

PSPP ON THE DEAD SEA

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Annotation

The authors propose building a pumped storage complex between the northern and southern Basins of the Dead Sea, including a Pumped Storage Power Plant (PSPP), an upper basin and a turbine conduit.

Key words: pumped storage complex, pumped storage power station, PSPP, upper and lower basins, dam, turbine conduit, closed water circuit, thermal power plants, energy cost, Dead Sea.

Purpose of the proposal

The technical significance of the proposed complex.

The Pumped Storage Power Plant (PSPP) operates in the pump mode at night, uses the energy from the power grid and pumps water from the northern basin of the Dead Sea to its upper basin, which is built between the northern and southern basins. In the daytime, the PSPP turbines are driven by water from the upper basin, and generators deliver electricity to the grid. Power equalization of Thermal Power Plants (TPP) will significantly increase their reliability, and also allow to provide additional power to the network during the daytime. (About 80% of repair and emergency stops of the thermal power plants are caused by rapid changes during operating mode.)

The economic significance

The storage complex is capable of generating the most valuable emergency energy. In essence, with the help of the PSPP, cheap night-time electricity is transferred to the daytime interval, when its cost is much higher. This will create profit, increase country's energy supply and improve its defense capability - through the generation of emergency energy.

PSPP State of the Art

PSPP is an established technology that has existed for more than a century. In many countries, a significant amount of PSPP plants with tens, hundreds and thousands of MW capacities were built. For example, according to the US Hydropower Market Status Report 2017, by the end of 2016, there were 38 PSPP projects, at a certain stages of the development, 32 of which were in the process of completing feasibility studies. [1]

PSPP is considered the most mature energy storage technology; most projects originate from the 1970s and 1980s, and its concept arose long before that. More than 170 GW are installed on the internationally and are in operating condition. Several proposals for the construction of a PSP were published in Israel, for example, [6, 7, 8,9 ,10]. However, no project is being implemented. In 2020, the total capacity of power plants in Israel exceeds 13,800 MW. A typical daily load curve of the power consumption for 2010 is shown in [2] At peak hours, as the graph shows, gas turbine stations are turned on, and at night, the power of thermal stations is reduced.

The Upper Basin. The upper basin is located in a desert territory, with no economic activity. The upper basin is located 5 km North from Ein Bokek resorts. The upper basin is isolated from the northern and southern basins of the Dead Sea and therefore does not affect the environmental conditions of the southern basin of the Dead Sea, as well as the operation of the Israeli and Jordanian Dead Sea Plants. It is important to note, that authors managed to find a unique place for the construction of the upper basin with the required specifications.

For the creation of a pumped storage complex with the required power - the upper basin must satisfy the following requirements:

- The upper basin must be pretty close to the northern basin of the Dead Sea.
- The triggering prism of the upper reservoir must have a volume of about 120 million m³ to equalize the daily operation of thermal stations and obtain a sufficient amount of peak and emergency power.
- Using the existing level difference between the upper basin and the northern basin of about 40m.
- Minimizing the length of additional dams forming the upper basin - in order to reduce the cost of its construction.

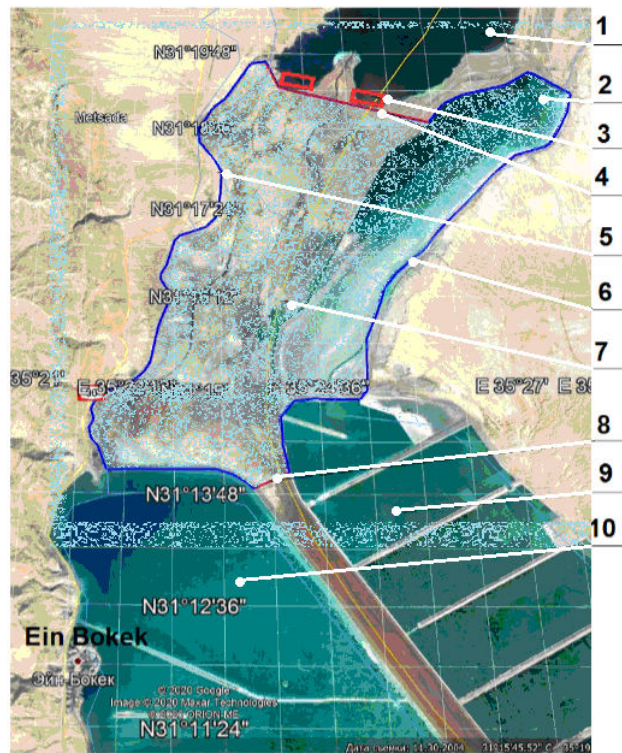


Fig. 1. The upper basin [Google Earth Pro].

