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INTRODUCING THE HYDRO PEAKING UNITS IN THE EGYPTIAN POWER SYSTEM

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(HPPEA)*

1. Introduction

Different studies had been carried out during the last 25 years for a number of sites for the development of hydropower pumped storage plants in the Unified Power System (UPS). These studies covered the all potential sites in Egypt.

From 1980/1981 to 1999/2000 the installed capacity in the Unified Power System (UPS) rose from 4706 MW to 14582 MW or more than three times. The hydropower generation todays represents about 20% of the total installed capacity of the UPS and there is only a very limited potential of hydroelectric power that remains to harness.

The UPS future expansion will include thermal power plants, with steam turbine and combined cycle plants for base load production and gas turbine plants for peak load production as a reserve. As an alternative to gas turbines, Pumped Storage Plants (PSPs) can be considered for peak power generation.

The main feature of a PSP as a hydropower plant is operated in peak-time on water flowing from an upper to a lower reservoir. In the off-peak period the flow is reversed and the upper reservoir is refilled. The electricity needed for operating the motor-generators is produced by surplus thermal power capacity available in the off-peak demand periods.

2. The Egyptian Unified Power System

Egypt has had long experience of high growth rates for electric power demand in the second half of the last century, of the second millennium. The average growth rate has reached about 12% in 1960's then has dropped to 8% in 1980's and 6% in 1990's. It is noticeable that the power demand has increased in the last two years to about 10% due to the high consumption of the air-conditioning loads.

In year 2000, the total installed capacity of the Egyptian Unified Power System has reached about 14.6 GW. The hydroelectric installed capacity was 2810 MW, but the hydropower is usually dropped to about 1440 MW during the period of low discharge in the winter season. The thermal generation system is composed of dual fired (natural gas/oil) steam turbines, and combustion

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* HPPEA: Hydro Power Plants Executive Authority

turbine units. The small diesel generating units are used in the remote areas, which are not connected to the National Unified Power System. The wind farm of about 63 MW total capacity was introduced in the power system in the last year, on the Suez Gulf.

The total generated energy in 1999/2000 was 73.3 TWH thereof 15.3TWH was generated from the hydropower schemes. The generated power is transmitted to the distribution system through an interconnected network covering all the country. This transmission network is composed of different voltage levels (500 KV, 220KV, 132KV and 66 KV).

Before the end of the last century, the National Unified Power System of Egypt was extended to the east, to be connected with the Jordanian power system, and to the west to be connected with the Libyan power system. Table (1) shows the peak demand, generated energy, annual growth of demand and energy for years from 1990/1991 to 1999/2000.

Table (1)

Year	Peak Demand MW	Annual Growth Rate %	Generated Energy GWH	Annual Growth Rate %
1990/91	7004	5.1	43478	4.4
1991/92	7215	3.0	45482	4.6
1992/93	7503	4.0	47096	3.5
1993/94	7657	2.1	48604	3.2
1994/95	8149	6.4	51300	5.5
1995/96	8491	4.2	54444	6.1
1996/97	9235	8.8	57656	5.9
1997/98	9850	6.7	62336	8.1
1998/99	10919	10.9	67981	9.1
1999/2000	11736	7.5	73310	7.8

3. Hydropower System in Egypt

El-Azab mini-hydro power plant in EL-Fayom, southwest of Cairo was the first utilization of hydropower in Egypt. This first hydropower scheme was started in operation in 1926 by generating 500 KW to feed the surrounding area by clean source of energy. The next hydropower plant was built in south west of El-Fayom based on drainage course. At the same period a small hydroelectric power plant of 2.7 MW, was built on a diversion of Nag-Hammadi barrage in Upper Egypt. In 1960, Aswan-I hydro electric power station was completed with total capacity of 345 MW fram nine units were energized into the electric power network. Aswan-I power plant was designed for a head varying between 32 meters in winter and 10 meters in summer. It is equipped with nine kaplan turbines which are operated as run-of -river mode for base load.

