Energy and Economic Analysis of a Hydroelectric Power Plant: A Case Study

Can Coskun, Zuhal Oktay, Bahadir Birecikli, and Serdar Bamya

Abstract — In this study, the electricity production and energy costs of hydroelectric power plant is analyzed by using actual power plants data. Using long term actual data, the capacity utilization rates of the hydroelectric power plant were estimated on an hourly basis. Economic analysis of the power plant and factors affecting the energy production costs (initial investment cost, operating-maintenance costs, etc.) were researched and the energy production costs of the power plant were assessed in detail. Additionally, for the first time in this study, a dimensionless number was defined to denote the variation of electricity consumption in the country on an hourly, monthly and yearly basis. This number was called the hourly electricity consumption coefficient (HECC). A detailed investigation of the electricity consumption in Turkey was analyzed.

Keywords — Electricity Production, Energy Analysis, Economic Analysis, Hydroelectric Power Plant.

I. INTRODUCTION

Electricity consumption is one of the most important markers of a country’s development and is an indispensable element of modern life. With the effect of global growth, the demand for electricity is increasing every day. Increasing electricity demand has caused electricity production power plants to gain great importance. In Turkey, thermal power stations, hydraulic power stations, wind power stations, solar power stations and geothermal power stations are all used for energy production. In thermal power plants, the fuel used is fuel oil, diesel, imported coal, natural gas, hard coal and lignite. Hydraulic power stations benefit from the potential energy of water to transform potential energy to kinetic energy and later transform this to electrical energy via a generator linked to the turbine rotor and produce energy. In the electricity production process in Turkey, the majority of thermal power stations work continuously over 24 hours. Electricity produced by renewable energy power stations is included in the system depending on fluctuations over time. Hydroelectric power stations supply high electricity demand and work at certain hours of the day to compensate for the fluctuation in electricity produced by renewable energy power stations. In Turkey, the majority of electricity production (mean 76.6%) is supplied by thermal power stations. The rate of electricity production from thermal power plants as a percentage of total electricity production has varied from 69% to 81% over the last 10 years.

The variation in electricity production from hydroelectric power plants as a percentage of total production is between 19 and 30%.

The gross hydroelectric potential in our country is 433,000 GWh/year, with a technical potential of 216,000 GWh/year and economic potential of 127,381 GWh/year. The gross potential of 433,000 GWh/year in Turkey is 1% of the world's total potential, and about 16% of the total potential in Europe [1]. Gross potential represents the potential of available head and mean flow. Gross hydroelectric energy potential is a function of topography and hydrology. Technical potential shows the technological upper limit of hydroelectric energy production from a river basin. Depending on the applied technology, there are unavoidable losses from head, flow, and transformation. Economic potential shows the limit value of economic optimization of hydroelectric energy production in a river basin and defines the total production from hydroelectric projects including those technically possible to develop and economically viable [2].

II. ELECTRICITY CONSUMPTION IN TURKEY

In our country considering electricity consumption in the last forty years, there is fluctuation between 17% and -2% with an 8.4% mean increase on a yearly basis. The electricity use in Turkey can be gathered under seven main headings. These are electricity use in residences, in commercial enterprises, in government agencies, by industry, for agricultural irrigation, for lighting and other uses of electricity. In the last ten years the use of electricity in residences has varied between 22.5% and 25% with a mean level of 23.75%. Electricity in commercial enterprises has shown a consistent increase as a proportion of total electricity production from 9% to 19%. The mean value is 13.2%. The use of electricity by government agencies varied from 3.5% to 5% with a mean level of 4.33%. The use by industry as a proportion of total electricity consumption varied from 45% to 52.5% with a mean of 48.3%. In terms of electricity consumption by industry, the province of Kocaeli has the highest consumption. The use of electricity for agricultural irrigation varies from 2 to 3%. For agricultural irrigation, the highest electricity consumption occurs in Konya.

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In Rize the electricity consumption for agricultural irrigation is zero. Electricity used for lighting as a percentage of the total consumption reached 5% and then proportionally reduced to 2%.

Electricity consumption has a dynamic form, varying on an hourly, daily, monthly and yearly basis. After detailed research into this fluctuation, the electricity production amounts were identified on the basis of hours of the day. This study defines a dimensionless number to represent the distribution of electricity consumption on an hourly, monthly and yearly basis in a country. This number is called the ‘hourly electricity consumption coefficient (HECC). It is obtained by dividing the hourly or monthly electricity consumption amount by the mean hourly or monthly electricity consumption.

\[
\text{HECC} = \frac{E_{\text{act}}}{E_{\text{ave}}} \tag{1}
\]

In (1), the terms \(E_{\text{act}}\) and \(E_{\text{ave}}\) represent the actual and mean electricity consumption amount. In Turkey when data over many years are investigated, the variation of the monthly electricity consumption coefficient is presented in Fig. 1.

