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Repowering of Lowshan Power Plant

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ABSTRACT

Nowadays, repowering is considered as the most common methods for improving status of current power plants. Each methods of repowering from "para repowering" to "full repowering" shall probably be the best choice for special national and economical power plant. In this paper different repowering methods have been introduced. Moreover, application of those methods were investigated for Lowshan power plant. Technical calculation including parts designing as well as calculations concerning to heat cycle changes have been done for each methods.

Additionally, by paying attention to the technical limitations an economical study have been performed for comparing the said two methods.

INTRODUCTION

Repowering 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 for 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 give 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 the increase in generating capacity over the next decade. (taylor, 1998)

Table 1- An overview of the different options of repowering

Option	Description	Power Increase %	Efficiency Improvement %-point	Limiting Factor	Invest-ment % [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	Steam Turbine	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

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 plant (i.e. the remnant life) on one side and typical needs of the utility. 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.(Ploumen, Veenema, 1996)

An overview of the different options of repowering is given in table 1.

In general existing power plants in the size between 50 and 200 MW are most suitable 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%).

FEED WATER REPOWERING

Lowshan steam power plant was selected as a case study in order to repowering methods application investigation.

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 to steam turbine in 530 °C and 121 atm.

The available energy of gas turbine flue gas is sufficient for Feed Water Heating Repowering and there is no need to purchase the additional gas turbines. Figure 2 shows a 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 energy of flue gas caused by gas turbine to heat feed water-entering boiler.

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This option could be executed in different ways as steam turbine has six extractions, which deliver steam to feed water heaters and deaerator. Due to elimination of turbine extractions, more steam will pass through the turbine blades and therefore the output power will increase.

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				

The most applicable methods are discussed below:

A) Elimination of all extractions save the one that delivers steam to deaerator.

Figure 3 shows a schematic of this method.

As shown, feed water leaving condenser passes through the low-pressure gas-liquid heat exchanger and then enters to deaerator. In high-pressure gas-liquid heat exchanger, feed water leaving deaerator is heated up to 229 °C and then lead to boiler.

In these heat exchangers hot fluid is flue gas from gas turbine. For this option, increase in power reaches to 17% of nominal capacity.

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	

B) Elimination of high-pressure turbine extractions saves deaerator extraction.

A schematic of this method is shown in figure 4.

Feed water leaving condenser passes through low-pressure heaters and then enters to deaerator. High-pressure gas-liquid heat exchanger, heats feed water leaving deaerator up to 229 °C before it enters boiler.

In this option power increase is about 10% of nominal capacity.

Table 2 shows the characteristics of required hat exchangers for both A and B methods.

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

Plant Restriction for FW Repowering

Elimination of turbine extraction causes an increase in steam passing rate through the turbine blades and as a result the amount of water in the condenser may exceed from permissible limit (20- 25% of nominal load).

Also there is a restriction for steam passing rate through turbine blades , which should not exceed 20% of 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 nominal load, it consists of no technical problem for condenser. Increase of 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.

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

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

Economic Evaluation for FW Repowering

In order to defining specifications of the plant utilities. Always requires for economic evaluation of a repowering option.

The improvements are:

Decrease in heat – rate, NOx – emission decrease and capacity increase. (Bazzini, 1992)

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 modification.

The economic evaluation is done with the following assumptions: Fuel price 2.5 $/GJ, NOx 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. (Liudy etal, 2001)

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

The economic evaluation has been done for option (B) and the results are shown in table 4.

HOT WINDBOX REPOWERING

Repowering an existing unit using Hot Windbox repowering could be considered as an option with the following advantages: increase in unit capacity efficient and better based on environmental laws. Technical restrictions of the unit and 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 increase for this option could be between 20 to 30 higher than the present capacity. In HWB repowering the flue gas exiting gas turbine 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 change in Oxygen to fuel flow-ratio, which is depended on both air and flue gas from gas turbine.

Therefore it could be equal or more than Oxygen to fuel ratio in design condition(Ploumen and Veenema,1996)

$$\frac{{}^{m}O_2}{{}^{m}fuel} \geq \frac{{}^{m}O_2, Design}{{}^{m}fuel, Design} \qquad (1)$$

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

$$\phi = \frac{{}^{m}air}{{}^{m}air, Design}; F = \frac{{}^{m}fuel}{{}^{m}fuel, Design} \qquad (2)$$

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

$$m_{g,\min} = \frac{m_{O_2},_{Design} \times a \times (F - \phi)}{b} \qquad (3)$$

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

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

or

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

Furnace analysis and heat transfer calculations would be the first step. Adiabatic flame temperature will be changed 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 present conditions of boiler. Due to some change in radiation flux, temprature profile and combustion products flow, the above-mentioned changes occur.

Considering the increase in combustion product's volume and temperature leaving furnace, mass velocity and metal temperature in heating surface area must be calculated Hot Wind box repowering method need to make som changes in size and arrangement of heating surfaces.

