Evaluation of Al Qattara Depression Renewable Energy Potentials

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***Abstract*:-** In this study; a brief evaluation has been presented for hydropower capabilities of proposed Qattara Depression Reservoir - maintained at 60 m BSL - served via two routes of water conveyance, an excavated tunnel and pumped water pipeline using the available renewable resources (such as Solar and Wind Energies) as a power source in the first stage of the project, both power demand and power potentials of the project have been presented along with the possibility of maintaining the salinity of the proposed reservoir in the upcoming years of the project, water desalination potentials are among other promising by-products of such project that is presented briefly here.

***Key-Words*:** -Qattara, Egypt Renewable Energy, Solar, Wind.

1 Literature Review

Berlin Geographer Mr. Penk first suggested Qattara Depression (Egypt) as hydroelectric project in 1912, followed by Ball in 1927 who studied its potential as hydroelectric source at lakes maintained at different elevations below the sea level; and hence different surface areas and evaporation rates, he recommended a lake at 50 meter below sea level, and a route (among other proposed routes) started to the west of El Alamein City and extended in southwest direction, table - 1

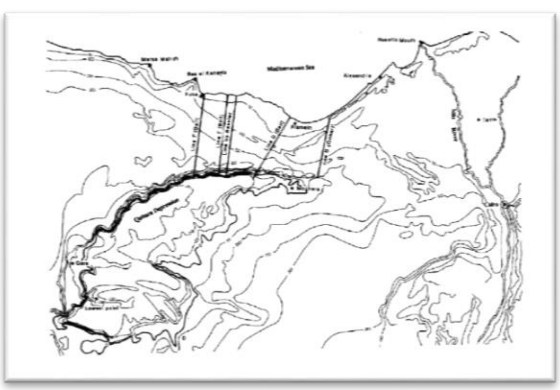

Fig. 1: Proposed routes by Ball and other [12]

shows the different lakes surface areas and its elevations BSL [10].

The unique nature of the north-western desert between Egypt and Libya attracts many researchers and governments to look into the advantages of the difference in the levels of the Mediterranean sea and Al Qattara depression which goes down to 130 meter BSL (Below sea Level) [12]. Such difference may get utilized as a sustainable source of Hydro-Power Generation, and support the efforts toward creating opportunities for developing this unpopulated area; through making it an attractive spot for the dens population of Egypt. Many projects and blueprints proposed by researchers discussed hydropower potentials of conveying saline sea water from Mediterranean Sea to Qattara. Among these proposals was the one prepared by Siemens in 1950, where they proposed an artificial balancing reservoir naturally available on the rim of Qattara Depression continuously fed by two conduits from the Mediterranean.

In 1954 Professor Bessler of the West German Ministry of Economy by then; studied the depression, proposed his scheme as per Fig. 2, and concluded in his article (published in 1986) that either boring a tunnel or opening a channel to convey the water would be very expensive; he proposed using some explosive techniques in executing the project, such frightening opinion encouraged the government in Egypt to decline their support to the project [13].

The environmental impact of such saline water reservoir on underground water and the aquifers have been presented as a concern that may slow down the seepage from the adjacent underground water aquifers, and may increase the water table in these aquifers [6],[9]. The salinity - driven by evaporation - is another challenge for the project, as it may turn to be another Dead Sea in case of poor Salinity Maintenance/ Control of the reservoir.

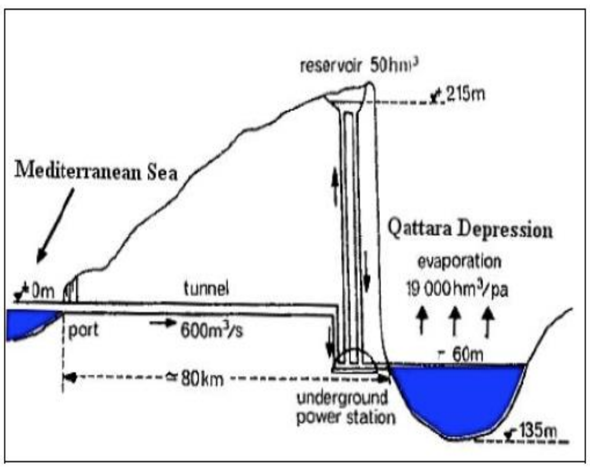

Fig. 2: Proposed Project Scheme [11]

One of the latest proposals in this regard is to convey the Nile fresh water (instead of the Mediterranean sea) to create a reservoir at 80 m BSL as per Dr. Mohammad Mahmoud [2], such proposal can serve the sustainability of the reservoir in Qattara as it will be clarified in the evaluation stated here.

