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Hydro and solar-pond-chimney power scheme for Qattara Depression, Egypt

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This study summarizes previous proposals and studies concerning Qattara power projects and gives some details about a new concept, which aims to produce hydropower like all previous proposals, and also extra electric power and fresh water via a site specific solar-pond-chimney system. Sea water from the Mediterranean Sea and re-used water from the end of Rosetta branch would feed an artificial lake in the Qattara Depression, where salt gradient heating phenomena would be exploited. The proposed scheme entails two inlet water ways (for sea water and re-used water) and an outlet water way for the produced fresh water. Several experimental studies in a hydraulic lab will be required to clarify technical and economic feasibility aspects.

Key words: Desalination, hydraulics, hydro power, Qattara Depression, reused water, solar ponds.

INTRODUCTION

The utilization of Qattara Depression for the purpose of hydropower generation was first investigated (Ball, 1933) by Professor Penk in 1912, and later by Dr Ball in 1927. The depression is located in the north-western part of Egypt and is the world's fifth deepest natural depression (Figure 1). The depression has, at sea level, a length of about 300 km, a maximum width of 145 km, and an area of 19,500 km^2. The northern edge of the embankment is bounded by a hilly ridge with an elevation of about 200 m above sea level, with the shortest distance from the Mediterranean Sea of about 56 km. Among the development schemes studied by scientists and engineers, the following ones are singled out: Ball (1933), Bassler (De Martino, 1973), Gohar (De Martino, 1973), and lately in 2010 MIK Technology (http://miktechnology.com/powerfromseawater.html,1973; Kelada, 2010). All these proposed schemes and studies focused on hydropower production, but the scheme proposed by Kelada (2010) exploits the physical phenomenon of osmosis and allows production of both hydropower and desalinated water.

The current study reviews previous schemes and proposes a new concept which entails storing both sea water and drainage water to produce hydropower, and exploiting salt gradient heating phenomena in solar ponds (http://www.teriin.org/; http://www.teriin.org/) to produce both fresh water and extra electric power.

REVIEW OF PREVIOUS SCHEMES AND STUDIES

Qattara Depression project

As indicated by many scientists (De Martino, 1973; Kelada, 2010), the Qattara hydropower project has a primary objective to generate a sustainable source of energy corresponding to 315 MW and a secondary goal to provide an elevated storage of 45 million cubic meters to manage peak power demands.

