Feed-Water Repowering in Besat Power Plant: Technical and Costing Aspects

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Abstract: Repowering fossil fuel power plants has been considered to increase power output and reduce emissions at low cost and short outage periods. Besat is one of the oldest power plants in Iran which is located in south of Tehran. Besat net power output has been decreased about 19 percent, and its repowering is inevitable. As one of the most important parameters of repowering, size and type of the gas turbine is considered and Feedwater repowering schemes have been analyzed using thermodynamic simulations. The objective is evaluating the efficiency increase of the overall system, and also total power output. It seems that selection of gas turbine is directly dependent on the purpose of repowering. Results highlight the repowering as a suitable technology to reduce heat rate and increase total power output. It could help to increase power plant ability, in a short time and in a cost-effective manner.

Key-Words: Repowering, Feed-water heaters, Power plant, Heat rate, Gas turbine

1. Introduction
The country of Iran is experiencing in all fronts and areas and thus, consumption of electrical power is on the increase on a daily basis. Based on the ever-increasing electrical energy consumption, changes in generating system load requirements, lower allowable plant emissions and changes in fuel availability, steam power plants repowering has been investigated much more as a method for energy conservation. Considering the increased electrical energy consumption and annual growth rate of 4.5 percent[1] and according to the end of existing steam power plants life in Iran (like Besat power plant), repowering could be used as an economical method for increasing the output power with less investment than building a new power plant.

Repowering of steam power plant can be achieved in several ways. In a full repowering, several gas turbines (GT) and heat recovery steam generators (HRSG) are installed in a parallel arrangement dispensing with the conventional boiler. Live steam from HRSG is used in the original steam turbine. This is the best option to maximize the efficiency [3–6]. Repowered power plant efficiency could be 30–40% higher than the original and the power output could increase up to 200% [5, 7–10]. Hot wind box repowering implies a power plant redesign. GT exhaust gases are injected into the boiler and used as comburent [5, 8, and 11]. The reduction in oxygen content in the vitiated air, the elimination of air preheaters, and changes in flow patterns inside the boiler limit the efficiency improvement. An efficiency increase around 5–15% and power output 30–40% are the advantages of this option [7–9, 12]. Feedwater repowering takes advantage of the exhaust heat from the gas turbine to increase the feedwater temperature instead of bleeding steam. The effect of repowering, in this case, depends on the quantity of steam extractions eliminated, but power output could increase 30–40% and efficiency around 5–10% [7–9]. With parallel repowering a HRSG is used to raise extra live or reheated steam and drive the steam turbine. This is a suitable option with low level of modifications in the steam cycle. As mentioned above, the steam mass flow yield must be limited to avoid steam turbine redesign. It is possible to achieve a 20% of efficiency improvement and 20% of power output [4].
Considering the high cost of HRSG, many changes in existing power plant and also long outage period in different kinds of repowering, in this study only feedwater heater repowering has been investigated.

2. Case Study And Repowering Arrangements
Case study is a 3*82.5MWe net power output power plant with water cooling with mechanical draft cooling tower. Steam cycle is composed of two high-pressure and two low-pressure feedwater heaters and five steam extraction to feedwater heaters and deaerator. Steam production is 198.3 lb/s of live steam (1214Psia/940°C) without reheat. Power plant net efficiency is 30.75% based on LHV. In order to avoid any change in steam turbine, condenser-cooling system or generator, constraints include a limitation of steam mass flow rate augmentation and power output. Total power output has been limited to 82.5MWe, for each unit. In repowering, Fig. 1, high and low-pressure water heaters are substituted by different heat exchangers and gas turbine exhaust gases are used as heaters in the low- and high-pressure section of the Rankine cycle. The energy transferred from flue gases to steam cycle usually reduces the bleedings mass flows and increase the power production at steam turbines between 4% and 6% for low-pressure feedwater heaters and 12–16% for high-pressure feedwater heaters [11]. Therefore, the main variable for this configuration is the flue gas energy distribution between the low and high-pressure section of the steam cycle. Nevertheless, deaerator pressure limits this distribution.