![Fig. 1. Variation of monthly electricity consumption coefficient for Turkey.](image)

When the distribution of electricity consumption in Turkey is investigated, the highest and lowest monthly electricity consumption occurs in August and May. The mean electricity consumption in August is above 14.7%. The mean electricity consumption in May is below 6.22%. Considering the 8760-hour duration within a year, on an hourly basis the electricity consumption coefficient varies between 0.56 and 1.39. Within a year, momentarily the HECC value may rise above 39%. The highest incidence of hourly electricity consumption coefficient is 1.06, representing 3.33% of the total. The variation in HECC value over a year is shown in Fig. 2.

As observed in Fig. 2, the lowest electricity consumption time is between 05:00 and 06:00. When evaluated on a yearly basis, the highest consumption rate is from 11:00 to 12:00. When hour evaluation is completed on a monthly basis, the highest and lowest electricity consumption times appear to change.

The highest and lowest electricity consumption times on a monthly basis are given in Table I.

![Fig. 2. Variation of hourly electricity consumption coefficient for Turkey.](image)

<table>
<thead>
<tr>
<th>Month</th>
<th>Maximum Average</th>
<th>Minimum Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>18:00 04:00</td>
<td>19:00 05:00</td>
</tr>
<tr>
<td>February</td>
<td>19:00 04:00</td>
<td>19:00 05:00</td>
</tr>
<tr>
<td>March</td>
<td>20:00 05:00</td>
<td>11:00 04:00</td>
</tr>
<tr>
<td>April</td>
<td>12:00 05:00</td>
<td>11:00 06:00</td>
</tr>
<tr>
<td>May</td>
<td>12:00 07:00</td>
<td>11:00 06:00</td>
</tr>
<tr>
<td>June</td>
<td>12:00 07:00</td>
<td>11:00 06:00</td>
</tr>
<tr>
<td>July</td>
<td>11:00 06:00</td>
<td>12:00 07:00</td>
</tr>
<tr>
<td>August</td>
<td>14:00 06:00</td>
<td>15:00 07:00</td>
</tr>
<tr>
<td>September</td>
<td>11:00 06:00</td>
<td>12:00 07:00</td>
</tr>
<tr>
<td>October</td>
<td>12:00 06:00</td>
<td>11:00 05:00</td>
</tr>
<tr>
<td>November</td>
<td>18:00 05:00</td>
<td>19:00 06:00</td>
</tr>
<tr>
<td>December</td>
<td>18:00 05:00</td>
<td>19:00 06:00</td>
</tr>
</tbody>
</table>

In August on Mondays from 14:00 to 15:00, the hourly mean electricity consumption may rise above 30%. As known the amount of electricity consumption within a month may change on certain days. The highest electricity consumption rate was on Monday. Whereas close consumption values were reached on days from Tuesday to Friday, they fell on Saturday to reach their lowest levels on Sunday.

III. SYSTEM DESCRIPTION

This study completed analyses for a hydroelectric power plant built in the Black Sea region. Due to trade limitations of the company, the company name and town are not given in the study.

The results of the study are given by reducing the system capacity to 1 MW. The hydroelectric power station examined uses two different Francis turbines on a horizontal axis. The energy and economic analysis period encompassed the years from 2006 to 2015 and from 1999 to 2015.

Measurements of the system included hourly electricity production, flow rate and dam lake height. When precipitation amounts and operating conditions are considered in a 10-year period, the mean capacity utilization rate was determined as 39.8%.
The variation in capacity utilization rate per year is given in Fig. 3. As observed in Fig. 3, the capacity use rate fluctuated between 29.4% and 49.2% yearly.

IV. SYSTEM ANALYSIS

During the time interval of the hydroelectric power plant analysis, electricity production efficiency was found to vary from 43% to 94% depending on working conditions. The two turbines in the system were named Turbine-I and Turbine-II. Turbine-I provided yearly mean of 86.35% energy efficiency with 5727 hours of electricity production. Turbine-I worked for 2886 hours (about 120 days) with 94% energy efficiency. Turbine-II provided 84% mean yearly energy efficiency with 2997 hours of electricity production. The 1 MW capacity systems produced 3496 MWh/year electricity on a yearly basis using 40.96 million m$^3$ of water from the dam.