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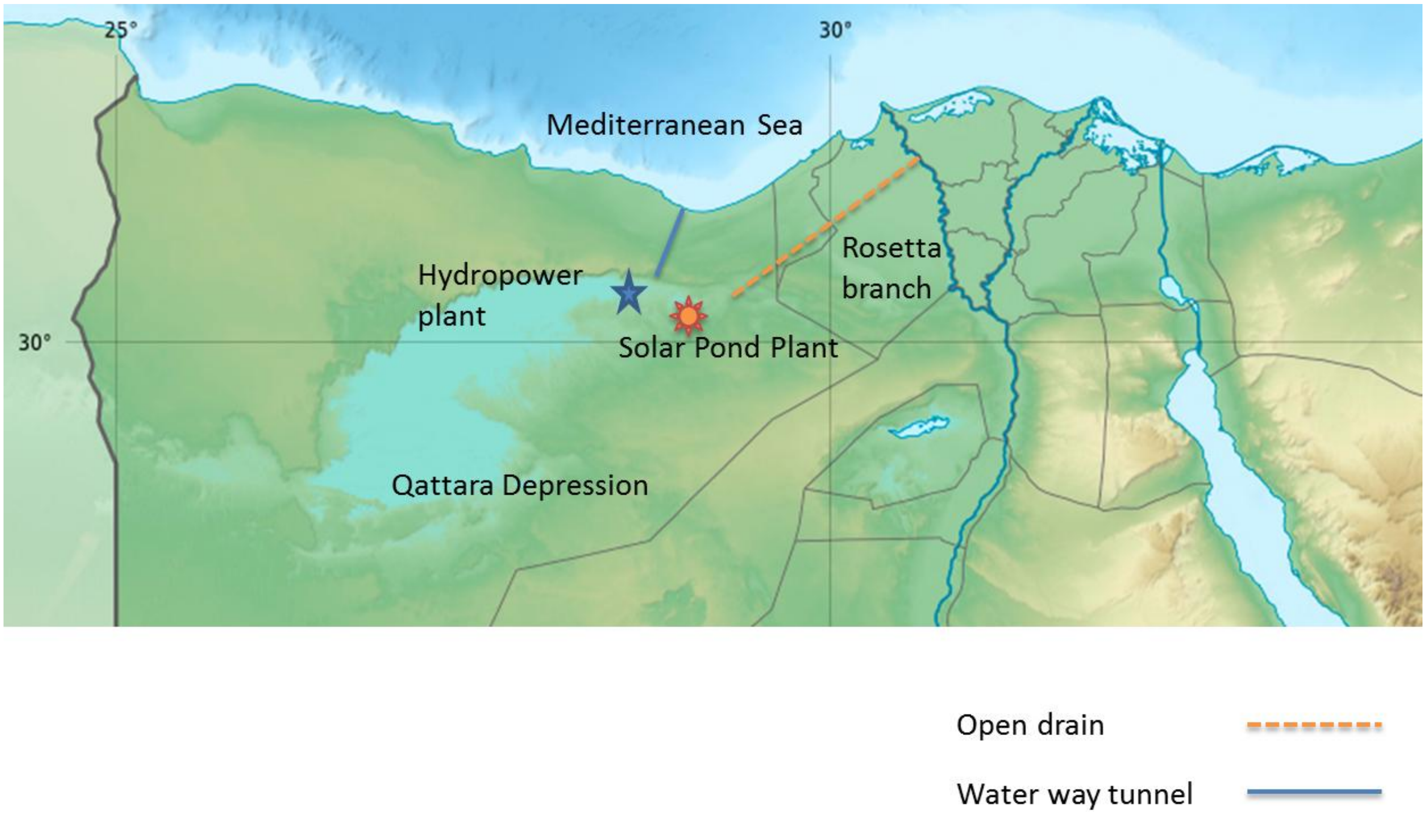

Figure 5. Aerial view for the settings of the hydro and solar-pond power plants, and the proposed water ways.

Ball's researches

Based on geological investigations, Dr. Ball (1933) studied the possibility of utilizing the Qattara Depression for hydropower generation through the formation of artificial lakes at final levels of 50, 60, or 70 m below sea level. The corresponding surface areas for the three alternatives were 13500, 12100 and 8600 km^2. Moreover, he indicated the most convenient water flow route related to each alternative. Ball considered variables such as rainfall, evaporation and seepage inflow. With respect to the rainfall, and taking into consideration the rainfall that would not precipitate directly into the lake but would find its way into the depression, Ball assumed a daily average rainfall depth of 0.15, 0.16, and 0.18 mm for the three lakes' water levels alternatives of 50, 60 or 70 m below sea level. Regarding the evaporation, and based on similar research studies at other nearby locations, he concluded that the average evaporation rates from the surfaces would be 4.6, 4.3 and 4.0 mm/day, for the same alternatives respectively. Regarding the volume of seepage inflow to the lake, Ball estimated that the daily volume would be equivalent to depths of 0.21, 0.24 and 0.33 mm, for the three alternatives, respectively. Balancing the difference between the evaporation volume and the sum of both rainfall and seepage inflow volumes, he estimated the daily volumes of feed sea water to keep the lakes' surfaces balanced at the specified levels. He could thus conclude that the daily volumes of sea water entering the depression should correspond to flow rates of 656, 546 and 348 m^3/s, respectively (Kelada, 2010).

Ball also studied the progressive increase of salinity in the artificial lakes and calculated that the maximum concentration would be reached after 160, 120, and 100 years for the three alternatives respectively (Ball, 1933). Finally, he showed that the most convenient solutions were those related to lakes' surfaces at 50 and 60 m below sea level. He suggested construction of an open channel for the first 20 km, and three tunnels of 11 m diameter to supply the required sea water. The resulting power potential would be about 175 MW for a lake surface level of -50 m. Moreover, he anticipated the possibility of using a power surplus during periods of low demands to pump part of the inflow water into a high-level reservoir and thus obtain a total head of 200 m for hydropower generation to meet peak-load requirements.