Fig 1. Schematic of Feedwater Heater Repowering of Besat Power Plant
3. system modeling
The thermodynamic model is based on existing power plant and integration of heat rejected by the gas turbine. This energy is integrated into the original steam cycle. Feedwater repowering scheme presented above have been analyzed using Thermoflow simulation software, and heat exchangers are simulated with mass and energy balances and with a constant minimum temperature difference of 20°C for high and low-pressure heaters. Once the exhaust gas temperature at exit is higher than 120 °C, the reduction in steam bleeding and the effect in steam turbine performance is calculated. Each component is simulated by thermodynamic relations, mass and energy balances. Heat rejected by the gas turbine is integrated in the original steam cycle reducing the existing boiler load and calculating the modified live steam mass flow and bleedings conditions. Condenser pressure has been considered constant in 1.228 Psia.

3.1. Site Condition
In this study, the site conditions have been obtained by Tehran synoptic stations information. These conditions include:
Ambient temperature: 18.1 °C, altitude: 1100 m, Atmospheric pressure: 0.889 bar relative humidity: 41% [2].

3.2. Gas Turbine Model
In the 6 old combined cycle power plants in Iran that are known to 6C.C (combined cycle), gas turbine model GE 9171 E is used. Nominal capacity of them is 2 * 123.4 MW (gas turbine) and 100 MW (steam turbine). In the 22 new combined cycle power plants benefit from the Siemens V94.2, the Nominal capacity for most of them including 2*158.9 MW (gas turbine) and 130 MW (steam turbine). Therefore, this study model turbines GE 9171 E and V94.2 as a common units in Iran and Siemens SGT-900 turbine for adjusting gas and steam power output. Gas turbines simulation has been carried out with manufacturer data and GT are supplied in nominal power outputs. Correction curves for the various ambient and installations for the compressor and gas turbine behavior have been used to find the actual performance.

4. The Effect of Failure in Heaters on Efficiency and Net Output Power Plant
Although several factors can reduce net power output and increase heat rate, but it seems one of the most important factors is feed water heaters failure and removing them from the circuit. In the following chart the effect of by-passing low and high pressure heaters has been investigated. In the right side of Fig. 2, effects of low pressure heater, and in the left side, effects of high pressure are given. As is noted, net power output reduction in the high pressure heater by-passing is significantly more than by-passing of low pressure heaters because of using steam in higher temperature.
Table 1. Results of Repowering with Different Gas Turbines

<table>
<thead>
<tr>
<th>Case No.</th>
<th>GT type</th>
<th>LPH</th>
<th>HPH</th>
<th>Net ST power output(kW)</th>
<th>Net GT power output(kW)</th>
<th>Heat rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>V94.2</td>
<td>-</td>
<td>ü</td>
<td>82500</td>
<td>140838</td>
<td>10970</td>
</tr>
<tr>
<td>2</td>
<td>V94.2</td>
<td>ü</td>
<td>ü</td>
<td>82501</td>
<td>141693</td>
<td>10890</td>
</tr>
<tr>
<td>3</td>
<td>GE 9171 E</td>
<td>ü</td>
<td>-</td>
<td>82501</td>
<td>105482</td>
<td>11127</td>
</tr>
<tr>
<td>4</td>
<td>GE 9171 E</td>
<td>ü</td>
<td>ü</td>
<td>82500</td>
<td>105472</td>
<td>11072</td>
</tr>
<tr>
<td>5</td>
<td>SGT-900</td>
<td>ü</td>
<td>ü</td>
<td>82500</td>
<td>31727</td>
<td>10446</td>
</tr>
</tbody>
</table>

1 Low Pressure Heaters
2 High Pressure Heaters
3 Stack Exit Temperature
4 Higher Heating Value (BTU/kWh)
5 Lower Heating Value (BTU/kWh)

5. Results and Discussion

In the Tab.1, the results of repowering with different gas turbines are shown and for every case, gas turbine power, steam turbine power, heat rate and gas turbine stack exit temperature are given. In the first case and the third only low pressure heaters have been replaced and in other cases we replaced all the low and high-pressure heaters with new heat exchangers. For better comparison, total power output and heat rate of different cases are compared in the Fig.3 and Fig.4:

For comparison, total power output and heat rate of different cases are compared in the Fig.3 and Fig.4:

Fig 3. Comparison of Site Net Power With Different Scenarios

As in the Fig.3 is clear in all cases, steam turbine has been reached the nominal output value and gas turbine exhaust is able to supply steam turbine in design conditions. If the priority of repowering is maximum power output increase, it seems repowering with gas turbine V94.2 will be more prominent. In comparison case 1 with 2 and 3 with 4 we find by-passing all heaters is more important than by-passing only high pressure heaters, because using more exhaust energy and reducing its temperature, overall cycle efficiency is increased. Comparing all the different scenarios of heat rate, significant differences will be determined by the fifth case, and heat rate about 10 percent will be reduced.