In fig. 1 shows the upper basin (7). The area of the upper basin is 50 km² and is limited by dams of the Israelis and Jordanian Factories. The red lines show additional needed dams: (4) 4.2 km long with an average height of 22 m (415-393) and dam (8), 0.8 km long with an average height of 5 m. The blue lines (5 and 6) show the existing operational dams of the Plants with a total length of 32 km. The upper level of all dams is not lower than minus 393 m.

In addition to the facilities mentioned above, Figure 2 shows: 2 - part of the southern Jordanian basin, 9 - production basin of the Jordanian Dead Sea Plant, 10 - production basin of the Israeli Dead Sea Plant.

The PSPP buildings (3) are located directly under the additional dams at the bottom of the northern basin (1). Turbine pipelines run at minus 415 m to the pump intakes at minus 445 m and therefore have a minimum length of only 50 ... 100 m. The PSPP water intake is submerged

below the level of the northern Dead Sea basin to minus 445 m. In the PSPP, several hydraulic units are used, which are connected as necessary. The turbine water conduit is made in the form of parallel pipes with a diameter of 3 ... 4 m. They are able to withstand a water pressure of about 50 m.

PSPP operation mode

Figs. 2 show a graph of daily changes in power consumption in Israel. Israel daily power consumption has maximum power $P_{max} = 10,930$ MW and the minimum $P_{min} = 6670$ MW. Fig.4 shows the proposed schedule with the stable power of thermal stations P_{const} . When consumption is less than P_{const} , hydropower units accumulate energy by pumping water to the upper basin. When consumption is greater than P_{const} , hydropower units generate energy by using water from the upper reservoir. The operating time during pumping mode is $T_p = 10$ hours (from the graph in Fig. 4), the operating time during the generating mode is $T_g = 14$ hours.

Based on these graph data, we calculate the stable power of thermal stations P_{const} . We estimate the efficiency in the pumping and generating modes around $k = 0.87$. Simple calculation gives Energy during pumping (E_p) and generating (E_g) modes are (here we assume that the power graphs could be approximated by parabola):

$$E_p = \frac{2}{3} * P_p * T_p * k, E_g = \frac{2}{3} * P_g * T_g / k.$$

$$P_{max} = 10,930 \text{ MW}, P_{min} = 6,670 \text{ MW}, dP = P_{max} - P_{min} = 4,260 \text{ MW}, T_p = 10 \text{ h}, T_g = 14 \text{ h}, k = 0.87.$$

Here P_p and P_g are the maximum powers during pumping and generating modes.

The energy E_p should be equal to the energy E_g . Hence we have $P_p * T_p * k = P_g * T_g / k$,

$$P_p * T_p * k^2 = P_g * T_g, P_p * T_p * k^2 = dP * T_g - P_p * T_g, P_p (T_p k^2 + T_g) = dP * T_g,$$

$$P_p = dP * T_g / (T_p k^2 + T_g) = 4,260 * 14 / (10 * 0.87^2 + 14) = 2,770 \text{ MW}. P_g = 4,260 - 2,770 = 1490 \text{ MW}.$$

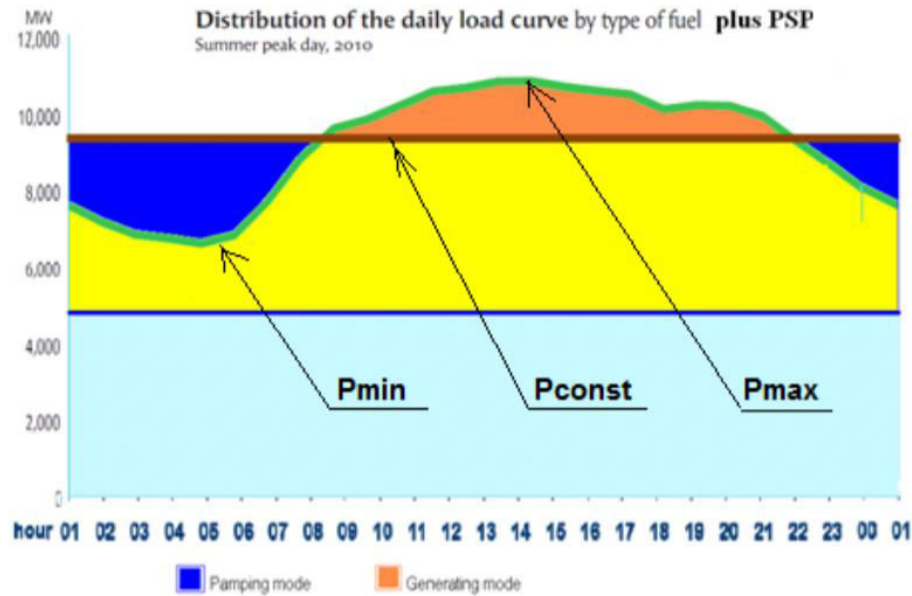


Fig. 2. Graph of the daily power consumption in Israel including the interaction of the PSPP with the country's electric grid.

