A NOVEL STRUCTURE IN DESIGNING CHP PLANT VIA FEEDWATER HEATING REPOWERING

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Abstract- In ordinary, repowering is converting old steam power plants in to combined cycle plants. In this paper, considering the distinguished characteristics of feedwater heating option for new power plants, study their application requirements on Steam power plants. After determining characteristics of more suitable power plants for repowering using this procedure, introduce common methods of feedwater heating option and explain the characteristics of each manner for using in steam power plants. In the second step, considering expected conditions, compare suitable cases for repowering. This paper offers main points in different types of feedwater heating option and their specifications.

Keywords- Repowering, Gas Turbine, Feedwater Heating, Steam Power Plant

I. INTRODUCTION

Increasing need and considerable growth in energy consumption have provided a reason for more studies in optimization and developing power generation systems. Increasing the efficiency of these systems is a key factor in decreasing final price of productions. Steam power plants are one of the most important power stations in the country. Despite applied changes in the power industry's policies toward providing these kinds of power plants, about 30 percent of the country's needed power is provided by these plants. Currently, many of these plants are at the end of their useful life or are moving toward that. In addition, many of steam power plants, despite their short life, do not have an acceptable efficiency. Among the actions that can be taken in to account for improving steam power plants generation and increasing their efficiency is scrutiny of repowering processes and their influence on these power plants. Repowering is used in two general methods, full repowering and partial repowering. Full repowering is converting power plant in to combined cycle plants, in which the existing boiler can be replaced by heat recovery boiler and gas turbines.

Mostly the power plants that are more than 25 years old are suitable for applying this operation.

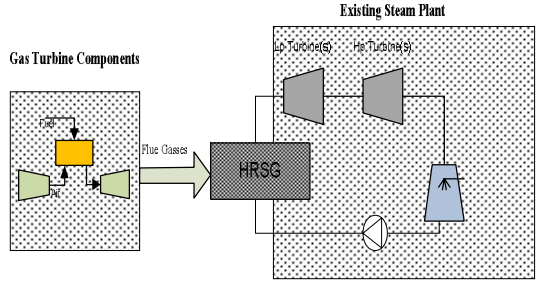


Fig 1: Boiler replacement (Full repowering)

Partial repowering options can be done in three ways included:

1. Hot windbox repowering option: This method can be done by adding gas turbines to mentioned power plant and sending gas turbine stack gases to hot windbox of existing boiler. The preferred plants for performing this method are new, modern and preferably larger plants.

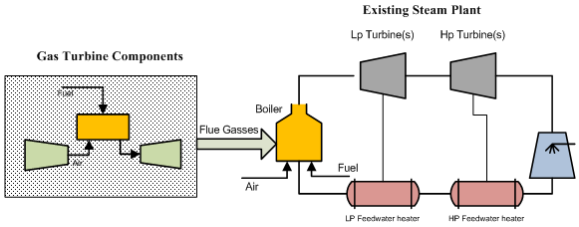


Fig 2: Hot windbox repowering

2. Feedwater heating option: In this method gas turbine stack gases are used for heating boiler feedwater. Suitable power plants for feedwater heating option are as the same suitable plants as Hot windbox repowering option.

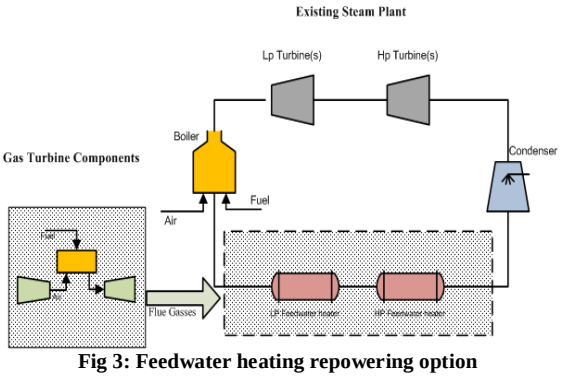


Fig 3: Feedwater heating repowering option

3. Supplemental boiler option: This option includes adding gas turbines and supplemental boiler to mentioned power plant without removing the existing boiler. Heat recovery boiler can be added to existing cycle in different ways. Here Heat recovery boiler stack steams path can be classified, considering Heat recovery boiler stack gasses path.

