TOSHKA PROJECT ELECTRICAL POWER DEMAND
(Mubarak Pump Station)

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ABSTRACT

Electrical energy is one from the important forms of energy. In the past few years, Egypt energy requirements are increasing very tremendously due to the increasing of population, standards of livings, and the vital need for new major projects to face the economic challenges. This research is a part of serial research studying and evaluating power demand and potential supplies. This serial research has evaluated the electric power in Egypt especially hydropower and its future under different conditions and most unfavorable scenarios in addition to the effect of a major national project; Toshka Project; on the power in Egypt. This paper is focused on the effect of the project on the power generation from High Aswan Dam and the power requirements and operation of this major project. Two mathematical models have been developed by the author for the operation of the project. The first model is used to compute the effect of the project on HAD generation and the other model is used to determine the pump operation according to project water requirements all over the year. In addition, the software analyzes the hourly power demand for the Egyptian United Network historical data and to propose the optimum operation hours for the projects pumps hour the year. The research results are illustrated during this research and some important recommendations are highlighted for the decision makers.

Keywords: Egyptian United Network, Toshka Project, Hydropower Generation, Power Demand in Egypt.

I. GOAL

Toshka Project is a national major project in Egypt. It is a major water project designed to irrigate about 540,000 new feddans = (56,700 Acres) by elevating water from Lake Nasser. The estimated required water discharge is about 5.5 BCM/year taken at 265 km upstream the High Aswan Dam. This extracted huge volume from the lake has a major and magic effect on irrigating the desert land. But it, also, has some
other major side effects since it is taken from the limited Egyptian share of 55.5 BCM/year and electric source for the project is depending on the united network.

II. INTRODUCTION

As a result of rapidly growing demands and a shortage of financial investment by governments, private power production sector is encouraged in the traditionally monopolistic power industry in developing countries [1]. The amount of distribution generation (DG) is increasing worldwide, and it is foreseen that in the future it will play an important role in electrical energy systems. An original approach and computational method to assess the impact of DG on investment deferral in radial distribution networks in the medium and long-term have been presented in [2]. Load profiles may vary from 24-h constant to only nighttime or oppositely only daytime load profiles. Celik [3] presents on the system performance. Optimal dispatch systems at hydroelectric plants manage the energy conversion process such that under all conditions the station efficiency is maximized in [4]. The optimal operation of the reservoir for electric generation with varied conditions such that long and short term hydrothermal scheduling, distributed regional demand in order to analyze operation characteristics of electric utilities appropriately, is presented in [5, 6]. In bringing energy needs and energy availability into balance, there are two main elements such as energy demand and energy supply. In this regard, every country should put efforts to attain such a balance and hence conduct research and development studies to develop its own energy conservation programs for the existing and new energy resources [7]. In 1993 the World Energy Council (WEC) published the results of a major study it had undertaken of global energy supply and demand in the period 1990 to 2020 under the title "Energy for Tomorrow's World – the Realities, the Real Option and the Agenda for Achievement" [8]. About 84 percent of Egypt's electric generating capacity is thermal power and the remaining 16 percent is hydroelectric power generated mostly from the Aswan High Dam. Electricity demand, in Egypt, is growing from 5%-7% and has reached about 11% during the past year due to the increasing power demand, we will study and manage the available resources to face the increasing requirements and economic challenges.

III. TOSHKA PROJECT CHARACTERISTICS

This project consists of three main parts: Canal intake, Mubarek Pump Station (MPS), and South Valley canal. The characteristics of MPS operation are as follow:

1- The required annual water for the total area of the project is $5.5 \times 10^9$ m$^3$ per year and the designed discharge capacity of a single pump is estimated to be about $(17 \times 10^6$ m$^3$/day).

2- Minimum and maximum suction levels (minimum and maximum operational water levels in Lake Nasser) are 147 m and 182 m, respectively, Figure 1.
3- Delivery level (South Valley Canal) is 201 m, consequently, minimum and maximum statically water raising heads are 19 m and 54 m respectively. The project consists of the following parts:

![Fig. 1 Cross Section at Canal Intake with Different Water Levels](image)

**A. Canal Intake**

It is an open channel with 4.5 km length and 10 m width at the bottom with side slopes 2:1 (horizontal, vertical), Figure 2. It extends from Lake Nasser to the suction basin of the pump station. The path of canal intake was designed to reach level of (+134.00 m) inside Lake Nasser by the minimum length and by the lowest cost. This design allows the operation of pump station at the minimum water level in Lake Nasser which is (+147.00 m).