Bassler's scheme

The question of developing Qattara project was raised again at the end of the 1950s. Then Siemens proposed a scheme involving the creation of an artificial balancing

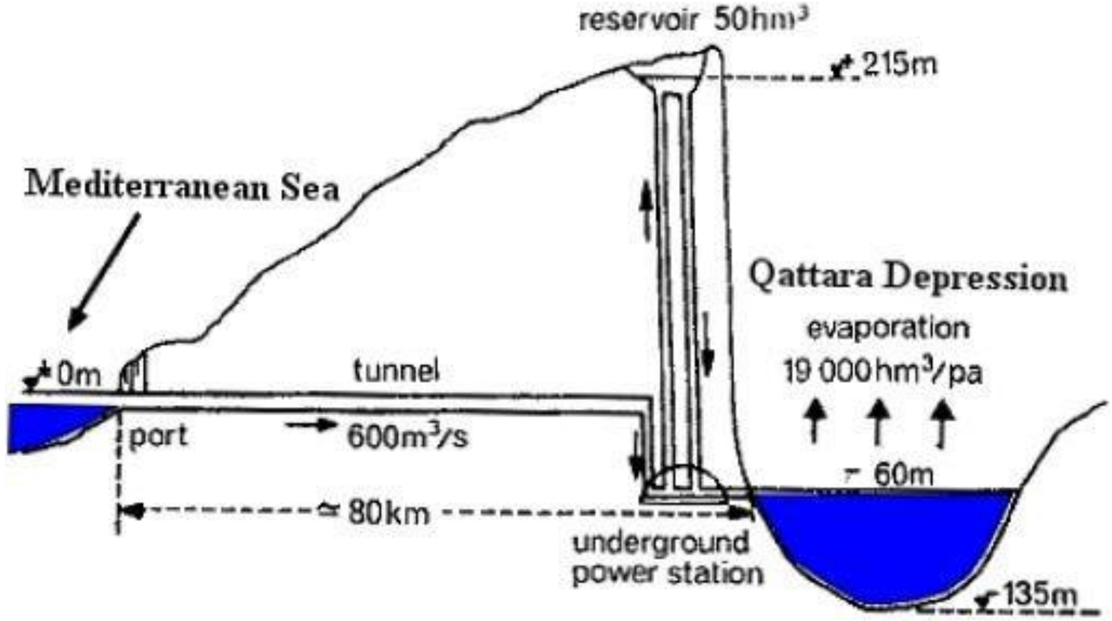

Figure 2. Cross section showing the outline of the hydropower scheme proposed by Professor Bassler.

reservoir on the edge of the depression, continuously fed by two conduits from the Mediterranean. The estimated power potential was about 100 MW, and the turbines were to function only for 6 h (De Martino, 1973). In 1964, Professor Bassler was appointed by the West German Ministry of Economics to study in greater details possible development schemes. Following geological and engineering researches, Bassler presented the scheme shown in Figure 2. The research, which was carried out in 1964 to 1965, aimed at investigating the technical and economic feasibility of a power plant in the Qattara Depression. According to Bassler (De Martino, 1973), it was also anticipated that the Qattara artificial lake would have to be fed by a sea water flow of 600 m^3/s to compensate for the evaporation volume. Similar to Ball's scheme, the construction of three tunnels having a length of 80 km would be required to feed a hydropower plant as shown in Figure 2. During the hours of low demands, the energy produced could be used to pump water into a high-level natural reservoir having a capacity of about 50 million cubic meters. Such a basin is located at the edge of the depression at an elevation of 215 m above sea level.

To summarize, this scheme combines a low head with a high head system, can produce peak power up to 450 MW, and is adaptable to a varying demand pattern.

Gohar's scheme

Gohar suggested an alternative scheme in which sea water is supplied from the Mediterranean Sea via one specific channel (route) located to the east of the routes suggested by Dr. Ball (De Martino, 1973). His point of view is that this route has more advantages than the routes suggested by Ball. He also indicated that the highest point of land between the sea and the depression was located only 11 km from the Mediterranean coast, and he suggested that sea water could be pumped up to a convenient location and then made to flow in an elevated open channel. According to Gohar (De Martino, 1973), his design could result in a simpler and more economic scheme than Ball’s and Bassler's schemes which have three tunnels. At the end of the channel, the water could be carried out to supply an underground power station at a suitable location midway from the depression. However, water would need to flow in a tunnel to reach the depression. He suggested that the best scheme among various possibilities was the formation of the lake at a level of -75 m, along with a channel at a level of +80 m discharging 266 m^3/s.