2 Project Basic Layout

Choosing among different water conveyance routes proposed by many researchers (like Bessler and Ball) would be considered as the proposed project layout, then to evaluate the size of the reservoir at 60 m BSL; the anticipated evaporation capacity; the pumping requirements to make the storage reservoir right on the rim as clarified in figure 2, the renewable energy potentials to serve pumping requirements, then the power generation capacity of a hydropower plant associated with the chosen route of tunnel, and finally the pumped storage right on the rim of Qattara depression and its utilization to maintain the sustainability of the Qattara Project.

For the sake of analysis; the project scheme of Ball (line D) is adapted here (which is specified in the figure 4).

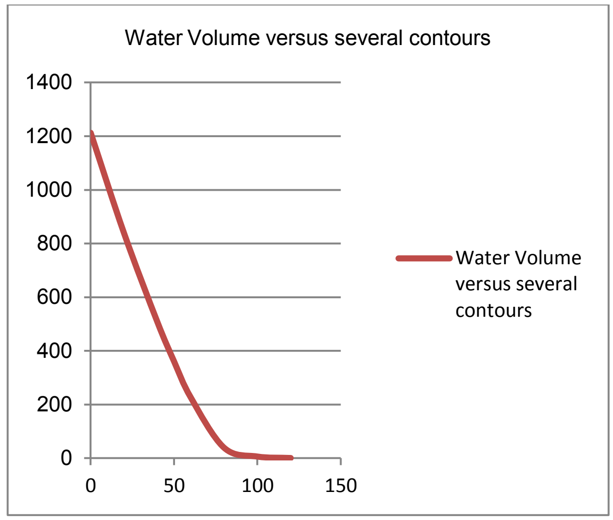

Fig. 3: Water volume plotted based on data in table 1.

Table 1: Qattara Anticipated Lake Volume[12]

Depth Below Sea Level – BSL	Lake Surface Area (KM^2)	Total Volume of water in the lake (KM^3)	Expected annual evaporation (KM^3)
50 meter	13500	361.2 (estimated from the plot above)	8.377
60 meter	12100	227	7.508
70 meter	8600	114.7 (estimated from the plot above)	5.336

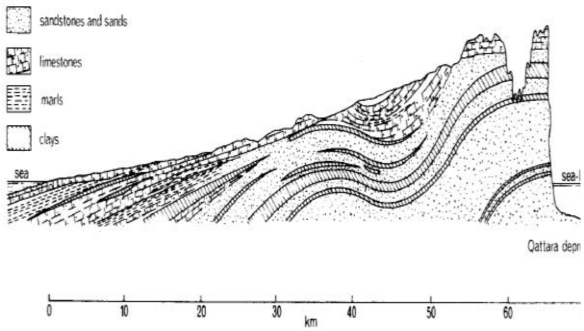

Fig. 4: The topographical details of Line D route proposed by Ball [6]

The following assumptions have been considered:

- The evaporation rate: This can be calculated relying on the equation (1) by Zein and the others [6]

$$ER = 8.96 \times 10^{-4} \times (W_2/(D \times AL) \times (ES - E_2) \times F) \quad (1)$$

As per this study; the validity of this equation has been supported by the investigations performed on Lake Mead, Nevada –Arizona (Harbeck et al. 1958) and Lake Nasser, Southern Egypt (Omar & El-Bakry, 1980) [6].

The pre-reservoir evapo-transpiration rates for the nodes occupied by the reservoir were replaced by an evaporation rate of 1.7×10^{-3} m/day calculated based on the equation 1. Also based on the calculated evaporation rate from the pre-reservoir field work at nodes located at 60 meter BSL, and considering the surface area of the reservoir at the same level, the total quantity of evaporation per day:

Total Evaporation = ER (per day) × Surface area (At 60 m BSL) = $1.7 \times 10^{-3} \times 12{,}100{,}000{,}000$ = 20.57 million m^3/day, so annually the total evaporation quantity will be around 7508.05 million m^3 per year.

