CAUSAL ANALYSIS AND BOILER EFFICIENCY CALCULATIONS OF A THERMAL POWER PLANT

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Abstract: The aim of this paper is to present the functionality of a thermal power plant, on the one hand, and the boiler efficiency calculations, on the other hand. This is why we present a stratification survey by circuit, by equipment and by organ witch the objective is to determine the possible reasons of the deterioration of the plant heat rate. This survey concerns particularly the application of the causal analysis in order to determine the different losses at the level of the boiler of a thermal power plant.

Key words: Thermal power plant, boiler efficiency, causal analysis, performance evaluation.

1. Introduction

In a thermal power plant (TPP), the prime mover is steam driven. Water is heated, turns into steam and spins a steam turbine which drives an electrical generator. After it passes through the turbine, the steam is condensed in a condenser. The greatest variation in the design of TPPs is due to the different fuel sources. Some prefer to use the term energy center because such facilities convert forms of heat energy into electrical energy [1].

In TPPs, mechanical power is produced by a heat engine which transforms thermal energy, often from combustion of a fuel, into rotational energy. Most TPPs produce steam, and these are sometimes called steam power plants. TPPs are classified by the type of fuel and the type of prime mover installed.

The electric efficiency of a conventional TPP, considered as saleable energy produced at the plant busbars compared with the heating value of the fuel consumed, is typically 33 to 48% efficient, limited as all heat engines are by the laws of thermodynamics. The rest of the energy must leave the plant in the form of heat.

Since the plant efficiency is fundamentally limited by the ratio of the absolute temperatures of the steam at the turbine input and output, the efficiency improvements require the use of higher temperature, and therefore higher pressure of the steam [2-4].

This overheated steam drags the high pressure turbine in rotation and relaxes to the exit of the high pressure turbine, so it comes back again in the furnace to be until 540° after, it will be sent back to the intermediate pressure turbine then to the low pressure turbine.

During these steps, the calorific energy is transformed in available mechanical energy on the turbine. Thus, this mechanical energy will be transmitted to the alternator, being a generator of alternating current, in the goal to produce the electric energy [3].

After the condensation, water will be transmitted thanks to pumps of extraction in the station of low pressure to be warmed progressively before being sent back to the furnace through the intermediary of the food pumps.

This warms progressive of water has for goal to increase the output of the furnace and to avoid all thermal constraints on its partitions. This station of water is composed of a certain number of intersections that is nourished in steam of the three bodies of the turbine. Finally, the cycle reproduces indefinitely since steam and water circulate in a closed circuit.

Most of the TPPs operational controls are automatic. However, at times, manual intervention may be required. Thus, the plant is provided with monitors and alarm systems that alert the plant operators when certain operating paracounters are seriously deviating from their normal range [5-7].

In order to assure an optimal production of electricity in the best conditions of efficiency and security, a TPP is brought to opt to an effective and a robust facilities choice.

The calculation of the net heat rate permits us to inform on the state of the TPP and allows operators to help to take out the reasons of deterioration of the average specific consumption of a TPP in the goal to reach the better one recorded at the time of receipt tests when facilities are new and the functioning is optimal, this value is realist and attainable [8].

The global efficiency of a TPP is tributary of a certain number of factors and mainly of the boiler efficiency. Otherwise, there is place to also notice that with regard to the turbine and the alternator that are facilities of big importance in the constitution of a TPP, the deterioration of their respective efficiencies hardly takes place long-term of a manner appreciable and this by reason of the ageing of some of their organs as: stationary and mobile aubages usury; increase of the internal flights; usury of alternator insulations, etc.

The objective of this paper is to analyze the different losses at the level of the boiler of a TPP therefore to implant solutions in order to act in time and to improve its efficiency.

2. Presentation of a TPP in Tunisia

The electricity production center of Radès (near to Tunis) is composed of two steam thermal power stations which the total power installed is 700 MW. This center uses combustible both natural gas and heavy fuel-oil [9].