The continuous net power production for his scheme would be about 100 MW, while the maximum power capacity would be 345 MW.

MIK technology scheme

The MIK Technology (http://miktechnology.com/power fromseawater.html) concept for power generation is based on the osmosis phenomenon, targeting world saline dry natural basins and salt lakes such as the Qattara Depression-Egypt, and Great Salt Lake-U.S.A. Simply, osmotic power can be generated by running salt water solutions of differing concentrations along the two sides of a suitable semi-permeable membrane (Kelada, 2010). Water tends to permeate spontaneously into the more concentrated solution and this water flow can be used to drive a power generation turbine. MIK Technology alternative scheme (Kelada, 2010) is an osmotic power generation facility that provides a source of sustainable energy at a comparable power potential, and at a considerably reduced sea water intake requirement than previously mentioned schemes. The proposed osmotic power system requires only 60 m^3/s of sea water to generate 360 MW of power. Since osmotic power requires high salinity brine, then seawater has to be concentrated by solar evaporation to reach the required salinity. Therefore, an area of low land approximately 630 km^2 will be required as proposed by Kelada (2010) to generate the brine for this process as shown in Figure 3.

HYDRO AND SOLAR-POND-CHIMNEY POWER SCHEME

Here a new concept for the Qattara Depression, conceived as a two-stage power system is introduced. The first stage concerns a conventional hydropower scheme fed by sea water and somewhat similar to previously proposed ones. The second stage concerns a hydropower scheme fed by re-used water and a site-specific solar-pond-chimney power system. The first-stage power plant would produce hydropower of about 190 MW, while the second-stage power plants would raise the total production to reach about 410 MW.

Solar-pond-chimney power system

The 'solar pond' exploits a heat storage phenomenon in a large salt water body such as a lake, which operates as a natural collector of solar radiation (http://www.greenidealive.org/; http://www.solar-chimney.biz/). For various applications, the temperature of the water should be as hot as possible but lower than 100°C to avoid boiling at the bottom of the lake. Relatively high temperatures (60 to 80°C) may be obtained, by exploiting the higher density of the more concentrated salty water of the lake, in a so called salt gradient solar pond. So below a thick insulating gradient layer, a hot bottom layer heated by the sun can store heat for several days (http://www.teriin.org/). The mean temperature of the bottom layer of the pond will be around 60 to 80°C and that of the cooler upper layer 30°C. Similar to other researches, the Solar Pond is coupled to a suitable vertical chimney to generate power by the solar chimney effect (Dhahri and Omri, 2013; Akbarzadeh et al., 2009). To this end, saturated air at the lake surface is heated by extraction of heat from the hot water bottom layer of the solar pond and fed into the Chimney at its base. After rising by the chimney effect, air gets back saturated and cooler at the lake surface.

Here, it may be diverted to chillers to catch desalinated water, and then fed back again into the chimney to repeat the cycle.

Project description

The Qattara project proposed in the present study envisages two construction stages. Stage 1 concerns the construction of a conventional hydropower plant fed by sea water, and stage 2 concerns the construction of a conventional hydropower plant fed by re-used water and a Solar-Pond-Chimney Power Plant (SPP). Figure 4 shows the cross section of the combined power system with indication of the artificial lake, the two hydropower plants and the chimney. Figure 5 shows an aerial view for the settings of the project components. The first stage hydropower plant at the left side would have a potential head of up to 70 m for the lowest lake surface level, and a sea water flow rate Q_s = 460 m^3/s. The available head would drop to 50 to 60 m at the construction end of the second stage with re-used water delivered at the top of the lake surface. The expected generated hydropower for the first stage would be around 190 MW for the lowest lake surface level of -70 m and for 60% turbine efficiency. The SPP, at the right side of the figure, should be fully operational with the completion of the second stage of the project. An additional re-used water flow rate Q_r of about 200 m^3/s would be needed to keep the lake top water level balanced at –50 m. This flow rate would be diverted from the surface drainage water of the Delta at an average salinity of 0.1% and would produce about 60 MW of hydropower with 60% turbine efficiency.