The results of the investigation on an hourly basis are presented in Fig. 6. On an hourly basis the highest electricity production occurred between 18:00 and 19:00. The mean capacity utilization rate for this hour reached 62.8%. As observed in Fig. 6, the variation in hourly electricity production was between 3 and 6%. The lowest and highest electricity consumption occurred in the hours from 06:00 to 07:00 and 18:00 to 19:00. The increase in electricity consumption at nighttime increased the amount of electricity production as observed in the results of the study. In situations where water does not flow from rivers, the hydroelectric power station has the possibility to work at full capacity for 13 hours by completely draining the dam lake. The precipitation in the region falls as rain and snow. The snow falling on the mountains is stored in the winter. Though there is a reduction in the amount of precipitation in April, the melting snow increases the amount of water in the rivers. After June as the snow melts decreases there is a reduction in the amount of water in the rivers.

The monthly mean capacity use rate values are given in Fig. 5. In the period from January to May, the system capacity use rate increased on a monthly basis to reach 98.8%. In the period after June, the capacity use rate reduced reaching its lowest value of 14.8% in October. The total electricity produced in the months of April, May, and June provided 57% of the yearly electricity production from the hydroelectric power plant.

The variation in precipitation amount in the form of rain and snow at the 1 MW hydroelectric power plants is given in Fig. 7. On a monthly basis the amount of water flowing in the rivers varies between 2 and 9 million m$^3$/month.
V. ECONOMIC ANALYSIS

For economic analysis, costs were exchanged into dollars for calculations. To observe the situation of the dam investigated in our study in terms of Turkey’s other dams, the long-term electricity production amounts and capacities were noted and yearly mean capacity use rates were determined for 49 hydroelectric power stations linked to the Electricity Generation Company in Turkey (EUAŞ). At the end of our calculations, the capacity use rates varied from 49.4% to 7.5%. The mean capacity utilization rate for 49 hydroelectric power stations was identified as 23.8%. The power station we examined worked at capacity utilization rates well above this mean rate. Though it has a good capacity utilization rate, under real operating conditions with current trends, the time for the hydroelectric power plant to repay investment was calculated as 17 years (Fig. 8). The time for the system to repay investment is affected by the amount of precipitation, operating conditions and variations in dollar exchange rates.

VI. CONCLUSION

The basic conclusions obtained as a result of the study are listed below.

1. After analysis of the hydroelectric power station, the initial investment cost per kW was found to be 3300 US$/kW. According to 2010 data from the US Energy Information Administration [3], initial investment costs are predicted to be 3200 US$. We reached a close value with our calculations. As there are no fuel costs for hydroelectric power stations, the cost for this variable is accepted as zero. Calculations were made by adding labor and maintenance costs to the operating costs. The results of the calculations show that operating and maintenance costs vary from 18.8 to 34.3 US$/kW-year on a yearly basis with a mean of 25.5 US$/kW-year. Even in the best year, the 14.13 US$/kW-year value calculated by the US Energy Information Administration [3] was not reached.

2. The capacity utilization rates for 49 hydroelectric power stations linked to the Electricity Generation Company in Turkey (EUAŞ) were determined to vary from 49.4 to 7.5%. The mean capacity use rate for the 49 hydroelectric power stations was identified as 23.8%.

3. The return on investment period for the hydroelectric power plant analyzed was calculated as 17 years.

4. Investigations on an hourly basis showed highest electricity production occurred from 18:00 to 19:00. In this hourly period the capacity use rate reached a mean of 62.8%. Considering the precipitation amount and operating conditions in a 10-year period, mean capacity use rate was determined as 39.8%.
5. At the investigated power station the 1 MW capacity systems produced 3496 MWh/year electricity on a yearly basis using 40.96 million m$^3$ water from the dam.

6. When the variation in electricity consumption in Turkey is investigated, on a monthly basis the highest and lowest electricity consumption was in the months of August and May. The mean electricity consumption in August was above 14.7%, with mean electricity consumption in May below 6.22%.

CONFLICT OF INTEREST

Authors declare that they do not have any conflict of interest.

REFERENCES


Can Coskun is an Associate Professor of Mechanical Engineering at Izmir Democracy University, Turkey. He received BS (honors) in Mechanical Engineering from Cukurova University (CU), Turkey in 2005, M.S. from Balikesir University and a Ph.D. in mechanical engineering from Balikesir University in 2011 while he was working in Balikesir University. He worked as a research assistant in the Mechanical Engineering Department of Balikesir University from 2006 to 2011. Dr Coskun joined Recep Tayyip Erdogan University in 2011. He is a director of Izmir Democracy University Energy Studies Application and Research Center. His research has been involved with combustion systems, emissions, energy, exergy, exergoeconomic and exergoenvironmental analyses and assessments of energy-related systems, energy/exergy efficiency and management, ground-source heat pumps, utilization and potential of renewable energy sources and sustainable energy technologies. Dr Coskun is author and co-author of over 70 papers on national and international as well as several national and international books and book chapters. He has chaired and co-chaired many national and international conferences, symposia, workshops and technical meetings. He has served as a consultant for industry in cases involving his research area.

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