![Fig. 2 Intake of Sheikh Zayed Canal](image)
B. Suction Basin

It is a deep basin with 48 m depth from the natural ground level (+182.00 m) where its base level is (+134.00 m). The dimensions of that basin are 167 m x 75 m at base level and rises with side slopes 2:1 (horizontal, vertical).

C. Pump House

It is a concrete water resistant structure inside the suction basin. Its dimensions are 140 m x 45 m and 60 m in height. It is designed to resist earthquakes and consists of nine vertical stores start at level (+132.30) and end at level (+188.30).

IV. MUBARAK PUMP STATION (MPS)

Mubarak pump station is located on the left bank of Lake Nasser about 8 km north of Toshka spillway. The pump station is designed to raise water from Lake Nasser to Sheikh Zayed main canal with maximum static raise of 54 meters to cover the difference between the lowest level of Lake Storage at elevation 147 meters, and main canal water level at elevation 200 meters. The withdrawal from the lake will be through tunnels and discharge through pipelines with a total designed discharge of 25 M.m$^3$/day that could be raised to a maximum of 37 million m$^3$/day using 24 pumps. The total annual volume required for the nominal irrigated perimeter over 540,000 feddans is 5.5 billion cubic meters. The peak discharge at the main pumping station is about 240 m$^3$/sec, to be sustained about 2 months in June and July with an average raise of 38 meters. The existing equipment of the pumping station 334 m$^3$/sec at maximum raise of 54 m will accommodate easily this discharge. The minimum requirements which would correspond to the mid-January period would be about 67 m$^3$/sec, less than one third of peak requirements. This water will be diverted northwestward, pumped out at the largest pump station in the world just north of Toshka outfall. Fig. 3 represents the single line diagram from 220 KV substation to 11 KV SWG for Mubarak Pump Station where sample motor in the drawing with rate 12 MW.

Overall Power and Energy Requirement

Many studies were performed to determine the required power and the energy for the project. Operation scenarios are different in each study; one scenario determines the peak power requirements for pumping stations by about 165 MW, of which 105 MW is allocated for main Mubarak Pumping Station. The associated annual energy requirements are about 950 GWh, of which 575 GWh is allocated for the main pumping station [9], Table 1.
Fig. 3 Single Line Diagram for Mubarak Pump Station
In terms of power demand, total peak requirements of 315 MW would represent 15% of the installed capacity of the high dam; this percentage will rise during drought periods.

V. DEVELOPED PROGRAMS

There are many mathematical models that can be used to predict the relation between the electrical power and water. By using FORTRAN and VISUAL BASIC software, two models are developed; the first is a numerical developed with special conditions to achieve study requirements such. It is developed by the researcher particularly to study, analyze, and present the effect of the new SV project operation on the electric generation of the HAD power station. The special characteristics conditions of the model and the proposed simulation are considered as:

1- The release discharge should be controlled during all time steps.
2- The upstream Water level should be controlled to avoid any water level exceeding 182.00 m.
3- The unique simulation of dam operation conditions.
4- The evaporation loss functions are governed by both lake water levels and meteorological conditions.
5- Seepage losses are governed by lake water levels.
6- Toshka spillway and South Valley Canal located about 265 km from upstream the High Aswan Dam.

Also, the first model is developed based on multiple regressions of hydropower, discharges, and head relationships, with special conditions related to the nature of the location and other reasons such as:

- In this study the special complicated nature of the problem since the storage volume reach up to 162 BCM/year with a length of about 500 Km and the existence of many types of outflows (point and non-point outflows) at different locations.
- The major task is to simulate the actual occurring scenarios rather than indicating the optimal scenarios (for example by using dynamic programming) so the
developed approach was used in this study to analyze the actual occurring conditions for different cases. It can be briefly summarized as follows:

Hydropower Module

This module depends on a new equation for HAD turbines operation, this equation was created by multiple regression analysis using stat graph software. Multiple regression analysis, is a statistical technique that can be used to analyze the relationship between a single dependent is named criterion variable which is represented in our study as power $P$ and two independent variables are named predictor variables which are represented as discharge through turbines $Q$ and the pressure head $H$. 153 actual data record monthly for $P$, $Q$, and $H$ from 1988 to 2000 are used to predict this relation, where these data contains measured power in GW, pressure head in m, and turbines discharges in M.m$^3$/month. Formula for this relation was represented as linear equation 

$$P = C_1 \times Q + C_2 \times H + C$$

and given as:

$$P = -689.41 + 0.167 \times Q + 9.62 \times H_1$$

Where:

$H_1$ is the head acting on the turbines (m).