The water level in the northern basin drops year after year, and in 2020 the level is below minus 435 meters. Water level in the southern basins of the Dead Sea Plants (both Israeli and Jordanian) is minus 395 m. Water level in the built upper basin can be set, for example, minus 393 m according to the height of existing and additionally built dams. Therefore, the level difference between the northern basin and the built upper basin is about $H = 40$ m.

The total daily water flow rate in the pumping and generating modes are Q_p and Q_g [m^3], water flow - q [m^3 / s], power P [W]. In the northern basin, water (brine) density is $\rho = 1235$ [kg / m^3].

We calculate the maximum water flow and the total daily water amount:

$P_{gmax}=1490$ MW, $P_g=g*p*q*H/k$, $q=P_g/g*p*H/k=1490,000,000/9.81*1235*40*0.87=3534$ m³/s, $Q_g=2/3*q*T_g*3600=2400*14*3434=119$ Mm³.

$P_{pmax}=2770$ MW, $P_p=g*p*q*H/k$, $q=k*P_p/g*p*H=0.87*2770,000,000/9.81*1235*40=4950$ m³/s, $Q_p=2/3*q*T_p*3600=2400*10*4950=119$ Mm³.

The area of the constructed upper basin is 50 km², so the prism of operation will be about 2.5 m (= 119/50).

As of 2010, the constant average daily power of thermal stations is $P_{const} = P_{max} - P_g = 10,930 - 1490 = 9440$ MW.

When designing the future PSPP, increased energy consumption in Israel and the Kingdom of Jordan, should be taken into account as well as increase in the share of renewable energy.

Power plants in Israel amounted to 13,800 MW in 2020; Jordan achieved 3,312 MW capacity in 2012. [11]

The proposed hydro complex will not create any environmental problems in the resort area near Ein Bokek and the southern Dead Sea resorts. The healing properties of Dead Sea water and air will not alter either.

Construction payback

Most PSPP projects were developed in the 1970s and 1980s and, according to a report by the US Land Reclamation Bureau, cost of their accumulated energy is about \$ 2020 / kW. The cost of the equipment of the power plant is \$ 825 / kW, and the cost of earthwork (civil engineering) is \$ 80 / kW. Depending on the terrain, the cost of tunnels, the upper tank and the lower tank can reach up to \$ 420 / kW. In general, for a 10-hour storage period, the estimated Installed Capacity Cost (ICC) of a project with high-pressure (700+ feet) and high power (500+ MW) is from 2,600 to 3,100 US dollars / kW. The payback period for the construction of a pumped storage complex has long been proven by world practice - with thousands of built complexes and complexes under construction. [1].

In Israel alone, utilizing different energy consumption tariffs for day and evening hours, the PSPP will yield millions of shekels of income. As can be seen from the table below, nightly electricity rates are lower than daily rates. [3]

For the proposed complex, agreements must be established with the Hevrat Hashmal company. In a first approximation, we assume that energy consumption throughout the year corresponds to the graph in Fig. 5, the average annual tariff per day, energy generation is 0.52 shekels per kWh, and the average annual tariff is 0.24 shekels per kWh.

The PSPP will supply to the network in the generation mode $E_g = 2/3*1490*14=13,907$ MWh per day (see above). The cost of generating energy is 7,230,000 shekels (=0.52*13,907,000). The PSPP consumes in the pumping mode $E_p = 2/3 * 2,770 * 10 = 18,467$ MWh/day. The cost of energy consumed in the pump mode 4,430,000 shekels (=0.24*18,467,000). Income per day is 2.8 (=7,23-4,43) million shekels and for 300 working days a year 840 million shekels.

Estimated cost of construction of the complex (**without need of the high-pressure dams**), with a total capacity of 2,000 MW, is about \$ 1 billion [1, 4, 5]. Estimated payback time will be no more than 5 years.

In the Russian Federation, the Leningrad PSPP has been designed and is under construction. (2017)[12] Leningrad PSPP has capacities similar to those proposed PSPP: 1560/1760 MW (in generator / pump modes). The estimated cost of the project is 73.8 billion rubles, i.e. about \$ 1 billion. This similarity will be an advantage and could significantly reduce the cost of the proposed PSPP.

The upper basin is partially located in the Kingdom of Jordan. It will allow the Kingdom to take advantage of all the benefits of the project and receive additional income from the operating PSPP. Also providing its territory for the station, the Kingdom will receive additional energy

source. This will reduce financial load on Jordan since she imports over 90% of its energy resources.

The article considers only energy problems. The authors estimated the cost facilities according to the data taken from Internet. With real design and construction and taking into account the required capacities, the cost of the project and the payback time will be slightly different.

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