The demineralized water is used like support of energy, it undergoes a closed thermodynamic cycle continually while passing the liquid state to steam state then state steam to the liquid state [10].

During this cycle water recovers the calorific energy in the boiler that it restores at the time of its detente in the turbine as a mechanical energy to the rotor of the turbine. The rotor of the turbine being harnessed to the rotor excited of the alternator, the mechanical energy of the turbine is transformed then in electric energy in the alternator (Figure 1).

The TPP of Radès is composed of a SCADA (supervisory control and data acquisition) system. It collects data instantaneously (ON LINE) of their sites and to transform them in numeric data. This centralized supervision allows operators, since the room of control of the TPP, to control facilities in their domain of exploitation and the different types of incidents [11-16].

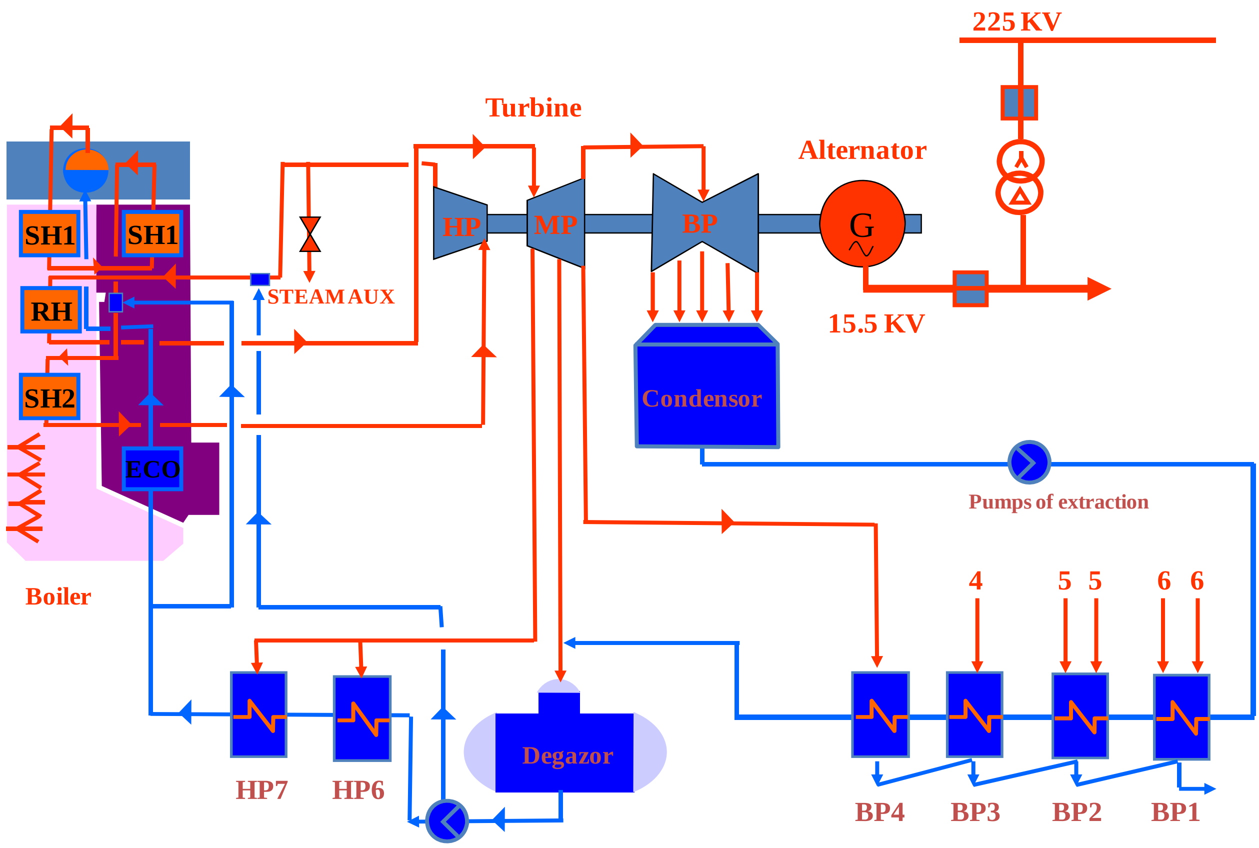

Fig. 1. Functionality of a TPP

3. Boiler accessories

The boiler is a steam generator that assures the spraying of water (Figure 2). At this level operates the transformation of the chemical energy in calorific energy by combustion of a mixture "air-fuel".

The boiler is composed by three essential elements: the combustion room; the economizer; the ball of the boiler

- The combustion room

It constitutes a surrounding wall of contiguous tubular bundles inside in the water circulates. It is in this combustion room the transformation of the chemical energy in calorific energy by combustion of a mixture "air-fuel". This calorific energy frees a quantity of heat that will be transmitted to water to produce the steam of water in a temperature and under a very determined pressure.

- The economizer

It has for role to recover a part of calories remaining in the gases of combustion to increase the temperature of the feeding water what will have for effect the increase of the thermal output of the installation and the elevated thermal constraint suppression in the metal of the reservoir.