The SPP has a tall vertical chimney suitably sited above the lower lake surface. The air over this surface, and in the neighborhood of the chimney base, is first heated by hydrophobic heat wheels that convey heat from the hot water bottom layer of the lake and then enters the chimney base. The air flowing over the lake surface would be saturated by water vapor at a temperature of 30°C and, after being heated; it would have a temperature of 80°C and a density of 1 kg/m^3. With a density of the saturated air around the chimney of 1.2 kg/m^3, a pressure difference of (1.2 - 1) × 9.81 × 1000 = 1.962 kPa would be available for a chimney height of 1000 m. The chimney wind turbines may exploit this pressure difference to generate useful electrical power. For a chimney with a throat area of 1400 m^2, the electric power produced only by the SPP system would be around 200 MW (http://www.greenidealive.org/; http://www.solar-chimney.biz/). With the functioning of the SPP system and the hydropower plant fed by 200 m^3/s of re-used water, the available head would drop to about 55 m, and the additional hydropower produced by the re-used water plant would be around 66 MW at 60% turbine efficiency. The overall electric power produced by the

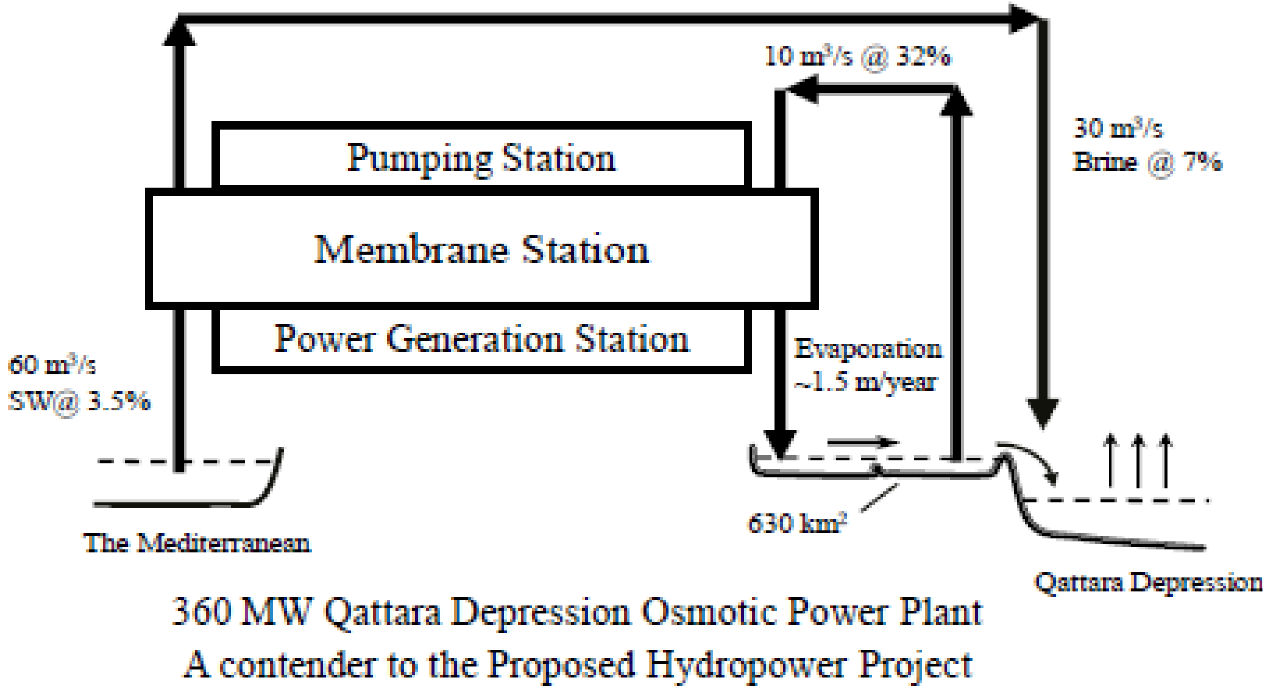

Figure 3. An alternative energy scheme for a hydro-solar system proposed by Kelada (2010).