As per Ball for such reservoir , the total amount of water required to compensate for the evaporation should be 17000 million cubic meter per year, which means around 546 cubic meter /second to pump. While Dr. Bessler asked for around 600 cubic meter/second to compensate for evaporation, and a total volume of 19000 million cubic meter/year which is considered here in this study. [11]

- A tunnel will be used as the basic mean of coveying sea water to maintain the reservoir on 60 m BSL, so a tunnel to be sized up to accomodate required flow to compensate for the evaporation. The required tunnel flow is 600 m^3/s or around 19000 million m^3 per year.
- The natural reservoir which is prposed at an elevation of 219 m above sea level just by Qattara Depression rim, will be maintained through the available Renewable Energy Resources (such as wind or solar energy resources). The total volume of such naturally formed storage reservoir is about 50 million m^3 [10].
- The desired flow to make the reservoir and compensate for the daily evaporation is affected by the reservoir total volume at 60 meter below sea level and the daily evaporation rate during the build up of the water level inside Qattara.
- Referring to figure 2, Qattara reservoir to be maintained at 60 m BSL; here it is targeted within the first 50 years of conveying sea water through both tunnel and a pipeline toward the naturally formed reservoir on almost 200 m ASL during the buildup of the reservoir (during the flood stage).

2.1 Qattara Depression Flood (Reservoir buildup) – Project Phase I

A – The flow rate required to reach the steady state reservoir at 60 meter BSL in 50 years (exclude the evaporation) is equal to 143.97 m^3 /s.

B – Considering Bessler approach, the required flow to compensate for the evaporation is almost 600 m^3/s (assuming that the evaporation rate will be the same over the span of 50 years, while in reality it will vary over years, As the surface area of the reservoir grow the evaporation grow as well).

C – The total flow rate required for a period of 50 years is equal to minimum 744 m^3 /s.

D – It is not within the scope of this study to design the hydraulic pipelines and water control structure. The scope here is to define the potential power required to make such reservoir, and the potential power gain of the hydroelectric capabilities of such project.

As per the proposed layout clarified in figure 5, there will be a need to convey water to Qattara depression via a tunnel and through pumping water up to 219 meter level reservoir which will be serving two functions: to supply water to the reservoir and generate a hydroelectric power due to the flow of the water from 219 above sea level down to 60 meter BSL. So assume the height of the water reservoir on the rim of the depression is 219 meter (figure 2), and the total horizontal distance as per the figure 3 is almost 80 km.

The total required power to pump 144 m^3/s, up to 219 meter is around 409.2 MW, relying on equation (2).

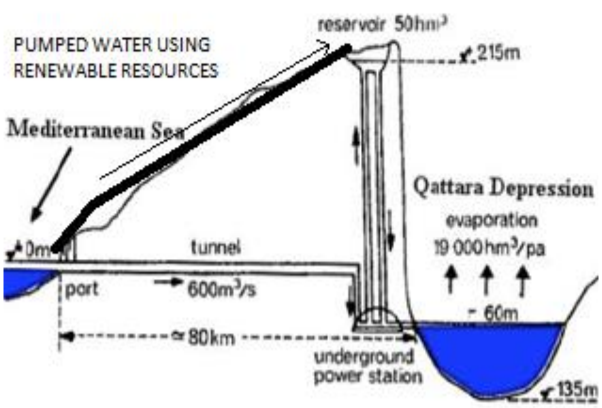

Fig. 5: Proposed Pumping Scheme.

2.2 Qattara Depression Reservoir – Project Phase II

After reaching steady state condition, and forming the reservoir at 60 m BSL, the project operation scheme can be defined through the same layout and power generation infrastructure to sustain it.

- The evaporation compensation: can be maintained via the tunnel flow (which has been assumed to be around 600 m^3/s.) This would guarantee a sustainable power source that will be presented throughout this paper.
- The pumped storage reservoir right on the rim of the depression, would serve the following purposes:

1 – Acting as a backup mean of seawater conveyance in case of shutting down the tunnel flow abruptly or for the sake of planned maintenance.