In 1960, the works had been started in the Aswan High Dam (AHD). The main purpose of this dam was to store the flood water which would otherwise be passed into the Mediterranean sea, and to regulate the water for irrigation. A further intention was to be harnessed the tricky and uncertain floods as well as to feed the Nile River with stored water whenever the river level falls beyond a certain point. One of the major gains was the generation of low cost electric power from the available hydropower.

The Aswan High Dam power plant consists of 12 Francis turbines, each with an output of 175 MW, produce a total annual energy of about 11.5 TWH. The plant began operation in 1967 and is linked to the Unified Power System by two 500 KV transmission lines.

The total discharge through the Aswan High Dam Plant varies between 240 million cubic meters per day in summer and 110 million cubic meters per day in winter. The annual discharge from the Nile river is 55.6 billion cubic meters, of which 42 billion cubic meters of water has to be released through the hydroelectric power plant and the rest to be released through the old Aswan Dam (AD) sluices which is considered a very considerable loss of potential energy. That was the object of the Aswan II hydroelectric power plant to utilize this additional potential energy for power production. The Aswan II hydroelectric power plant was constructed in 1980-1985 and situated directly downstream of AD. The power plant comprises four turbines of Kaplan type, each with an output of 67.5 MW produced an annual average energy of 1.8 TWH. The plant is operated as base load generation.

The old Esna Barrage is one of the oldest irrigation structures in Egypt. It was constructed in 1908 near the town of Esna, located on the Nile river, 167 Km north of Aswan Dam. The Esna barrage was remodeled in 1945 to allow a head difference of 5 m instead of 2.5 m, to improve irrigation. The discharge of water through the barrage was being ensured by 120 sluices. Due to the continuous increase in the head difference because of degradation in the river channel, the need to raise upstream levels to supply the different canals with required irrigation water and to make use of head difference between upstream and downstream to generate electrical power, the new Esna Barrage and Esna hydroelectric power plant was constructed 1200 meters downstream of the old structure during the period 1989-1995. Esna hydroelectric power plant is equipped with six double-regulated low-head Kaplan Bulb turbines with rated capacity of 14.8 MW each. This power plant is linked to the Unified Power System through 132 KV double-circuit overhead lines. The plant is operated as run-of-river mode for base load.

Rehabilitation and modernization of Aswan High Dam Power plant had been begun in 1982 and finished in 1995 and of Aswan I power plant had been begun in 1991 and finished in 1996. In 1987 the rehabilitation and upgrading of El-Azab mini hydro power plant of 680 KW had been started and finished in 1990. In 1997, the rehabilitaton work of Nag-Hammadi small hydroelctric power plant was completed and the installed capacity increased to be 4.5MW. A new plant of 64 MW is planned to be operated in 2007.

El-Lahoun mini hydropower plant of 800 KW is located at El-Lahoun Barrage on Bahr Yousef Canal in El-Fayoum. The construction of plant has been begun in 1998 and it is planned to be finished by the end of year 2001. The plant comprises two kaplan-pit turbines of 400 KW each, the discharge is 55 m3/s and the head difference is 1.67m.

4. Pumped Storage in The System Planning

While many factors directly affect utility need to add to present generating capability, the ultimate decision on what type of unit to add, is based on necessity and economics.

When the requirement for power generation plant is less than a few hundred hours per year (i.e.low capacity factor), combustion turbines with their low capital costs appear attractive . At the other

end of the capacity factor scale,fossil fuel plants appear most attractive when they can be used in excess of several thousands of hours per year.

From 500 to 3500 hours of operation per year at rated load (equivalent to capacity factors of 5% to 40 %) ,energy storage plants and existing oil-fired cycling units appear to be the economic choice. The portion of this mid-range load, which can be economically carried by an energy storage plant, can be significant.