$Q$ is the outflow discharge through the turbines (m.m$^3$/month), and it is the discharge for reservoir.

The correlation factor for the equation was given as $R^2 = 0.991$.

The results of the new equation were compared with actual generated power; the error is given as 2.3, also. Table 2 represents the range which it is valid to use and Table 3 represents the maximum and minimum for actual, computed power and maximum, minimum values for difference between them.

This equation is valid for these data, where range of head, discharge through turbines and generated power are specific, Figure 4.

<table>
<thead>
<tr>
<th>Equation</th>
<th>$P$ (MW)</th>
<th>$Q$ (M.m$^3$/month)</th>
<th>$H$ (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max.</td>
<td>1247.48</td>
<td>7650.7</td>
<td>73.6</td>
</tr>
<tr>
<td>Min.</td>
<td>290.31</td>
<td>2206.28</td>
<td>48.18</td>
</tr>
</tbody>
</table>
Table 3 Maximum and minimum errors for computed power by equation

<table>
<thead>
<tr>
<th>Equation</th>
<th>$P_{\text{actual}}$</th>
<th>$P_{\text{computed}}$</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max.</td>
<td>1247</td>
<td>1228</td>
<td>49</td>
</tr>
<tr>
<td>Min.</td>
<td>256</td>
<td>215</td>
<td>-125</td>
</tr>
</tbody>
</table>

Fig. 4 Power Computed by New Equation and Power Actual is closed

Second Program Calculations

The computations in the developed program are depending on one main function with three factors. The first factor is the electrical consumption of a single pump in the station, the second factor is the water discharge raising rate of a single pump, and the third factor is the number of daily working hours. Discharge distribution at the project is shown in Figure 5 and Table 4 for different months.
Fig. 5 Monthly discharge for Toshka Project

Table 4 Project Monthly Discharge in Toshka M.m³/day

<table>
<thead>
<tr>
<th>Month</th>
<th>Discharge (M.m³/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>8</td>
</tr>
<tr>
<td>February</td>
<td>11.13</td>
</tr>
<tr>
<td>March</td>
<td>14.09</td>
</tr>
<tr>
<td>April</td>
<td>14.09</td>
</tr>
<tr>
<td>May</td>
<td>17.22</td>
</tr>
<tr>
<td>June</td>
<td>22.96</td>
</tr>
<tr>
<td>July</td>
<td>22.43</td>
</tr>
<tr>
<td>August</td>
<td>20.17</td>
</tr>
<tr>
<td>September</td>
<td>13.74</td>
</tr>
<tr>
<td>October</td>
<td>11.13</td>
</tr>
<tr>
<td>November</td>
<td>10.43</td>
</tr>
<tr>
<td>December</td>
<td>8</td>
</tr>
</tbody>
</table>

From Table 4, it can be shown that the required monthly discharge is different for each month. Maximum discharge occurred in three months; June, July, and August while the minimum discharge occurred in two months; January and December, these variance in the discharge gives work load on the pump station, where it should be manage this variability. Mubarak Pump Station (MPS) contains 24 pumps with 24 electric motors, 21 for base load and 3 as spare motors, the electrical rate for every motor is 12 MW per hour and its rate of raising the water is 17 m³/sec. Mubarak pump station program calculates number of working pumps, the number of working hours, and working period in day related this equation:
\[ Q_p \times \frac{N}{D_h} \times h = Q_{req} \]  \hspace{1cm} (1)

Where

- \( Q_p \) = Rate discharge for every pump in the station = 17 m\(^3\)/day
- \( N \) = number of working pumps (selected based on scenario)
- \( D_h \) = represents hours of the day = 24 h
- \( Q_{req} \) = water discharge required for irrigation, where; it varies from month to another
- \( h \) = No. of working hours.