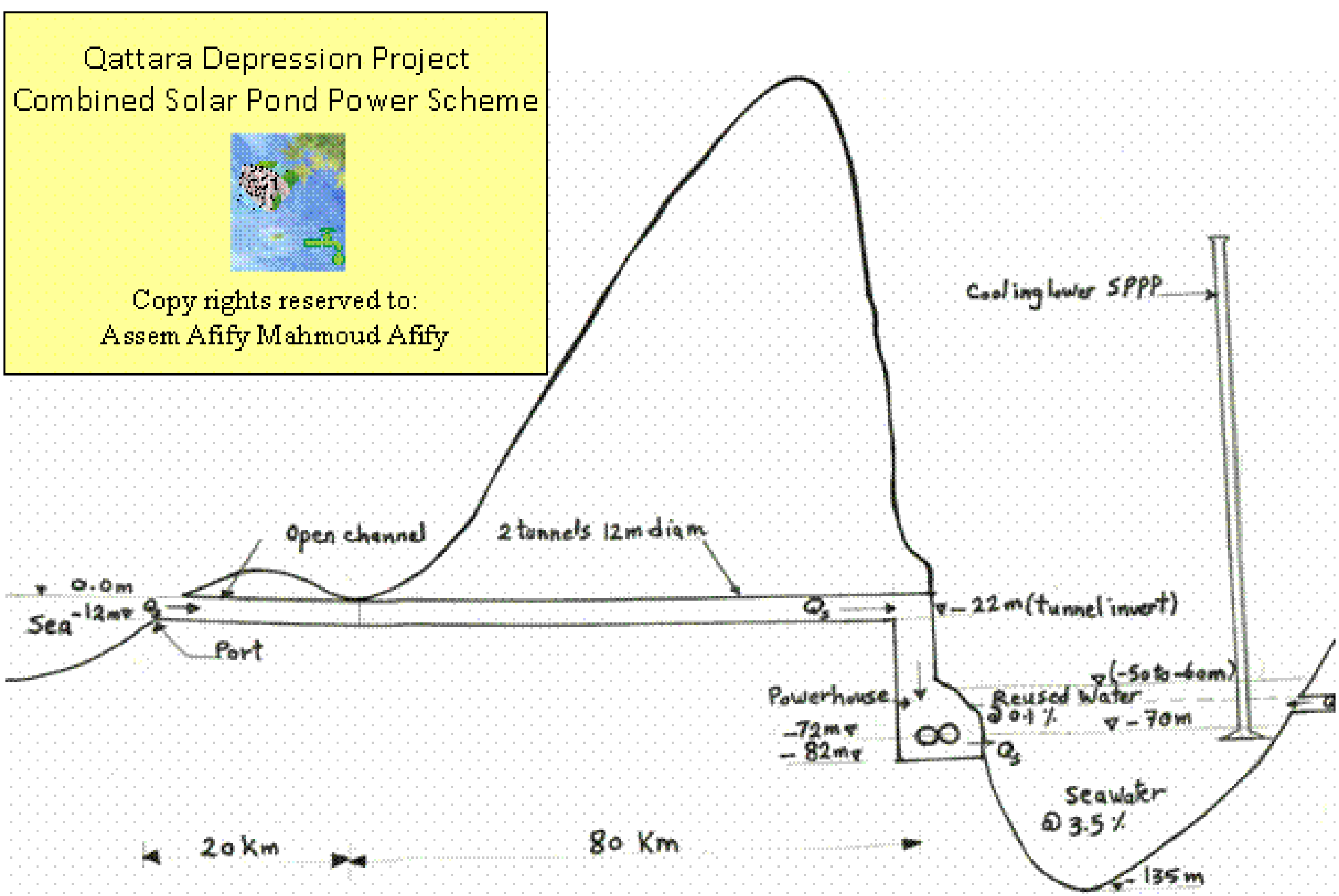

Figure 4. Cross section showing the configurations of two hydropower plants and a Solar-Pond-Chimney power plant.