4.1. History of Previous Studies From 1975-1997

To evaluate and quantify the benefits associated with PSP, a detailed Economic Expansion Planning of the Generation System 1985 - 2000 undertaken in 1978 by the Egyptian Electricity Authority (EEA) and it was assumed that the base load would be met by 600 to 900 MW steam turbine units, operated on heavy fossil fuel (mazout) or nuclear fuel, the intermediate load by the old thermal units and the peak load by 150 MW gas turbines, operated on distillate oil. In such a system the specific fuel costs per Kilowatt - hour would be some 3.5 to 3 times higher for peak load than for base load. Conseqently, a preliminary study on the optimal mix of gas turbine and pumped storage capacity was also elaborated.

At the time the study was made, in 1997, it had been estimated that at Mt.Ataqa the pumped storage potential was limited to 2100 MW. Hence, it was recommended that a survey be made for other suitable sites for hydro storage projects, for example at the Qattara Depression.

4.2 The QATTARA Project

In the studies of the Qattara Project that were undertaken in 1975 -81 by German consultants, the main feature comprised a conventional hydropower plant of 600 MW capacity, located on a headrace canal excavated with nuclear explosives, and operating on the head between the Mediterranean Sea and the depression lake. It was to be successively complemented by four pumped storage plants of 1200 MW capacity each, operating on a gross head of nearly 300 m between reservoirs located along the rim of the escarpment to the north, and the depression lake.

4.3 The MOGHRA Hydrosolar Project

The purpose of the Swedish consultant study of the same project that was undertaken in 1981- 83 under the name of the of the Moghra Hydrosolar Project, was to investigate the possibilities to excavate the headrace by conventional methods.

It was found that in this respect the most economic method would be by giant bucket wheel excavators of the type as used for coal or boxiest mining. The layout comprised an 1800 MW installation to be operated for eight hours per day during the filling and for five hours per day thereafter. It was found that the Moghra project would only be competitive with an alternative peak power production by gas turbines operated on natural gas in case equivalent fuel cost would exceed USD 29 barrel crude oil. It was further established that the direct construction costs would be of the same magnitude, whether the headrace be excavated by conventional methods or with nuclear explosives. The indirect cost for interest during construction, however, would be substantially less for the conventional method as the construction period would become shorter.

4.4 The AIN SUKHNA Project

In 1978-82 a pumped storage study was elaborated by an Austrian consultant. A number of possible sites were identified in the Nag Hammadi area in Upper Egypt, some 500 km south of Cairo, in the Mokattam mountains near Cairo, at the Fayoum oasis some 100 km south of Cairo and the Mount Ataqa and the Mount Galala areas close to the Gulf of Suez. Preference was given to the Galala site, where site investigations comprising core drillings and a test tunnel were undertaken. The salient features of the layout chosen comprised a 600 MW scheme, consisting of an upper reservoir of 12 million cubic meters storage and a maximum reservoir level of + 590 m above sea level, a headrace composed of two concrete - and steel - lined tunnels continuing in two open-air penstocks and ending in two 80 m deep shafts - each shaft contains two reversible pump-turbines of 150 MW each, and a short tailrace connecting to the Gulf of Suez, which would serve as the lower reservoir.

4.5 Pumped Storage Hydroelectric Power Study on Mt. GALALA

In June 1993 the Draft Final Phase 1 Report on "Pump Storage Hydroelectric Power Station Study, Egypt" was submitted by American consultants in association with an Egyptian consultant. In that report a comparison was made between peak power production by pumped storage or by combustion turbines. The estimated costs for pumped storage was based on data from a few recently completed or projected US projects, adjusted to apply for a head of 800 m and a storage for 10 hours daily continuous operation. Hereto was added the costs for adaptation to local conditions, such as for pipelines for water supply and a plant for desalination of seawater. The total capital costs thus attained USD 760/KW, excluding interest during construction. In the economic study the present worth of all capital and current costs for operating the UPS in the period 1995 to 2024 was estimated with and without a 600 MW pumped storage plant. It was found that in the year 2024 some 130 gas turbines of 150 MW would be required without the 600 MW PSP and 122 with the PSP.