- The ball of the boiler

To the exit of the economizer, the water of feeding goes up toward a reservoir situated in the part superior of the boiler called ball of the boiler that constitutes a surrounding wall in sheet metal in which is the liquid phase and the phase steam of the feeding water.

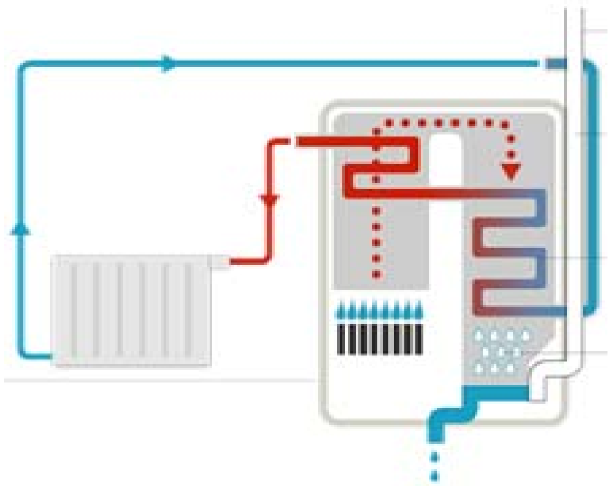

Fig. 2. Components of the boiler

- Superheater / Reheater

It is an intersection of heat constituted of tubular bundles re-serving the gases of combustion directly; therefore submissive to the most elevated temperatures of the combustion room. Steam coming from the ball is humid; it passes therefore in tubes of the heater where its temperature is raised to relatively constant pressure.

After having undergone a first detente in the high pressure body of the turbine, steam comes back to the generator of steam and enter in an intersection called primary reheater of temperature 330°C then it crosses the final re-heater of temperature 540°C, then it is sent toward the intermediate pressure body of the turbine. To the exit of the intermediate pressure body steam passes in the body low pressure of the turbine.

- Burners

The burner is the most important component to light the natural gas fuel-oil. Le role of the burner is of creates a zone of ignition to the sufficient temperature to maintain the combustion and to provide the necessary air mixture. The boiler include seven floors each one is equipped of four burners.

4. Boiler efficiency calculations

Among the multiple factors that can degrade the boiler efficiency, there is place to mention what follows as an example [17-20]:

- bad combustion following a bad working of the regulation;
- bad quality of the fuel used;
- heating inadequate of the used fuel;
- flights of water and steam;
- flights of air (comburant);
- encrassement of the boiler;
- encrassement of the air heating device…

Boiler efficiency can be calculated by one of two methods: the Input - Output method or the heat losses method [8].