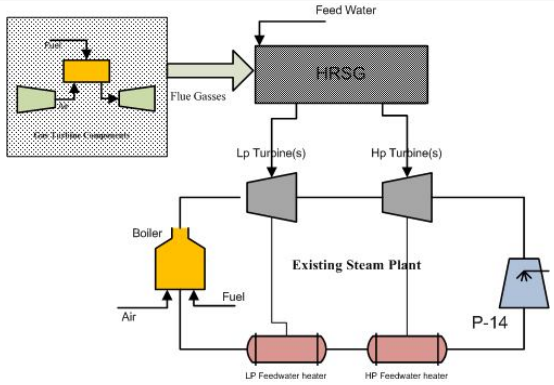


Fig 4: Supplemental boiler repowering

For parallel feedwater heating option repowery different scenarios can be offered that includes diverse items such as increasing efficiency, decreasing consumed fuel, increasing power generation, decreasing environmental contaminants, etc.

Considered option for repowering in this method can include some items among aforementioned cases that can be discussed and scrutinized simultaneously. Increasable steam turbines power connected to high pressure feedwater heaters is between 12 to 16 percent and 4 to 6 percent for steam turbines connected to low pressure feedwater heaters.

Technical-economical characteristics such as simplicity and flexibility of executable designs, low operation costs and finally lower electricity generation cost can be considered as significant advantages of feedwater heating options compared with other partial repowering options in general.

feedwater heating repowering option is discussed in two general types:

1. Design studies for power plant operation in full load: In this type, decrease in cycle efficiency occurs in plant performance on partial load.
2. Design studies for power plant operation in full and partial load: In this type, there is a negligible difference between power plant functional efficiency in full and partial load.

In the next sections, considering written code of a 250 MW power plant cycle for applying feedwater heating options, the results of this performed sample is used just in cases that some specifications are needed.

II. DISCUSSION ON THE INFLUNECE OF A STEAM PLANT ON POSITIVE CHARACTRISTIES OF PARTIAL REPOWERING

Now for discussing a steam unit power in positive characteristics for repowering (1) has been used.

$$\eta_{net} = \frac{\dot{W}_{st,net} + \dot{W}_{gt,net}}{\dot{m}_{fb}.LHV_b + \dot{m}_{fg}.LHV_{gt}}[\%] \qquad (1)$$

$\dot{W}_{st,net}$ and $\dot{W}_{gt,net}$ are net power generation of mentioned steam plants and net power generation of gas turbine on MW, respectively. $\dot{m}_{fb}$ and $\dot{m}_{fg}$ are Consumed fuel rates and LHV_b and LHV_{gt} are low heat values of fuel in steam cycle boilers and gas turbines respectively. During studying the influences of repowering on a steam plant, considering statistics of the country, average efficiency of the hypothetical steam plant is supposed 36 percent. Now, with respect to the aforementioned equation, it is attempting to rewrite that for independent values of Steam plant power generation and adjunct gas turbine. At first, (2) has been obtained as the power plant heating rate.

$$HR_{st} = \frac{(\dot{m}_{fb}.LHV_b)_{st}}{\dot{W}_{st}}.3600[Kj/Kwh] \qquad (2)$$

The relation between efficiency and the steam plant heating rate is expressed in (3).

$$\eta_{st} = (3600/HR_{st})[\%] \qquad (3)$$

Now (4) is used to determine the input gas turbine heating rate.

$$\dot{m}_{fg}.LHV_{gt} = 2.68\dot{W}_{gt} + 6.93[MW] \qquad (4)$$

Therefore, (1) is changed into (5).

$$\eta_{net} = \frac{\dot{W}_{st,net} + \dot{W}_{gt,net}}{(\dot{W}_{st,net}.2.77) + (2.68\dot{W}_{gt,net} + 6.93)}[\qquad (5)$$

The mounted gas turbines capacity with feedwater heating option is variable up to 20 percent of the considered plant. Therefore, regarding (5) and available steam power plants capacity in Iran, the diagram is expressive of efficiency changes of repowered plants according to steam plant power variations (Fig. 5). As you can see, with increasing the mentioned plant power and also the adjunct gas turbine power, the repowering characteristics increases tangibly.