4.6 MOUNT ATAQA Feasibility Study

In the 1997 the study investigated the technical, economical and environmental feasibility of a pumped storage plant at Mount Ataqa, some 12 km west of the city of Suez . Two alternatives of development have been prepared for the period 1995 to 2020; one without and the other with the Mt Ataqa PSP of 6x 350 MW. In both cases it is assumed that the demand will increase at a rate of about 4.5% per annum from 8300 MW in 1995 to 24500MW in 2020.

In the former case additional 3.200 MW combustion turbines, 4200 MW combined cycles and 13200 MW steam turbines would be required, over and above addition already commissioned or ordered. Practically all units would be operated on natural gas.

In the later case, with the Mt. Ataqa PSP taken into operation by the year 2005, the thermal power installation might be reduced by 1400 MW combustion turbines and 600 MW steam turbines. The resulting net savings would amount to a present worth in the year 2005 of some 1200 MUSD at a discount rate of 6 %, corresponding to the present real interest rate in Egypt.

The net benefit of the construction of a PSP of 6 x 340 MW capacity, would attain 225 MUSD when discounted to the year 1995 at a fuel cost USD 28, a discount rate of 10% and an investment

cost of USD 500 per KW. At a capital cost of about 800 USD the net benefit would be nil, that is peak power generation with gas turbine plants would be equally competitive with pumped storage plants. All variants are being in the positive in favor of a PSP.

From the Final Report, it could be concluded that:

- In the first instance,that already within 5 years from commissioning the pumped storage plant will have replaced 600 MW steam power and 1400 MW gas turbine plants.
- Secondly, the net benefits of the pumped storage development were in the positive for all variants studied, namely with fuel prices varying from 20 USD to USD 35 per barrel crude oil (corresponding to about 100 to 175 USD/toe) , with specific investment costs for the pumped storage installation varying from 450 to 550 USD/kW and with discount rates in the range of 8 to 12%.
- Thirdly, for the main variant, involving a fuel cost of USD 140/toe and a specific plant cost of 500 USD/KW; the economic rate of return would substantially exceed the opportunity cost of capital.

4.6.1 Salient Features of MOUNT ATAQA PSP

The salient feature of the project is an underground power plant comprising six reversible pump-turbine units with motor-generators operating between an upper reservoir at the top of Mt.Ataqa and two lower reservoirs at the foot of the mountain. The pump-turbines are connected to the upper reservoir by vertical, steel lined penstocks. The penstocks can be closed off at their upper ends by cylindrical gates, located in concrete intake towers, and at their lower ends by spherical vâlves, located in the machinery hall immediately upstream of the spiral casing.

Connection to the lower reservoirs is by vertical steel-lined penstocks, linked two by two to horizontal concrete lined tunnels . The penstocks can be closed off in their upper end by slide gates operated from a gate hall. The tunnels are in their powerhouse end provided with two cylindrical vertical surge shafts and can be closed off in their reservoir end by vertical cylindrical gates placed in concrete intake towers.

Access to the underground power plant is by a 1250 m long tunnel starting at the foot of the mountain at a level of about El + 280 m. It runs at an inclination of maximum 1 vertical to 7 horizontal. There is also a vertical main shaft, containing conductors, cables, a lift and a staircase, leading from the level of the transformer hall and up to the pothead yard on ground level at the upper reservoir. From the transformer hall a vertical shaft housing stairs, lift, cables and ventilation lead down to the generator floor in the machinery hall. The machinery hall is approximately 180 m long and 16m wide. The distance between each unit is about 21.2m. The length of the unloading bay is 20m. The two traveling cranes have a lifting capacity of 250 tones each, and can be combined with a yoke for a lift of 500 tones.

There are four main floors, viz. the machinery floor, the generator floor, the turbine floor and the valve floor. The runners of the pump turbines can be reached from the valve floor, the turbine cover from the turbine floor, and the stator room from the generator floor. Metal enclosed bus ducts connect the motor-generators to the 500 KV transformers. Each transformer is separated from the outgoing buses by gas-insulated switchgears placed in connection to the respective transformer. From there gas-insulated HV-conductors lead to the pothead yard at ground level. The transformer

hall is approximately 175 m long and 15m wide. The main transformers and the high voltage switchgears are located on the lower floor.