Heat transfer calculation in furnace and heating surface area is done because of determined temperature profile, heat flux in furnace and circulation rate for three following conditions.

The results are shown in table 6.

A: Nominal cycle load (440 ton/hr)

B: Maximum boiler loads (490 ton/hr and introducing 576 ton/hr of flue gas from gas turbine to boiler)

C: Operation of boiler decrease in 440-ton/hr load, in fuel consumption. And it introducing 576 ton/hr of flue gas to boiler in $430^{\circ} C$ in 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 presence of a duct burner would be necessary in boiler.

In option C, decrease of fuel consumption by using available energy of flue gas, is the main purpose. In both options B and C, FD Fan will be eliminated. Due to radiation decrease in furnace, flue gas temperature leaning furnace is increased and therefore metal temperature calculations in heating surface area for option B are necessary in order to avoid increase in local temperatures. Decrease in heat absorption inside furnace causes higher flue gas temperature in heating surface area and therefore having a larger economizer is necessary in order to have more energy absorption inside boiler and also avoid high temperatures in stack. Required additional surface in economizer is shown in table 6. as determined in option B more additional surface is required.

Increase in steam generation up to 50 ton/hr in boiler causes 9 to 10 MW increase in output power.

The most important parameters to quantitative evaluation of the improvements are flue cost, interest rate, capacity increase, Nox emissions decrease, additional power and cost of outage time during performing the project.

Total generation cost could be considered as a basic parameter in order to compare different options Equation 6 is used to calculate power generation cost for a HWB repowering project: (Werner etal, 1999)

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

Table 5- Boiler characteristics for lowshan power plant [3]

Properties (Unit)	**Amount**
Maximum Steam Flow-Rate (Kg/hr)	490000
Minimum Steam Flow-Rate (kg/hr)	110000
Design Pressure (bar)	147
HP Output Pressure	126
Drum pressure (bar)	143
Steam Output Temperature (^0C)	535
Feed Water Temperature (^0C)	280
Economizer Output Temperature (oil/gas) (^0C)	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 (^0C)	290
Air Flow-Rate Entering Burner (oil/gas) (Kg/hr)	487793/341064
Fan Output Pressure (mmWC)	810
Air Temperature Entering Fan (^0C)	27
Flue G as Temperature Leaving Economizer (^0C)	295/307

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

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 n per year

K_F : Capacity coefficient

Cap: Unit nominal capacity

Table 7- Total generation cost for option B and C using different economic 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

n_y : Operation hours of plant in a year

Table7 show total generation cost for option B and C using different economic parameters

CONCLUSION

For repowering an existing plant the final choice depends on unit capacity, energy, plant remained life and environmental concerns. Economic evaluation shows that full repowering is the most suitable option for Lowshan power plant. Considering total generation cost and the fact that gas turbine already exists, Feed Water heating repowering and Hot Windbox repowering sre the least suitable methods, respectively. Especially HWB repowering is the least suitable method for Lowshan power plant due to complication of method and economic concerns. In all repowering projects by gas turbine power increase from 8 to 12 percent and decrease in fuel consumption is also at the same range.

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 (${}^0C$)	2100	2150	1050
Flue gas temperature Leaving furnace(${}^0C$)	960	1050	1030
Heat absorption in Furnace(kW)	195000	185250	175500
Flue gas temperature leaving heating surface area(${}^0C$)	580	610	600
Heat absorption in heating surface area (kW)	105000	145000	124500
Flue gas temperature leaving economizer(${}^0C$)	280	280	280
Additional required surface in economizer to obtain desired output temperature (%)	--	25	15

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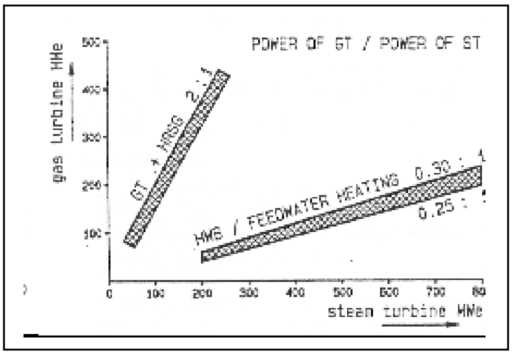

Figure 1- Capacity of gas turbine vs. capacity of steam turbine for different repowering options