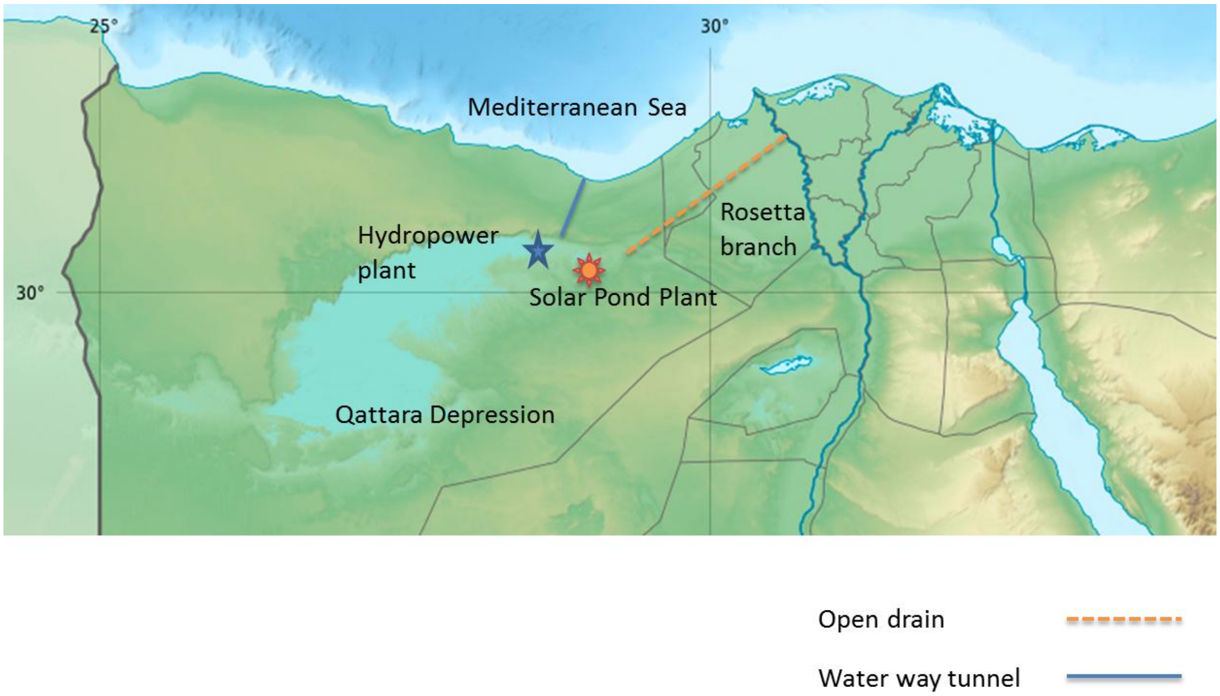

Figure 5. Aerial view for the settings of the hydro and solar-pond power plants, and the proposed water ways.

three power plants (in the first and second stages) might reach 480 MW with more efficient turbines.

Summary and comparison of schemes

Design parameters of the different schemes are summarized as listed in Table 1 for the purpose of comparison among them. The last column shows findings for the scheme proposed by the present study. The most important parameter is the artificial lake water level, which will finally govern all the remaining parameters. The lower the water level, the smaller the evaporation volume would be, and hence the needed flow rate of sea water would be less to keep the lake balanced. A clear example of this is Gohar's scheme, which proposes a water way (open channel) of reduced carrying capacity and dimensions compared to other similar schemes, such as the three tunnels proposed by Ball and Bassler. The present hydropower and Solar-Pond-Chimney scheme requires only two tunnels. However, additional water flow rates would be needed to balance the artificial lake if a partial flow rate of re-used water were diverted for the production of desalinated water. MIK Technology scheme is an exceptional case. It would require the least sea water flow rate of 60 m^3/s to produce 360 MW of hydropower, which is somewhat comparable to the peak powers expected in other schemes. However, if the sea water flow rate is relatively small with respect to the huge amount of evaporation loss, problems related with salt accumulation and unbalanced lake water surface have to be taken into account.

Project benefits and obstacles

When completed, the project would provide a yearly averaged power production of about 400 MW. In addition, it would create job opportunities in the area as well as benefit industrial and tourism developments. Excess power during periods of low demands might be used to produce desalinated water and thus help development activities. In particular, production of desalinated water may be obtained by coupling solar pond technology (Huanmin et al., 2002) with a thermal desalination plant.