2 – Acting as a power storage, where we will keep using the same renewable power resources infrastructures (used during the phase I) to maintain this pumped storage and respond to the high power demand during the peak consumption hours.

3 – Salinity Control: This reservoir can play a vital rule to maintain the salinity level of Qattara proposed reservoir, pumping the saline water from the bottom of the depression toward the pumped storage and then using the power generated from the hydraulic gradient to run a reverse osmosis water desalination plant can be an option among other water desalination options.

3 Utilization of Renewable Energy

3.1 Solar Power Potentials - PVP

Considering the PV as an option of generating power to serve project pumping requirements, then as per the solar calculator available in NREL website [2]; the only available cities are Cairo and Aswan, here we state the available data for Cairo, such data can be close to the one we may get in Qattara Depression or near the pumping stations which is around El Alamein. The location of Qattara Depression extends between latitudes of 28°35' and 30°25' North and longitudes of 26°20' and 29°02' east, which justifies assumption made here, based on these data; PVP (Photovoltaic Power Plant) will be designed to provide sufficient power.

From the solar power calculator provided by NREL, it can be noticed that the least power rating per day will be in January while the highest will be in June; which is almost double of January, and the average annual solar radiation ($kWh/m^2/day$) is 5.66.

Based on the definition of the peak sun which is 1000 Watt/ m^2, then the peak sun hours based on the annual average radiation is 5.66 hours, hence the available power potential is maximum 1000 watt on average of 5.66 hours daily per year, so if a panel of (10% efficiency of conversion) has been considered; then in the peak hours it will extract 100 watt per square meter.

Assuming the system is on grid, then all the generated power to be sold to the grid, and power needed for pumping to be served through the available grid, in such case what will be generated over the peak hours will be consumed in pumping water over the o'clock through the available grid. 5.66 ($kWh/m^2/day$) which is equivalent to 20.376MJ/m^2 /day, which is the total energy received during the peak hours for each day. Assuming 10% efficiency then the harvested energy from the peak hours during the day is around 2.037 MJ/ m^2. The pumping requirement is 410 MW, so the total energy required for pumping water per day is 35424 GJ (giga joules). Based on that, the brief estimate of total area required for such project = 35424000 MJ/ (2.037 MJ/ m^2) = 17.39 km^2.

3.2 Solar Power & Water Desalination Potentials – Solar Power Towers

The potential of utilizing the solar concentrators in Qattara proposed reservoir would act as a power generating source, and cut on the evaporation from the lake; hence the sustainability would be improved.

Solar power towers generate electric power from sunlight by focusing concentrated solar radiation on a tower mounted heat exchanger (receiver). The system uses thousands (if not millions in our case) of sun tracking mirrors called heliostats to reflect the incident sunlight onto the receiver as clarified in figure 5. [14]

Fig. 6: Proposed Floating Solar Power Tower

The tracking mirrors that can be utilized for this project should be of a floating type, such power plant can be built in the middle of the lake as a pilot plant to evaluate its efficiency in both power generation and controlling the evaporation, based on the practical evaluation of such unique floating power tower and the actual evaporation rate, the exact plant configuration (location, capacity…etc.) will be finalized and erected on the proposed lake.

A solar tower power can be used in such case to generate power, provide additional source for fresh water, and cut on the evaporation rate of the lake, through covering portion of the lake evaporation surface with the floating sun tracking mirrors.

A water desalination plant can be attached to the proposed solar tower, as the heat concentrated can be used to generate steam that will run a steam power plant and produce fresh water out of the saline water being pumped from the bottom of the lake.

3.3 Wind Power Potentials

Considering the wind as an option of generating power to serve project pumping requirements jointly with other available renewable resources (such as PVP) will be of a value to improve the uptime of the renewable resources serving the pumping requirements around Qattara during the phase I of the project, and will support the sustainability of the whole project on the long term through diversifying the power resources around the proposed reservoir.

