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Repowering as a Competitive Technology for Upgrading the Existing Power Plants

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Abstract: The growth of the electrical energy consumption form one side and the bounded available fossil fuel and other limitations from the other side, makes the thermal power plants upgrading as a main demand in the world. Decreasing the internal energy consumption, increasing the performance and the output power with the minimum costs are the important targets of the power plants retrofitting. Nowadays power plant repowering with the help of gas turbine that includes two manners (Full Repowering and Para-Repowering) is one of the best methods for the power plants progress. Different repowering methods according to their costs, amount of the output power increase and the power plant situation could be various solutions for the retrofitting. Choosing each of these methods can be done just by analyzing the related parameters. Technical and economic comparisons between different repowering methods needs an investigation of several technical and economic parameters and the characteristics of the electrical networks development as well. Combined cycling/cycles as a repowering method usually is used for low capacity units and for the bigger units para repowering could be more suitable. Feasibility study for repowering a power plant and choosing the best method should be done through a case study for that specific power plant. In this paper using different para-repowering methods has been studied for the Lowshan power plant. The results show that feed water heating repowering is the best method based on the cost of electrical energy generation in this case.

Keywords: Repowering, Hot Windbox, Feed Water Heater, Gas Turbine

1. Introduction

Repowering the existing fossil steam generating units with gas turbines and combined cycles or with other new technology options is emerging as a centerpiece of competitive corporate strategies aimed at transforming relatively unproductive assets into more efficient, low - cost producers.

A repowering strategy can simultaneously address load growth, environmental compliance and technological obsolescence. Using already established sites and existing facilities can help repowering projects substantial cost savings (20-40%) over new construction at a green-field site and offers environmental permitting and other advantages as well. As a result, repowering is expected to account for a major share of increase in generating capacity over the next decade [1, 2]. In this paper the possibility of using different repowering methods for Lowshan Power Plant has been studied and besides the introduction of each method and its technical limitations, the thermal cycle has been redesigned. With the identification of the components and their characteristics and the cycle calculation; the results have been given as an economic assessment based on the total net cost for the electrical energy generation. At last, analyzing all the results and important parameters will give the preference of using each method according to their preliminary aims.

2. Para-Repowering methods

There are several different options for repowering existing plants with gas turbines. A choice for one of the repowering options is based on the size and the technical condition of the existing plants (i.e., the remnant life) on one side and typical needs of the utility

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on the other side in repowering existing plants. The size and the quality of the existing boiler and steam turbine (Fig. 1) determine the main choice [3]. An overview of the different options of repowering is given in Table 1.

In general, existing power plants with the capacity range of 50MW to 200 MW are the most suitable plants for repowering with a gas turbine and a new heat recovery steam generator which delivers the steam to the existing steam turbine. The required gas turbine size is roughly twice the size of the steam turbine and therefore the power increase for this option is very high (200%) [4].

2.1. Feed water repowering

To explain this option, an existing power plant that has the capability of being repowered by performing a repowering project, has been selected. Lowshan power plant is located in Manjil and includes a steam and gas cycle. The capacity of existing boiler is 120 MW and steam enters steam turbine in 530 ˚C and 121 atm. The available energy of the gas turbine flue gases is sufficient for the good performance of Feed Water Heating Repowering and there is no need to purchase any additional gas turbines. Fig. 2 shows the schematic of Lowshan steam cycle before repowering.

In this option, turbine extractions are eliminated and two new gas-liquid heat exchangers are designed in order to use the energy of the gas turbine flue gases to heat feed water that enters the boiler.

This model could be executed in different ways as steam turbine has six extractions, which deliver steam to feed water heaters and deaerator. Due to the elimination of turbine extractions, more steam will pass through the turbine blades and therefore the output power will increase. The most applicable methods are discussed below:

A) Elimination of all extractions except the one which delivers steam to the deaerator. Fig. 3 shows the schematic of this method. As shown, feed water leaving condenser passes through the low-pressure gas-liquid heat exchanger and then enters the deaerator. In high-pressure gas-liquid heat exchanger, feed water leaving deaerator is heated up to 229 ˚C and then enters the boiler. In these heat exchangers hot fluid is flue gas from gas turbine. For this option, the power raise reaches 17% of nominal capacity.