4.1 Input / Output method

The expression of the boiler efficiency of the TPP is given by:

$$R_{ch} = \frac{\text{Output}}{\text{Input}}.$$

R_{ch}: Boiler efficiency.

The exit is defined by the sum of heats absorbed by the used fluid (water-steam).

The entrance is defined by the total energy introduced in the boiler.

The boiler efficiency is given by the following expression:

$$R_{ch} = \frac{[Q_{eal}(H_{sh}-H_{al})+Q_{injsh}(H_{sh}-H_{injsh})+Q_{vrh}(H_{rh}-H_{erh})+Q_{injrh}(H_{erh}-H_{injrh})]}{F_{h1}.Qf+B_e}.$$

Q_{eal} : debit water (kg/h);

Q_{injsh}: debit water injection;

Q_{injrh}: debit of the water of steam (Kg/h).

H_{sh}: enthalpy of steam to the exit;

H_{al}: enthalpy of water in entrance economizer;

H_{rh}: enthalpy of water (kcal/kg).

H_{erh}: enthalpy of water exit HP (kcal/kg).

H_{injrh}: enthalpy of water (kcal/kg).

F_{h1}: superior calorific power of fuel used (kcal/kg);

Q_f : debit fued (t/h);

B_e : total of heat introduced.

4.2 Method of heat losses

The boiler efficiency is given by the following expression:

$$R_{ch} = \frac{F_h - C_{per}}{F_h}$$

F_h : Total energy introduced in the boiler.

C_{per}: Sum of the calorific losses at the level of the boiler.

In the case of fuel, the total heat introduced in the boiler comes from fuel, of the air of combustion and the steam of atomization.

The calorific losses that one meets in a boiler are essentially owed to the heat carried away by the gases of combustion, to the presence of water in fuel as well as the existing humidity in the air of combustion.

5. Causal analysis of the boiler efficiency

In this part, we present a survey of a boiler of a TPP. The objective is to determine the possible reasons of the deterioration of the heat rate of the TPP at the level of the boiler [8].

Causal analysis represents the search for the cause or causes of particular events and objects. A causal factor is a variable which causes change in another variable.

Figure 3 presents an example of the boiler in a TPP in Tunisia.

Fig. 3. Example of a boiler of a TPP

In fact, we adopted a gait of problems resolution as well as quality management tools particularly the causal analysis [21-24].

All appropriate events (e.g., preventive or corrective maintenance, exploitation, in conformity of modification, related to working, work stops) are consigned on GMAO in order to constitute the historic and to permit its traceability. This historic has been consulted in the goal to bring a more for the possible cause's research (Figure 4).

Table 1 presents the diagnosis of performance parameters and corrective actions.