The upper reservoir has an ultimate active capacity of 9.0 million m3 at an upper storage level of El + 860 m and a regulation amplitude of 28 m. The two lower reservoirs have an initial capacity of 7.0 million m3, but can subsequently be extended to some 9.0 million m3 by the construction of a third reservoir at an upper storage level of El + 258 m, and a regulation amplitude of 31m. The energy storage will amount to 10 GWh in the first stage and to 13.4 GWh in the final stage.

The lower reservoirs are filled with sweet water by a 14 km long pipeline from Suez, feeding from the canal system which conveys Nile water from the Shoubra suburb to the north of Cairo via Ismailia to Suez city. The administration building, the main control building, and the workshops and stores will be located outdoors on the access road to the entrance of the access tunnel. The main access will be from a take-off on the highway from Suez to the south.

5. Economy of Hydro Pumped Storage

The main goal of the power utility is to supply low cost and reliable electric power to the consumer with minimum negative to the environment. Introducing hydro pumped storage to the Egyptian Unified Power System will certainly reduce the cost of the future generating system from both investment and operating sides. In addition to the cost benefit, the dynamic benefits embrace improved conditions for voltage correction, frequency regulation and load following, and reduced costs for spinning reserve and cycling of thermal generating units.

The economics of the hydro pumped storage project is based on the trade of electric power between the utility and the developer (owner). The developer purchases low cost energy from the utility at off-peak hours where the demand for the electric power is low, then the utility will purchase the electric energy from the developer at peak hours when the demand is high andthe other alternatives are more expensive. In fact the quantity of energy traded is not the same in the two directions of purchasing and selling . The difference in energy traded is the round efficiency during the pumping and generating operations. The opportunity cost of energy during the peak periods could be from gas-turbines diesel engines or other peaking generating units.

The following analysis will show the essence of the trade in the hydro pumped storage project.

If E_s is the energy sold on the bus-bar to the project and used for pumping the water, and P_s is the price per unit of electric energy sold from the utility to the developer of the project, then the charge of energy sold will be $E_s * P_s$.

On the other hand:

If E_p is the energy purchased by the utility from the project, which is equivalent to E_s, and P_p is the price per unit of energy purchased by the utility from the project.

Hence, the charge of energy purchased is $E_p * P_p$.

The round efficiency of the project $\eta_y = \eta_p * \eta_g = \frac{E_p}{E_s}$

Where η_p is the pumping efficiency & η_g is the generating efficiency.

In fact the price of KWh purchased by the utility P_p should include energy cost, investment cost IN_p and operating and maintenance cost (O&M) OM_P of the project.

Where the energy cost = P_s * $= \frac{E_p - Ps / \eta_y}{E_p}$,

and investment cost should cover capital cost, interest during construction and cost of money (interest, risk, ... etc).

From the developer point of view the project is economical when:

$$P_p > \frac{P_s}{\eta_y} + IN_p + OM_P$$

and from the utility point of view the energy trade is beneficial when :

$$P_p < OCE_{pt}$$

where OCE is the opportunity cost of energy at time of peak demand.

In addition to the direct benefits of the pumped storage hydro-power plants of providing a mean of, cheap energy during the peak demand, lower system operating costs and environmentally clean process, it also provides dynamic benefits. These potential dynamic benefits include: Spinning reserve, Load following, unit commitment, reduced system minimum loading problem, voltage and power factor correction, frequency regulation, reduced thermal plant cycling and improved system operation reliability.