B) Elimination of the high-pressure turbine extractions except the one which delivers steam to the deaerator. The schematic of this method is shown in Fig. 4. Feed water that leaves condenser passes through low-pressure heaters and then enters the deaerator. High-pressure gas-liquid heat exchanger heats feed water up to 229 ˚C after leaving the deaerator before it enters the boiler.

In this option power increase is about 10% of the nominal capacity. Table 2 shows the characteristics of the required heat exchangers for both A and B methods.

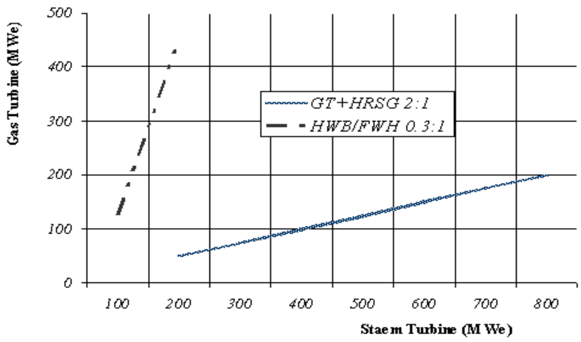

Fig. 1. Capacity of the gas turbine vs. capacity of the steam turbine for different repowering options.

Table 1. An overview of different options of repowering

Option	Description	Power Increase %	Efficiency Improvement %-point	Limiting Factor	Investment % 1	NO_x Decrease % 2	Outage Time months
A	Combined Cycle (GT+HRSG)	200	12	-	70-85	50-80	12-18
B	hot windbox (HWB)	15-30	3-6	Boiler	20-30	50-80	8
C	Suppl.Boiler+ windbox (SB+WB)	10-30	3-6	Boiler	20-30	40-60	8
D	Feed Water Heating (FWH)	10-30	2-5	Steam Turbine	15-20	10-20	2
E	IP-Steam Repowering	10-30	2-5	SteamTurbine	15-20	10-20	2

1) Relative investment compared to investment for a new combined cycle of the same capacity
2) Relative decrease of NOx-emissions of total plant after repowering

Table 2. Characteristics of heat exchangers

Properties	Low-Pressure HE		High-Pressure HE*	
	Shell Side	Tube Side	Shell Side	Tube Side
Fluid Type	Flue Gas	Feed Water	Flue Gas	Feed Water
Operating Press. (bar)	1	4	1	30
In/Out Temp. (°C)	430/190	60/120.7	430/250	186.5/188.8
Allowable Press. Drop (bar)	0.4	3 × 0.7	0.4	3 × 0.7
Fluid Flow-Rate (kg/hr)	343437	395026	412174	438414

* The characteristics of high-pressure heat exchanger for both options (A) and (B) are the same

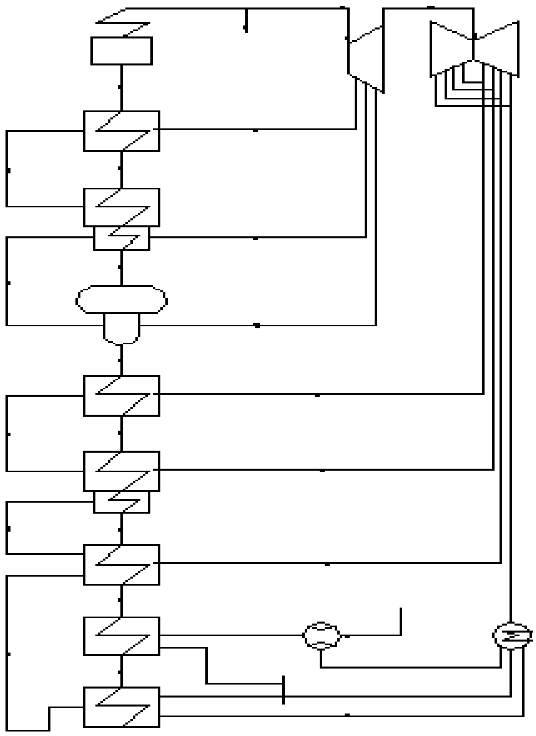

Fig. 2. Schematic of Lowshan steam cycle before repowering.