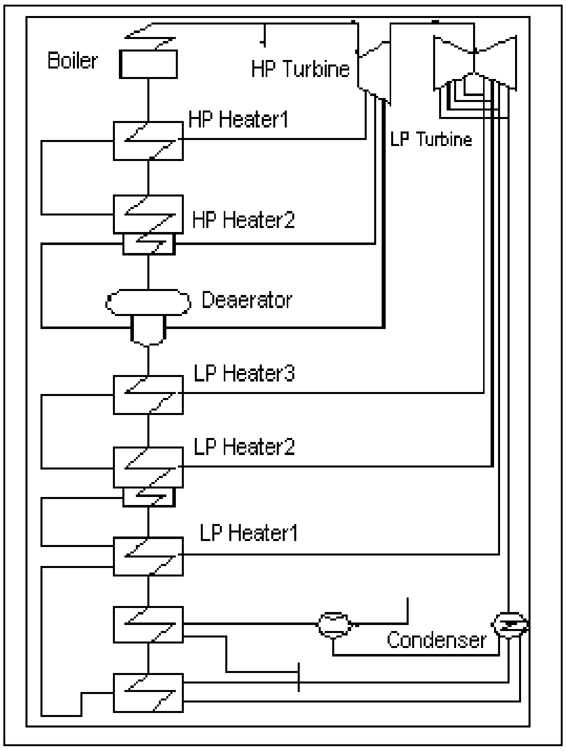

Fig 2- Schematic of main cycle

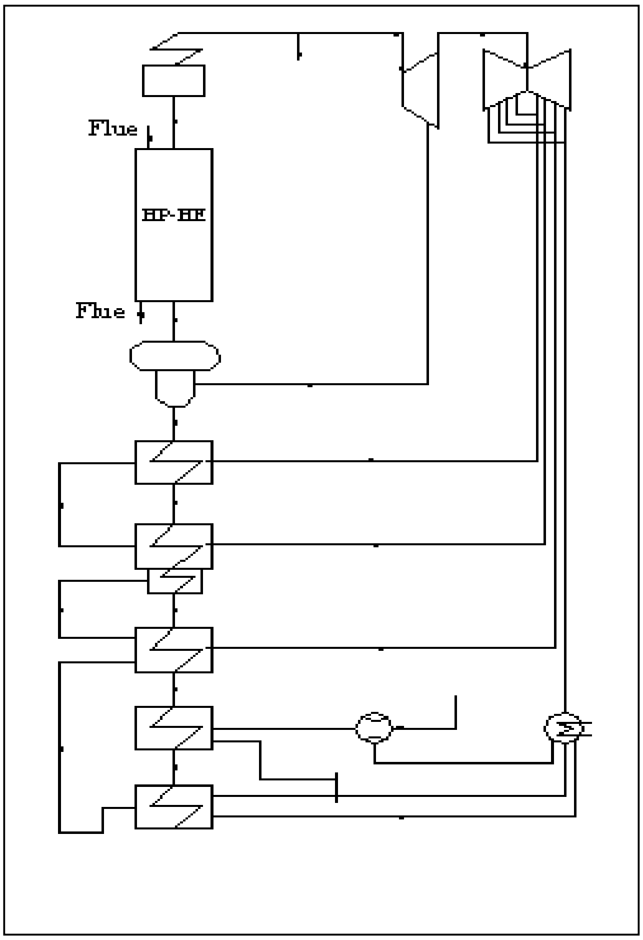

Figure 3- Schematic of option A

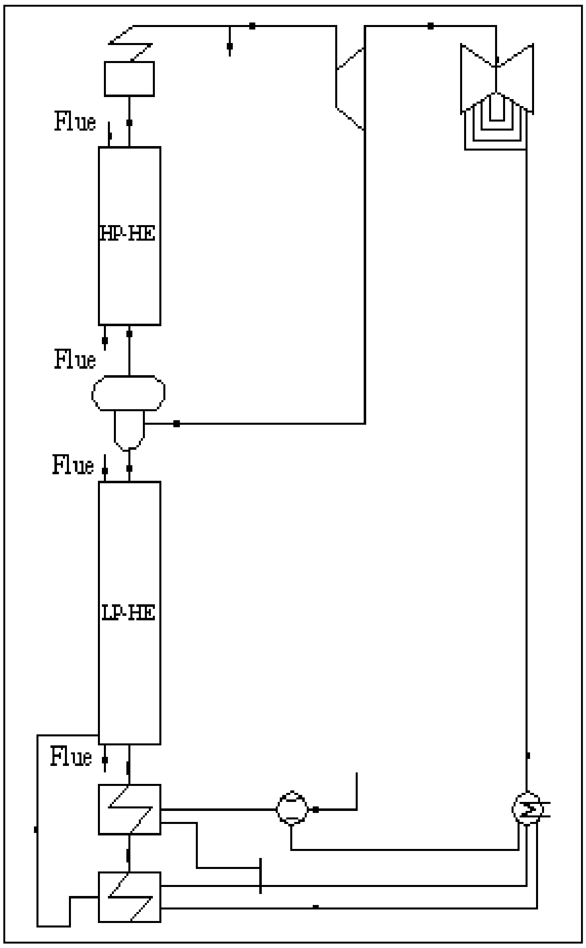

Fig 4- Schematic of option b