5.1 Spinning Reserve

Spinning reserve is the spare generating capacity which can respond rapidly to a sudden loss of a generating unit or imported power. Strictly speaking spinning reserve should be synchronized to the system. Since most thermal units are designed to a given maximum efficiency at or near their rated output, running a unit at part-load to provide synchronized spinning reserve is not the most efficient use of its capacity. Pumped Storage generating at less than its full capacity provides high quality spinning reserve and has a high value during the peak period when spinning reserve is expensive. Additional spinning reserve benefit could be realized by operation of the PSP in a synchronized but unloaded mode at those times when it is neither in a generating nor pumping mode.

5.2 Load Following

Thermal units cannot change their output instantaneously and sustain it . Oil fired or gas fired units typically have a ramp rate limit of about 1 % to 3% of maximum capacity per minute. Pumped Storage has a ramp rate capability in the range of 10% to 30% per minute. The daily load swings

between minimum and maximum may require multiple units or even combustion turbines to pick up load at the same time due to thermal ramping limitations. These units would then operate at part-load capacities with resulting increased costs. On the other hand, PSP can operate full pumping at light load, and as load grows, individual pumps can be turned off one at a time and then reversed to generation, thus following the load.

5.3 Unit Commitment

Unit commitment benefits refer to the potential savings related to the reduced number of startups and shutdowns of thermal generating units in the system due to the operation of the PSP. Unit commitment savings include the savings of starting costs, but also the savings from avoiding minimum loading of units at lower efficiency, and reducing the wear and tear of thermal units, etc.

5.4 Reduced System Minimum Loading Problem

Minimum loading problem means that the sum of the minimum operating capacities of all thermal units on line exceeds the system load at that time, generally at night when the load is low. This can require thermal units to be shut down. The storage-pumping load helps alleviate the minimum loading problem.

5.5 Voltage and Power Factor Correction

Pumped storage can be equipped to regulate voltage in its vicinity . The units can provide power factor correction and voltage regulation in the generating or pumping mode and can also operate unloaded as synchronous condensers.

5.6 Frequency Regulation

PSP is potentially ideal for frequency regulation with its fast ramming capability. Its efficiency does not degrade as steeply as steam units when the operating point deviates from the base point. Frequency regulation costs money because it requires a certain amount of generating capacity to be dedicated and reserved. The advantage of having pumped storage for frequency regulation is that it may allow a steam unit to be taken off frequency control and loaded to its maximum economic level.

5.7 Reduced Thermal Plant Cycling

Pumped storage potentially reduces the number of thermal unit startups. Load following and frequency regulation capabilities reduce the random fluctuations of system generation output. Utilization of these capabilities translate into reduced wear and tear on thermal units, lower maintenance costs , higher reliability , better efficiency and longer equipment lives.

Reduced forced outage rates for thermal units would result in lower annual production costs.

5.8 Improved System Operation Reliability

The fast response time of pumped storage makes it ideal for covering forced outages. Pump load can be disconnected instantaneously. In standby mode, units can be started and brought to full power in a few minutes. When the units are already on line, they can be rammed up much faster than steam units.

All these characteristics result in more reliable system operation.

6. Conclusions

- The study made of the required expansion of generation system from 1995 to 2020 with and without pumped storage showed that Mt. Ataqa pumped storage plant would replace fifteen 100 MW combustion turbines and a 600 MW steam turbine. The present worth of the resulting savings will amount to some 750 MUSD in favor of pumped storage plant, discounted to the year 2005. Hereof some 600 MUSD relates to reduce costs for the UPS and 150 MUSD to reduce losses from unserved energy to be credited to the consumers.

- The incorporation of PSP in the UPS will provide direct benefits such as: cheap energy during the peak demand, lower system operating costs and environmentally clean process and also provide indirect benefits such as spinning reserve, load following, unit commitment, reduced system minimum loading problem, voltage and power factor correction, frequency regulation, reduced thermal plant cycling and improved system operation reliability.

- In addition to investment cost as a main factor, economics of hydro pumped storage depend on how cheap is the energy used for pumping with respect to the cost of energy generated from other peaking generating units rather than the pumped storage.

- Involvement of private sector on hydro pumped storage projects should be tackled differently from traditional private thermal and hydropower projects.

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