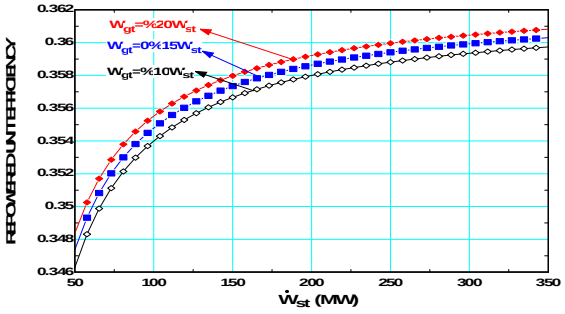


Fig 5: Existing steam plant power effect on feedwater heating repowering efficiency

Here, techno-economical properties of the repowered cycle have been comparing using two main objective functions.

1- Exergy efficiency :

$$\eta_{ex,cc} = \frac{\sum_{i=1}^{n} \dot{W}_i}{\sum_{i=1}^{n} \dot{E}_{f_i}} \quad (6)$$

Where $\dot{W}_i$ is net power of the new cycle [MW] and $\dot{E}_{f_i}$ is chemical exergy of the input fuel [MW].

2- Electricity generation cost: this function has been presented as below:

$$Z_E = (\frac{TCI.CRF.\varphi}{\dot{W}.H}) + C_f.HR_{pp}[\$/Kwh] \quad (7)$$

III. CHOOSING THE SUITABLE OPTION FOR FEEDWATER HEATING

In a thermodynamic analysis of studied repowering cycles, in addition to the influence of the gas turbine cycle efficiency added to the cycle, some other important characteristics are considered.

1. Excess amounts of steam, acceptable by condensers, for the values greater than 20 percent, can cause some problems in the cycle condenser section.
2. The exhaust steam pressure range, emitted through the last low pressure turbine, after repowering, should meet the ambient temperature calculations. As the ambient temperature occurs in greater ranges, the condenser pressure increase as well. Thus, the appropriate pressure range of condenser, after repowering, should be obtained considering ambient temperature.

In addition to common mentioned items, two general methods are considered for studying other characteristics of feedwater heating options.

A. The older method of feedwater heating option

In this option, the discussion is about complete eliminating of steam cycle extractions and is not about their reduction. In this method, a high pressure heat exchanger is used to replace high pressure heaters and an energy balance equation is expressed. This equation makes a relation between output gases of gas turbine and the needed heat for feedwater heating to equalize feedwater temperature emitted through exchanger with feedwater entering the boiler, in the initial plant.

Of course, if the study is about real repowering options, the difference between the temperatures of exhaust gases emitted through heat exchanger and input feedwater to exchanger should be respected. Considered scenario in expressing the characteristics of this type of repowering, is the option that cuts high pressure extractions and in scrutinizing the best possible types, considering aforementioned criteria, the best choice is introduced.

In the typical sample and also in other studied samples, this option is chosen as superior method, with respect to explained limitations in repowering by this method.

B. Parallel feedwater heating option

In this option, high and low pressure extractions reduction is used instead of cutting extractions, with respect to greatest available efficiency providing from repowering cycle.

In this study, the general goal is achieving greatest new plant efficiency with a unique performance in different applied load conditions and finally obtaining the lowest possible temperature of stack turbine gases from the heat exchanger.

1. The temperature differences of exhaust gases from high pressure heat exchanger are more important in this type of repowering. Usually in these conditions, the temperature of exhaust gases from low pressure exchanger, considering ambient pressure, is supposed a specified value. Because of differences in mass flow rate of feedwater that is transmitting through high and low pressure heat exchanger, and providing the use of a heat balance equation for heating feedwater by gas turbine, it is possible that gases temperature exhausting from high pressure exchanger be lower than input feedwater. This option can cause reduction in the influence of gas turbine gases on heating feedwater.
2. Providing installing two high and low pressure heat exchanger, reducing thermal losses between these two exchangers, has a positive influence on cycle efficiency.
3. In the low pressure section, extractions reduction, considering the accomplished calculations for determining capital cost investment for buying repowering equipments, with respect to similar experiences in doing such operations capital cost investment in buying low pressure feedwater heat exchanger is so high. Exempting condenser, other equipments costs lower in comparison with low pressure feedwater heat exchanger and it has lower influence on increasing positive technical characteristics of cycle (because of installing its turbine at the end of expansion section), the extraction reduction related to this section is negligible.
4. The different replacement costs of feedwater heater that mass flow rate of transmitting feedwater is the same, has illustrated in the figure 6 (for determining the location of typical cycle components refer to Fig.8). These cost differences are due to Log mean temperature differences.