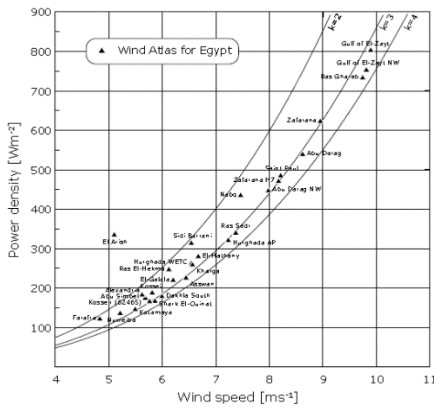

Fig.7: Mean wind speed/ power density of Egypt [1]

As per the research work [1] conducted on several coastal locations of Egypt, the wind energy potentials are promising in four main locations around Egypt; AL ARISH and RAFAH on the Mediterranean, HURGHADA and QUSAIR on the Red Sea. Figure 7 indicates the average wind speed for these sites along the year, which reveals that HURGHADA is the most promising site, followed by QUSIER on the Red Sea as well.

Based on the high potential wind energy in HURGHADA, the power generated through wind energy can be sold to the available Grid in Egypt , so it improves the economy of the Qattara project power generation; pumping power demand can be bought from the available grid in case of renewable power deficiency during the Phase I of the project, while in the project Phase II: combined Solar-Wind Resources can be the vital tools to improve the economy of the power generation through utilizing the naturally available reservoir on the rim of Qattara as a balancing (renewable energy storage) and load compensation for the grid in the power consumption peak hours.

So as a summary for the wind energy potentials:

- Wind speed around Qattara Depression is not that promising and that justifies proposing the wind energy resources to be on grid and the power to be generated in areas like Hurghada.
- The wind speed frequency is the highest around the mean wind speed of 5 m/s of a total of 1200 hours per year in Hurghada.

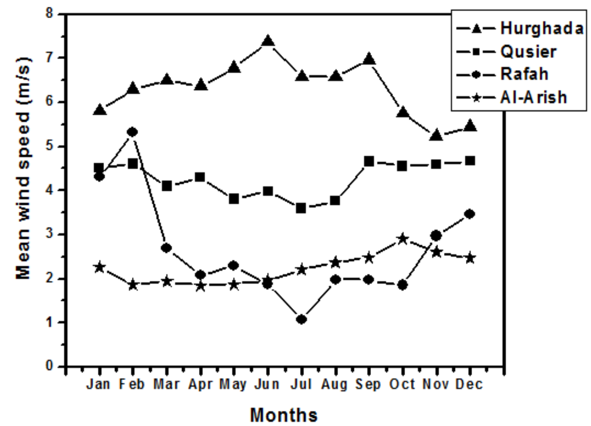

Fig. 8: Mean monthly wind speed in Egypt [1]

- Choosing a 1000 KW wind turbine would serve the pumping demand with total number of turbines equal to around 1000 Turbine that would cover up to 97.5 km^2.

4 Hydro-electric Power of the Proposed Project

The Hydropower generation potentials will be through the following flow routes:

- Flow through the tunnel, in which the water would flow from 0 (Sea level) to 60 m BSL (under steady state condition – Project Phase II).
- Flow through the water fall from 219 m above sea level to 60 meter BSL (under steady state condition – Project Phase II)
- Available power:

The available power in a water flow is stated in equation (3), so in the first route (0 to 60 m BSL and assuming that the turbine efficiency is 80%, then total power generated 282 MW.

In the second route (219 to 60 m BSL, assuming η=0.8), then the estimated power to be 227.9 MW (under steady state condition – Project Phase II)

But during the early stages of the project: the head gradient can be higher, for example: reaching 100 m BSL of the project - which would happen in the first 16 months of flooding - would give us minimum 315 MW (this calculation based on assumption that the evaporation rate is steady), the various power generation scenarios is summarized in table 2; in which the power generation (per tunnel) versus accumulated depth of the proposed lake is presented.

Table 2: Expected Power Generation for Lake Levels.

Depth BSL (m)	Power generation (per tunnel) (MW)	Power generation (pumping route)(MW)	Total Power
120	565	383	948
110	517	371	888
100	470	360	830
90	423	349	772
80	376	337	713
70	329	326	655
60	282	315	579
50	235	303	538

The duration of the project lake build up can be improved through increasing the flow (which will increase the power generation as well), in such scenario the required flow to build the lake will be increased, so in case of introducing another tunnel (identical to the one proposed here), the total flow will be 1344 m^3 /s, in such case the expected lake build up duration will be around 10 years only, accordingly the pumping power demand through the second route will be required only for 10 years which will improve the power generation economy of the project.