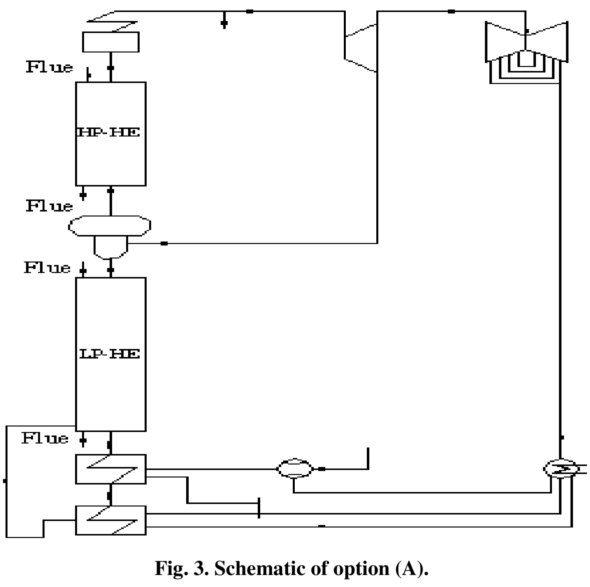

Fig. 3. Schematic of option (A).

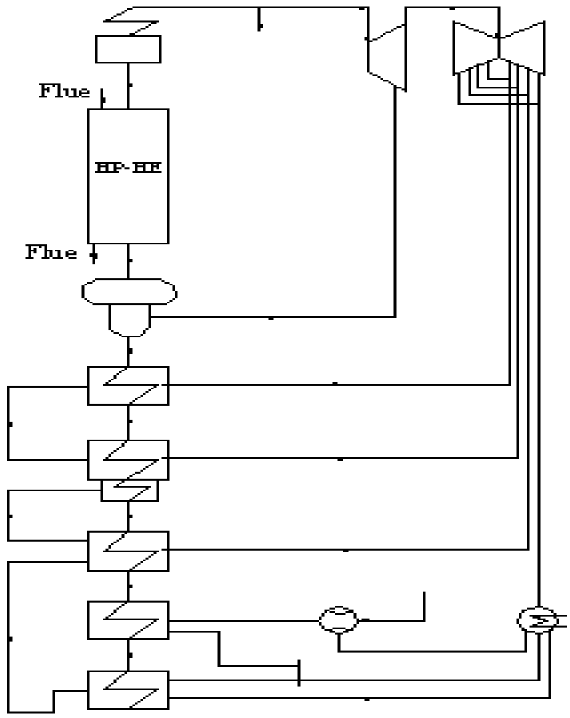

Fig. 4. Schematic of option (B).

A. Plant restriction for FW repowering

Elimination of turbine extractions causes an increase in steam passing rate through the turbine blades and as a result the amount of water in the condenser may exceed the allowable limit (20- 25% of nominal load). Also there is a restriction for steam passing rate through turbine blades, which should not be more than 20% of the nominal load. In option (A), the amount of condensed water is about 422 ton/hr, which is 18% more than nominal load. But as it is still less than 20% of the nominal load, no technical problem will happen for the condenser.

The increase in steam passing rate through turbine blades is from 19% in high-pressure cylinder to 41% in low-pressure one. Therefore these cylinders will have technical problems.

Table 3. Feed water flow rate and enthalpy of water and steam for methods (a) and (b)

Properties	Option (A)		Option (B)	
	Fluid Flow-Rate (kg/hr)	Enthalpy (kJ/kg)	Fluid Flow Rate (kg/hr)	Enthalpy (KJ/kg)
Main Steam	437789	342.11	437938	342.12
Extraction to 2nd HP Heater	-	-	-	-
Extraction to 1st HP Heater	-	-	-	-
Extraction to Condenser	15292	2683	24265	2664
Extraction to 3rd LP Heater	-	-	19190	2559
Extraction to 2nd LP Heater	-	-	23617	2445
Extraction to 1st LP Heater	-	-	21136	2288
Steam Leaving LP Turbine	422498	2118.19	349987	2096
Output Power (MW)	140		132	
Power Increase (MW)	20		12	

Feed water flow rate and enthalpy of water and steam for both methods are shown in Table 3.

In option (B), the increase of the water flow rate in the condenser is about 14 % of the nominal load (349 ton/hr), which is less than 20 %.

Steam raise in turbine cylinders is from 14% in high-pressure cylinder to 16 % in low-pressure turbine. Therefore performing this option consists of no basic changes in the cycle and this option could be considered as a suitable method for feed water heating repowering.

B. Economic evaluation for FW repowering

Always an economic evaluation of a repowering option is needed in order to define specifications of the plant utilities. The improvements are:

Heat rate and NO_x emission decrease, capacity increase [1].