Many obstacles face the Qattara project, and among them is the presence of dangerous explosives from the Second World War. As for site investigations, remote sensing can offer a solution to this problem. The problem of groundwater losses in the area has already been investigated through a hydro-geological study (Bastiaanssen and Menenti, 1990) using satellite data. Another critical issue for the project concerns the national strategic defense from the western side borders. The claims that the sea water channel would be a water barrier can be resolved, since a major part of this water way would be tunneled.

Groundwater salinity is also a big concern and has to be further studied with the help of hydraulic models so as to come up with the most suitable water level for the salty lake and thus prevent outward seepage flow.

Table 1. Design parameters in some schemes proposed for the Qattara project.

Design parameters	Schemes				
	Ball	Bassler	Gohar	MIK Technology	Present hydro SPP
Flow rate (m^3/s)	656	600	266	60	Q_s = 460 Q_r = 200
Lake water level (m)	-50	-60	-75	-40	Top = -55 Saline = -70
Mean power (MW)	175	190	100	360	190 (1st stage) 410 (from both 1st and 2nd stage)
Peak power (MW)	175	450	345	360	480
Project main features	Open channel for the first 20 km, followed by 3 tunnels with 11 m diameter.		Elevated open channel at a level of 80 m and reservoir capacity not mentioned	Brine lake to be formed with an area around 630 km^2, another lake "Qattara sea" at a level of -20 m	Lake is connected to the sea via two tunnels of 12 m diameter, and to the Delta via an open drain.
	Reservoir capacity not mentioned.	Elevated reservoir capacity of 50 million m^3 at a level of +215 m.			Solar-pond-chimney plant and two conventional hydropower plants.

CONCLUSIONS AND RECOMMENDATIONS

The proposed scheme promises some advantages with respect to previous schemes. In particular, for the hydropower plant fed by sea water (first stage), only two tunnels are needed rather than three as suggested by Bassler. Also, no elevated reservoir is needed since the produced power during low demand periods can be utilized in the desalination process of re-used water (drainage). Feeding a hydropower plant with re-used water (2nd stage) allows storing re-used water on top of sea water in the artificial lake and thus minimizes risks of increasing groundwater salinity. Funds for the construction of the SPP power plant (2nd stage), with suitable chimney dimensions, will be available by selling extra electric power generated and produced desalinated water for the development of tourism and industry. An overall feasibility study encompassing all aspects of project components is strongly recommended. Groundwater modeling should be specially investigated to find out the most suitable level of the artificial lake. A physical model may also be needed to find proper locations for the chimney and for the drain inlet of the re-used water so as to avoid hydraulic mixing with the insulating salty layer of the lake.

REFERENCES

Akbarzadeh A, Johnson P, Singh R (2009). Examining potential benefits of combining a chimney with a salinity gradient solar pond for production of power in salt affected areas. Solar Energy 83(8):1345-1359.

Ball J (1933). The Qattara Depression of the Libyan Desert and the possibility of its utilization for power-Production. Geogr. J. 82(4):289-314.

Bastiaanssen WGM, Menenti M (1990). Mapping Groundwater Losses in the Western Desert of Egypt with Satellite Measurements of Surface Reflectance and Surface Temperature. Water Management and Remote Sensing: Proceedings and information No 42, The Netherlands.

De Martino G (1973). The Qattara Depression. Technical repot, Hydraulics Institute, Naples, Italy. MIK Technology Website. http://miktechnology.com/powerfromseawater.html.

Dhahri A, Omri A (2013). A review of solar chimney power generation technology. Int. J. Eng. Adv. Technol. 2(3):1-17.

Homepage of Solar Chimneys Website. http://www.solar-chimney.biz/.

Huanmin L, John CW, Hein H (2002). Thermal desalination using MEMS and salinity-gradient solar pond technology. Desalination Research and Development Program, Report No. 80.

Kelada M (2010). Global hyper saline power generation Qattara Depression potential. Fourteenth International Middle East Power Systems Conference, Cairo, Egypt, December, 19-21.

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