Among the different types of turbines, The Reaction Turbine is proposed here, as it will serve both low (<30m/98 ft) and medium (30-300m/98–984 ft) head applications.

5 Discussion and Conclusion

- The project is a promising renewable solution for hydroelectric power that will support the increase demand of energy in Egypt for years to come.
- The total power demand for pumping water on massive flow rate like 144 m^3/s through the second route, can be achieved through relying on Solar- Wind Energy Resources, but the economy of this resource should be reconsidered; from the figures above, the area required (and hence the number of panels) is massive. The cost of setting up and operating such huge PVP, and the quite high power requirement for pumping are alarming, so a detailed cost analysis is required before proceeding through the pumping route.
- It can be concluded that the pumping versus tunneling is quite questionable option: increasing the tunnel diameter (increasing tunnel flow either within the same proposed route or through a separate tunnel) would increase the power gain, but with a sensible increase in the cost of the tunneling, i.e.: changing the flow from 600 to 800 would result in increasing the power gain from 288 MW to 384 MW (almost 100 MW),while as per the analysis for the second pumping option, increasing the flow from 144 m^3/s up to 344 m^3/s would increase the power demand from almost 410 up to 978 MW.
- The pumped storage reservoir can be utilized for the sake of storing renewable energy in a hydropower form to compensate for the high demand during the peak consumption hours.
- The proposed floating solar concentrating towers technique would act as a power source and a base for sustainable salinity solution through cutting on the evaporation expected from the reservoir.
- The salinity of the proposed reservoir should be controlled, through either pumping back the high dens saline water to the lake surface and

utilize it in producing fresh water via RO plants powered by the available renewable energy resources such as Wind and PV around the Qattara new reservoir.

- Utilizing the sewage water in balancing any potential salinity (after being treated) from adjacent cities to Qattara Depression and the potential new ones, would participate in balancing the salinity and maintain the sustainability of the reservoir, again the head gradient which is in favor of Qattara, would make it another potential for hydropower.

- Adapting the gravity pipeline proposed by Dr. Mohammad Mahmoud - to convey the fresh water from Nile toward Qattara - can be of a value to provide the required fresh water to Qattara and utilize the natural head gradient in generating another source of power maintaining the sustainability efforts of the Qattara reservoir.

- Finally, Qattara project is such a promising project in which it should be managed in a responsible manner to avoid any unwanted outcome economically or environmentally.

6 Appendix

- Equation (1):

$$ER = 8.96 \times 10^{-4} \times (W_2/(D \times AL) \times (ES - E_2) \times F) \quad (1)$$

Where:

ER: Evaporation rate per unit area.

W2: Wind speed at 2 meter above the water surface m/s.

D: Water Density kg/ m^3.

AL: Latent heat of Vaporization kcal/kg.

ES: saturation Vapor Pressure -millibar at water surface temperature.

E2: Vapor pressure at 2 m height above water surface in millibars.

F: A factor (1<) to indicate the reduction in vaporization due to salinity.

- Equation 2:

$$P\ (actual) = (Q \times \rho \times g \times h)/(\eta)\ (2)$$

Where:

- P = power (J/s or watts)
- η = *pump efficiency*
- ρ = density of water (kg/m³)
- g = acceleration of gravity (9.81 m/s²)
- h = head (m) which is the difference in head between the inlet and outlet levels. The total head equals the *pressure head* plus *velocity head*.
- Q= volumetric flow rate (m³/s)

- Equation 3:

$$P = \eta\ \rho\ g\ h\ Q\ (3)$$

Where:

- P = power (J/s or watts)
- η = *turbine efficiency*
- ρ = density of water (kg/m³)
- g = acceleration of gravity (9.81 m/s²)
- h = head (m) which is the difference in head between the inlet and outlet levels. The total head equals the *pressure head* plus *velocity head*.
- Q= volumetric flow rate (m³/s)

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