The authors used different scenarios by using MPS program to specify the numbers of working pumps, working period, and working hours, Figure 6. There are some conditions in the program, such that:

1. The electric power for working pumps as minimum as possible.
2. Avoid working for all pumps at the same time.
3. Working hours for pumps are continuous during one day to avoid the starting current effect.
4. Working hours for pumps at minimum hours load for united network daily load curve.

By taking into consideration the above conditions, the program output gives the optimum number of pump for working as four pumps from the twenty one pumps at the station and after that the program computes when and for how long the selected pumps are working each day.

\[ \text{No. of Working Hours (h)} = \frac{\text{Monthly Water REQUIREMENTS (Q}_{req})}{\text{Pump Water Discharge Rate (Q}_p)} \] \hspace{1cm} (2)
Start

Read Power Consumption for each pump

Read Water Discharge for each pump

Calculate no. of Pumps
\[ Q_p \times N/Dh \times h = Q_{req} \]

Calculate no. of hours
\[ h = \text{month req.} / \text{Pump Discharge} \]

If Water calculated > water Req.

Write no. of Working Hours

Draw Chart For Pump Station Load

End

Fig. 6 Flow Chart of Program
VI. RESULTS AND ANALYSIS

The summary of the output of the developed program is shown in Table 5 and Figures from 7 to 9. Different scenario outputs were examined to select the best one to be used for the project. The scenario which was applied gives these results; numbers of working pumps are four pumps, this number is constant in all days but the working pumps are alternated every day from all pumps in the station. Also, developed program depends on main relation between three elements, discharge required for the project, number of working pumps, and its working time in hours. By using this relation, developed program could specify the number of working hours every day throughout the year. It is found that the maximum power consumed by MPS occurs on June where the value reached to $9 \times 48 = 432$ MW/day and the minimum value for consumed power occurred on January and December it reached to $3 \times 48 = 144$ MW/day. It is noted that, consumed power for the station will rise in the drought periods because the required raising water level is increased.

It can be concluded that during all days, the period from 1 am to 9 am form the minimum daily load, so the developed program used variable hours through these period to operate the pump station.

Annual energy requirement for the total irrigated area at full development would therefore be in the order of magnitude of about 20% of the total output of the Aswan High Dam when the station works with full load.

Table 5 Working Hours for Mubarak Pump Station

<table>
<thead>
<tr>
<th>Month</th>
<th>Working Hours (Continuously)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>3 Hours, from 5 to 7</td>
</tr>
<tr>
<td>February</td>
<td>3 Hours, from 2 to 4</td>
</tr>
<tr>
<td>March</td>
<td>6 Hours, from 2 to 7</td>
</tr>
<tr>
<td>April</td>
<td>5 Hours, from 5 to 10</td>
</tr>
<tr>
<td>May</td>
<td>7 Hours, from 1 to 7</td>
</tr>
<tr>
<td>June</td>
<td>9 Hours, from 4 to 12</td>
</tr>
<tr>
<td>July</td>
<td>9 Hours, from 24 to 8 for next day</td>
</tr>
<tr>
<td>August</td>
<td>8 Hours, from 1 to 8</td>
</tr>
<tr>
<td>September</td>
<td>6 Hours, from 2 to 7</td>
</tr>
<tr>
<td>October</td>
<td>5 Hours, from 3 to 7</td>
</tr>
<tr>
<td>November</td>
<td>4 Hours, 2 to 5</td>
</tr>
</tbody>
</table>
Fig. 7 Daily Load Curve and Working Hours of PMS at January

Fig. 8 Daily Load Curve and Working Hours of PMS at May
VII. CONCLUSIONS

This approach is part of serial research studying and evaluating power demand and potential supplies the hydropower in Egypt and its future under different conditions and most unfavorable scenarios. In addition to the effect of a major national project- Toshka Project, on the hydropower generation in Egypt it is focused on power requirements and operation of this major project.

The approach divided into two main points; the first is the operation of High Aswan Dam Power Stations with Toshka project and second is effect of Toshka project power operation especial MPS on the daily load curve united network in Egypt, so two special computer programs were developed. By using the first program; new equation for High Aswan turbines was created and applied. The second program determines working pumps time. The minimum hours occur on two months January and December where the water required related to the crop types. The effect of working MPS with this approach is very low on the daily load curve. The electric load for the station is ranged between 144 MW at minimum load and 432 MW at maximum load that means; daily power required for the Mubarak Pump Station represents approximately third installed capacity of High Dam.

REFERENCES