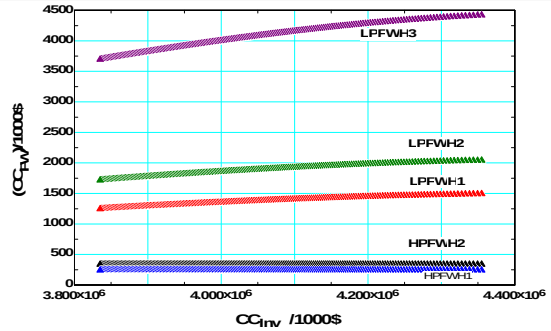


Fig 6: Heat exchanger operation cost relation with capital cost investment

Now, considering:

a. Higher costs of installing feedwater heaters (LPFWH2) compared with feedwater heater (LPFWH1)

b. Higher power due to the flow rate added to the main stream flow by extractions stream reduction (LPEXT1) in comparison with (LPEXT2). In extraction stream reduction in low pressure section, elimination of extractions stream (LPEXT1) is preferred. Although, if we were enforced to decrease streams in two low pressure heaters, two subjects were against each other.

a. More steams reduction from (LPEXT1) led to more increase in cycle power that make cycle efficiency grow and in result reduce electricity generation costs. On the other hand, by injecting more amounts of streams near the turbine (LPT1), heater (LPFWH2) replace by a larger one, which can cause more costs.

b. Contrariwise, in this method more extraction steams reduction can be done near turbine (LPT2).In these conditions, replacement costs of heater (LPFWH2) decrease, because of its smaller size. Nevertheless, positive technical characteristics of the cycle can be influenced by added steams quality reduction in low pressure turbines section. The question that which one is superior, can be answered based on repowering cycle efficiency and electricity generation cost in each type. Now, considering:

First: Plant partial load time duration
Second: The reduced amount of load sited in partial load

In a power plant some calculations are considered for computing the best values of extractions. These extractions reduction values, particularly in low pressure, are important factors in non-significant reduction in plant efficiency in partial load case.

The reason is that heat recovery of exhausted gases from gas turbine strongly depends on increasing feedwater transmitting from low pressure heat exchanger.

Now, considering all aforementioned items choose the best options for low pressure extractions reduction.

5. After discussion on methods for low pressure extractions reduction, high pressure extractions reduction values are important subjects in repowered cycle efficiency. If consider two extractions of Fig.8 as samples, high pressure extraction reduction value (HPEXT2), with respect to exergy efficiency and Electricity generation cost is equal to (HPEXT1) reduction ,in maximum value.

If horizontal axis indicates high pressure extraction reduction percent, vertical axis shows low pressure extraction reduction percent and lines represent general steam values reduction in high pressure section in typical cycle, extraction reduction values can be indicated like (Fig.7).

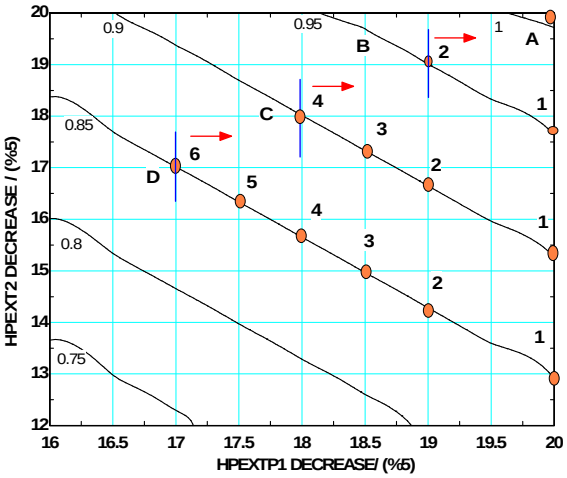


Fig 7: High pressure extraction reduction based on limitations

Steps in repowering analysis are: considering the temperature difference of exhausted gases from high pressure heat exchanger and further influence of high pressure section's steams, extractions reduction values of this section can be determined. After that, considering supposed temperature exhausted from low pressure heat exchanger, the superior values of reduction of low pressure section have been chosen. Condenser's limitations should be considered due to the fact that they are key factors in determining the best possible scenario with highest efficiency. Chosen gas turbine power is determined based on its exhausting gases temperature.