For a specified repowering project, most of the following repowering parameters have to be defined. These parameters are plant heat-rate, plant emission before and after repowering, plant capacity, plant dispatch, plant availability, plant O & M cost, total investment cost and total time for non-availability during the modification. The economic evaluation has been done with the following assumptions:

Fuel price 2.5 $/GJ, NO_x value 1000 $/ton, interest rate 8%, O&M cost 1.5 $/kWh for steam cycle and 3 $/kWh for combined cycle and full repowering option [3, 6]. The results of the economic evaluation for option (B) are shown in Table 4.

2.2. Hot windbox repowering

Repowering an existing unit using hot windbox (WHB) repowering could be considered as an option with the following advantages:

Table 4. Economic evaluation for option (B)

Properties	Option B
Efficiency (%)	35
Investment cost (USD/kW)	44.3
O&M cost (¢/kWh)	1.5
Present Worth (¢/kWh)	0.56
Total investment (MMUSD)	48.68
Investment rate (¢/kWh)	0.46
Fuel cost (¢/kWh)	1.8
Total generating cost (¢/kWh)	3.76
Power increase (MW)	12

Efficiency increases in the unit capacity and a better adaptation with the environmental laws. Technical restrictions of the unit and the boiler conditions must be taken into account before choosing a gas turbine. In this option the capacity of the suitable gas turbine is roughly twice the capacity of steam turbine. Power raise for this option could be between 20MW to 30MW higher than the present capacity. In HWB repowering, the gas turbine flue gases could be used as a source of oxygen to improve combustion in boiler. Lowshan's boiler information is shown in Table 5. The first problem is due to a change in oxygen-fuel flow ratio, which depends on both air and flue gas from gas turbine.

Therefore it could be equal or more than oxygen-fuel ratio in design condition [1].

$$\frac{m_{o2}}{m_{fuel}} = \frac{m_{o2,Design}}{m_{fuel,design}} \tag{1}$$

If we consider φ and F as air and fuel ratios respectively:

$$\phi = \frac{m_{air}}{m_{air,design}}, F = \frac{m_{fuel}}{m_{fuel,design}} \tag{2}$$

Then minimum required flue gas could be calculated by the following equation:

$$m_{g.min} = \frac{m_{o2,Design} \times a \times (F - \phi)}{b} \quad (3)$$

"b" remains constant while the composition of flue gas does not change. Considering that steam flow-rate must not exceed 120% of the design condition, maximum allowable flue gas flow-rate could be calculated. This restriction could be explained by the following equations:

$$m_{air} + m_g + m_{fuel} \leq 1.2(m_{air.D} + m_{fuel,D}) \quad (4)$$

or

$$m_{g,max} = \frac{m_{air,D}}{m_{fuel,D}}(1.2 - \phi) + 1.2 - F \quad (5)$$

Furnace analysis and heat transfer calculations would be the first step. Adiabatic flame temperature will change due to utilization of combustion products instead of combustion air. The change in adiabatic flame temperature is negligible while the difference in the flue gas temperature leaving furnace is large comparing to the one for the present conditions of the boiler. These changes are due to the changes that take place in radiation flux, temperature profile and flow of combustion products.

For the consideration of the volume and temperature raise of the combustion products that leave the furnace, the mass velocity and the metal temperature in the heating surface area must be calculated. Performing Hot windbox Repowering could consist of changes in tube arrangement for heating surface area

Table 5. Boiler characteristics for Lowshan power plant [6]

Properties (Unit)	Amount
Maximum Steam Flow-Rate (Kg/hr)	490000
Minimum Steam Flow-Rate (kg/hr)	110000
Design Pressure (bar)	147
HP Output Pressure (bar)	126
Drum pressure (bar)	143
Steam Output Temperature (°C)	535
Feed Water Temperature (°C)	280
Economizer Output Temperature (oil/gas) (°C)	275/285
Fuel Properties	
Fuel Flow-Rate in Load of 100% (kg/hr)	30112
Gas Flow-Rate in Load of 100% (Nm^3 / hr)	34412
Combustion Properties	
Air Temperature Entering Burner (°C)	290
Air Flow-Rate Entering Burner (oil/gas) (Kg/hr)	487793/341064
Fan Output Pressure (mmWC)	810
Air Temperature Entering Fan (°C)	27
Flue Gas Temperature Leaving Economizer (°C)	295/307

and also additional surface in economizer. Using a cooler to decrease flue gas temperature before entering the boiler could also be expected. Heat transfer calculation in the furnace and in the heating surface area has been done because of the determination of the temperature profile, heat flux in the furnace and the circulation rate for three following conditions. The results are shown in Table 6.

