) desalination, were described in this part. The following are the important points of this article:

PV cells have a poor conversion efficiency, which is regarded the technology's main flaw, despite research efforts over the previous decade allowing for efficiency improvements and cost reductions.

Table 3 Cost Calculation of the PV System.

Component	Number	Price (L.E)
Modules	1819	2500*1819
Inverter	4	4*70000
Cables DC	5000m	250,000
Cables AC	600m	
Protections		
Installation		

The regulations governing brine disposal and the regulations governing the needed water quality are the two main elements that determine the cost of Seawater RO. SWRO costs rise as rules become more stringent.

For water desalination, a variety of linked PV-RO systems have been investigated; the most common ones make use of batteries and grid connections to assure system efficiency and cost effectiveness.

References

[1] WWAP, The United Nations World Water Development Report 2018: Nature-based Solutions, UNESCO, Paris, 2018.

[2] T. Luo, R. Young, P. Reig, Aqueduct Projected Water Stress Country Rankings, World Resources Institute, Washington, D.C, 2015.

[3] Technavio, Global Desalination Market 2018–2022. 2018.

[4] Al-Karaghouli A, Kazmerski LL. Energy consumption and water production cost of conventional and renewable-energy-powered desalination processes. Renew Sustain Energy Rev 2013;24:343–56..

[5] Ahmed FE, Hashaikeh R, Hilal N. Solar powered desalination – technology, energy and future outlook. Desalination 2019;453:54–76.

[6] Elsaid K, Taha Sayed E, Yousef BAA, Kamal Hussien Rabaia M, Ali Abdelkareem M, Olabi AG. Recent progress on the utilization of waste heat for desalination: a review. Energy Convers Manag 2020;221:113105.

[7] Gholizadeh T, Vajdi M, Rostamzadeh H. A new trigeneration system for power, cooling, and freshwater production driven by a flash-binary geothermal heat source. Renew Energy 2020;148:31–43.

[8] Shankar R, Srinivas T, Reddy BV. Investigation of solar cooling cogeneration plant. Appl Sol Energy 2018;54:65–70.

[9] Shankar R, Srinivas T. Performance investigation of Kalina cooling cogeneration cycles. Int J Refrig 2018;86:163–85.

[10] Voutchkov, N.(2012) Desalination engineering: planning and design, McGraw Hill Professional.

[11] Islam, M. S., Sultana, A., Saadat, A. H. M., Shammi, M., and Uddin, M. K. (2018). Desalination technologies for developing countries: A review. Journal of Scientific Research, 10(1), 77-97.

[12] Mandani, F., Ettouney, H., and El-Dessouky, H. (2000). LiBr H2O absorption heat pump for single effect evaporation desalination process. salination,128(2), 161-176.

[13] Strathmann, H. (2010). Electrodialysis, a mature technology with a multitude of newapplications. Desalination, 264(3), 268-288.

[14] Salman and Hosny, The nexus between Egyptian renewable energy resources and economic growth for achieving sustainable development goals, Futur Bus J 2021, 7(1):47

Dongola (1890-2020). Processed and Compiled by Elzein, A. S. (2020).

[15]http://www.northsinai.gov.eg/english/about%20the%20governorate.aspx.