IV. COMPARISON AMONG AVAILABLE METHODS

In optimized chosen method from older method of feedwater heating option, the power plant can convert in to its initial type. In other words, removability of gas turbines from repowering cycle and converting it into initial type. This method has some disadvantages in the case that it is used in partial loads:

1. Non-use of positive characteristics of repowering in efficiency upgrading of mentioned plant.
2. reduction values of constant power

In the case of repowering by this method in usual power plant's performances these items can be considered:

1. non-appropriate use of exhausting gases from gas turbine due to high temperature of feedwater entering an installed heat exchanger
2. Low flexibility of the cycle in applying load between repowering cycle capacity and initial steam power plant cycle. Performance in such a load causes cycle efficiency reduction and electricity generation costs may increase. But in parallel feedwater heating option according to aforementioned criteria using for optimized operation in different ranges, feed water heaters have been replaced. In this paper, the key factor for the number of involved heaters for replacement are accessible efficiency and final electricity generation cost. In typical pattern for choosing the best option of repowering, 4 heaters among 5 available heaters have been replaced. Considerable flexibility of power plant for working in partial loads, is one of the characteristics of this method. Accordingly, high pressure extractions values will increase for working in partial loads and because of non-removing of extractions of this section , accessing to lower power (due to considerable effect of turbine (IPT1) on power generation of plant) is possible through increasing these extractions. This method has advantages compared with other methods which cut the high pressure extractions. On the other hands, considering transmitting feedwater reduction, from the high pressure heater, to prevent loss of efficiency and making better use of exhausting gases' heats from gas turbine, low pressure extractions values increase.

CONCLUSIONS

Feedwater heating option has many advantages and is especially appropriate for new and larger power plants. In studied typical cycle, heating efficiency in full load is approximately equal and about 4/4% in two discussed cases. Thus, because of lower costs of old repowering method, capital cost recovery period time is less than 4 years in this method and in parallel feedwater heating method is about 6 years. these values have obtained during a study about a 250 MW power plant operation in full load. If the power plant is in long lasting partial load and has a great harmony between working in partial load and extractions reduction values, according to aforementioned discussions, these values may change. Plants power increase in old repowering methods is about 11.5 % more than power plant capacity in parallel feedwater heating option. Cost investment in old method is about 80% of parallel feedwater option per Kw added capacity.

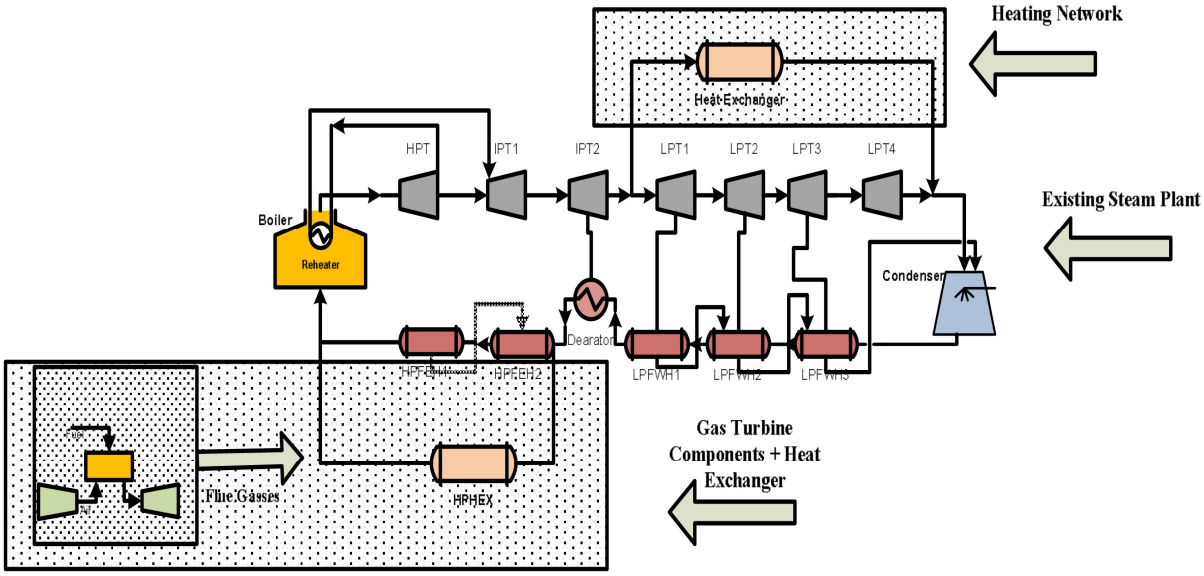


Fig 8. New Proposed steam plant repowering cycle layout

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