Option B, required extra heat is about 122×10^6 kJ/hr while the available heat in flue gas is about 113×10^6 kJ/hr. Therefore the presence of a duct burner would be necessary in boiler. In option C, lowering of fuel consumption caused by using available energy of flue gas, is the main purpose. In both options B and C FD Fan would be eliminated. Due to radiation decrease in the furnace, temperature of the flue gases that leave the furnace increases and therefore the metal temperature calculation for the heating surface area for option B is necessary in order to avoid increasing in local temperatures. In lowering in the heat absorption inside furnace causes higher flue gas temperature in the heating surface area and therefore having a larger economizer is necessary in order to have more energy absorption inside the boiler and also avoid high temperatures in the stack. The required additional surface in the economizer is shown in Table 6. As it was determined, in option B more additional surface is required. The raise in steam generation up to 50 ton/hr in the boiler causes 9 to 10 MW increase in output power.

The most important parameters for the quantitative evaluation of the improvements are fuel cost, interest rate, capacity increase, NO_x emission decrease, additional power and cost of the outage time during the project performing.

Total generation cost could be considered as a basic parameter in order to compare different options. Eq. 6 is used to calculate power generation cost for a HWB Repowering project [7]. Table 7 shows total generation cost for option B and C using different economical parameters.

$$C_u = (R_l C_t + M + C_f)/W \quad (6)$$

$$W = K_F \times Cap \times n_y$$

Table 6. Boiler parameters for options (a) to (c)

Parameter	Option A	Option B	Option C
Fuel flow-rate (kg/hr)	30112	31316	26000
Air flow-rate (kg/hr)	341064	-	-
Flue gas flow rate (kg/hr)	-	576×10^3	483×10^3
Adiabatic temperature of flue gas (°C)	2100	2150	1050
Flue gas temperature Leaving furnace (°C)	960	1050	1030
Heat absorption in Furnace (kW)	195000	185250	175500
Flue gas temperature leaving heating surface area (°C)	580	610	600
Heat absorption in heating surface area (kW)	105000	145000	124500
Flue gas temperature leaving economizer (°C)	280	280	280
Additional required surface in economizer to obtain desired output temperature (%)	--	25	15

A) Nominal cycle load (440 ton/hr).
B) Maximum boiler loads (490 ton/hr and introducing 576 ton/hr of the flue gas from the gas turbine to the boiler).
C) Operation of boiler in 440-ton/hr load, decrease in fuel consumption. And it introduces 576 ton/hr of flue gas to boiler.

Table 7. Total generation cost for options (b) and (c) using different economical parameters

Item	1	2	3	4	5	6	7	8	9	10	11	12
Interest rate	10	10	10	10	12	12	12	12	14	14	14	14
Fuel cost ($/GL)	2.5	2.5	3	3	2.5	2.5	3	3	2.5	2.5	3	3
Unit life (year)	15	20	15	20	15	20	15	20	15	20	15	20
Option B	4.7	4.68	5.1	5	4.82	4.75	5.21	5.18	4.92	4.8	5.21	5.22
Option A	4.65	4.62	4.95	4.9	4.85	4.8	5.15	5.14	5	4.85	5.12	5.14

Where:

C_u : Total generation cost
C_t : Total investment cost
C_f : Flue cost
M : Operation and maintenance cost
R_l : Pay back rate
W : Energy generation per year
K_f : Capacity coefficient
Cap : Unit nominal capacity
n_y : Operation hours of plant in a year

3. Conclusions

For repowering an existing plant, the final choice depends on unit capacity, energy, plant remained life and environmental concerns. Although based on the capacity, the complete repowering method could be the best way (technically and economically) for the power plant upgrading, according to the pre-invest as a pre-assumption for the economic and technical studies and investigations of the para-repowering methods for the Lowshan power plant, Feed Water Heating Repowering is a more suitable method for the plant optimization compared to hot windbox repowering. Also, HWB Repowering is not a suitable method for the Lowshan power plant due to its complexity and economic concerns. In all repowering projects by gas turbine, power increases from 8 to 12 percent and the decrease in fuel consumption is also in the same range.

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