Fig 4. Comparison of Heat Rate with Different Scenarios

6. Economical Calculation

Tehran province has 13% of the total nominal power in Iran but its electricity consumption is 19% of total electricity production and in 2008 has had 300000MWh electricity shortage so it seems logical that the highest amount of gas turbine power and the maximum working time be considered.

Since the main purpose is to compare repowering cases and existing steam cycle is the same in all cases, similar costs have been removed (for example: the existing boiler fuel).

The fuel used for the gas turbine is natural gas and the average heat value of the natural gas [1] is 39 MJ/m³. In Iran natural gas and electricity prices are typically lower because of subsidies. Two cases are investigated: Iran prices (Natural gas price: 1 cent/m³, Electricity price: 2.9 cent/kWh)[1], international prices (Natural gas price: 14.5 cent/m³ assuming oil
price 50US$/barrel, Electricity price: 8cent/kWh[13].
The costs of the project are divided into two categories: investment and annual costs. The income of the project is based solely on the sale of electrical energy.

6.1. Input-Assumptions
The assumptions refer to the input data used in the Thermoflow software as well as the investments in the new equipment and gas turbine and economical assumption refer to central bank of Iran as the following table shows.

<table>
<thead>
<tr>
<th>Table 2. Input-Assumptions</th>
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<tbody>
<tr>
<td>Project life in years</td>
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<tr>
<td>Operating hours per year (full-load equivalent)</td>
</tr>
<tr>
<td>Straight line depreciation life in years</td>
</tr>
<tr>
<td>Depreciable percentage of total investment</td>
</tr>
<tr>
<td>Debt term in years</td>
</tr>
<tr>
<td>Debt percentage of total investment</td>
</tr>
<tr>
<td>Debt interest rate</td>
</tr>
<tr>
<td>Overall tax rate</td>
</tr>
<tr>
<td>Fixed O&amp;M costs, USD per net kW of capacity per year</td>
</tr>
<tr>
<td>Variable O&amp;M costs, USD per kWh</td>
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<tr>
<td>Annual inflation rate</td>
</tr>
</tbody>
</table>

The Thermoflow software calculates the annual income and cost of the plant and this value is used as input in an Excel file to calculate the cumulative net cash flow and rate of return of the investments in the gas turbine. It should be mentioned that cases 2, 4 and 5 referring to Tab. 1, with different prices have been investigated. In the Tab. 3, the economical results of repowering with different gas turbines are shown.

<table>
<thead>
<tr>
<th>Table 3. The Economical Result of Repowering</th>
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<tbody>
<tr>
<td>Price mode</td>
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<tr>
<td>----------------------------------------</td>
</tr>
<tr>
<td>International price</td>
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<td>International price</td>
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<td>International price</td>
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<tr>
<td>International price</td>
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</tbody>
</table>

*: include gas turbine ,transmission and generating package, civil, engineering and plant start up, building, electrical assembly and wiring, mechanical and other equipment.
**: Internal Rate of Return

7. Conclusions
This paper analyses the concept for repowering of steam cycles with gas turbines. An optimization problem for feedwater repowering of existing power plant considering the effect of gas turbine on overall output and heat rate has been achieved. One of the main conclusions of this work is that repowering of the case study is necessary, and replacement of all heaters with new heat exchangers is more suitable for feedwater repowering. With considering the maximum output increase as the main goal, repowering with turbine V94.2 and for heat rate priority turbine SGT 900 is recommended.

Also the capital cost of one kWe engine including installation and the additional equipment needed is between 463 to 763 USD and it is reduced for bigger engines. As the results especially ROR shows, repowering benefit with international prices of natural gas and electricity will be more prominent. It should be mentioned that repowering with turbine SGT-900 has no economic justification because its rate of return is under the interest rate.

8 References
of repowering steam power plants, GE Industrial & Power Systems.