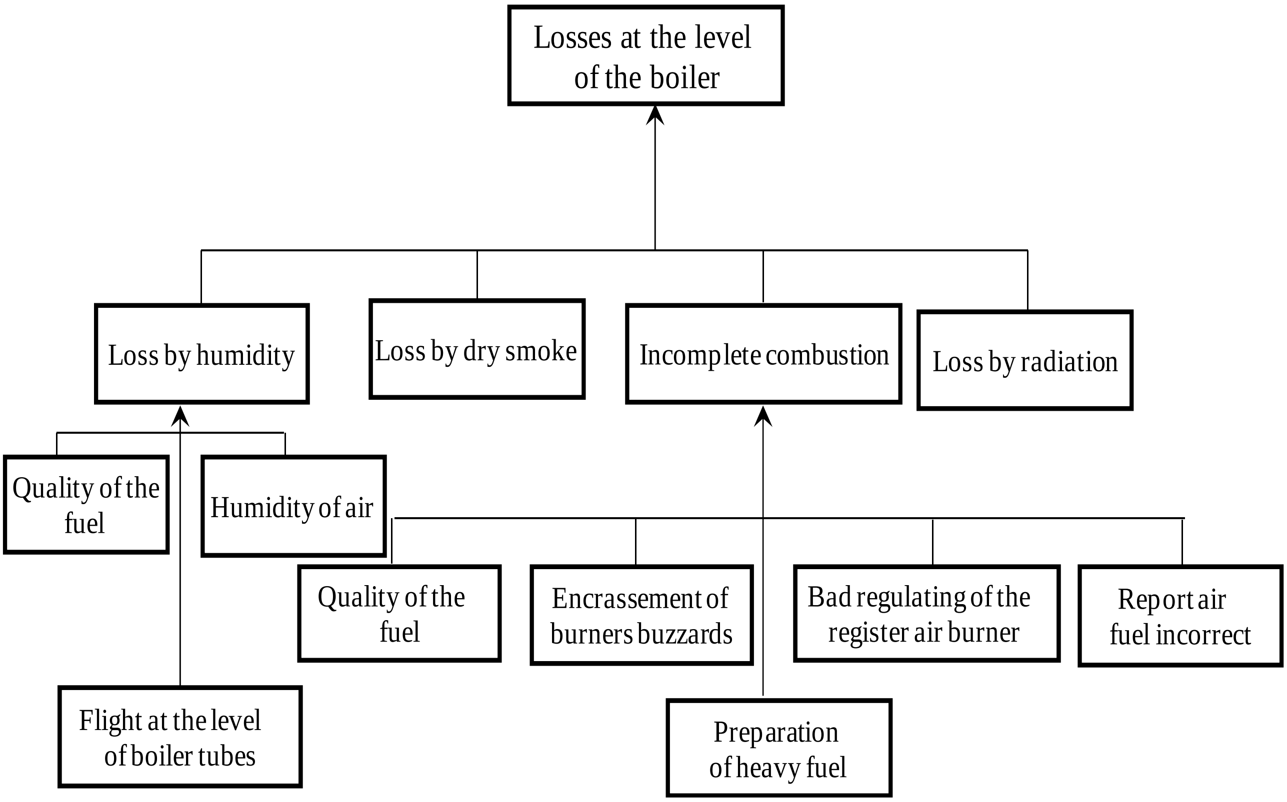

Fig. 4. Causal tree of the analysis of the boiler

Table. Diagnosis of performance parameters and corrective actions.

Parameter	Cause	Confirmation test	Corrective action
Debit injection SH very high	Instrument error	To verify with the redundant measures To calculate the debit from the temperature entrance and exit heating	To calibrate instruments
	Order point of steam temperature very low	To verify the order point steam temperature	To increase the value of the order point
	Debit injection on manual order point very high	To see system of regulation	To adjust the station of control of injection debit
	Very high air excess	To verify the excess of air: (parameter of performance)	
	Low water temperature:		
	a- by-pass HP heating	To verify temperature water before and after by-pass HP	To close floodgate by-pass HP heating device To eliminate the flights
	High TD heating HP	To verify TD heating HP : (parameter of performance)	
	Very low pressure steam admission turbine	To verify pressure steam admission turbine	
	Flight floodgate control of injection	To close the floodgate of insulation To verify if the conduct is hot	To repair the floodgate
Debit injection RH very high	Instrument error	To calculate the debit of steam from the temperature of entrance and exit	
	Very low order point of temperature steam	To verify the order point	To increase the value of the order point
	Very high debit injection on manual order point	To verify the control station	To adjust the control station
	Very high air excess	To verify the air excess (parameter of performance)	
	Low water temperature:		
	a- by-pass heating HP	To verify temperature water before and after by-pass HP	To close floodgate by-pass HP heating ; To eliminate the flights
	High TD heating HP	To verify TD heating HP : (parameter of performance)	
	Very low pressure steam admission turbine	To verify pressure steam admission turbine	
	Flight floodgate control of injection	To close the floodgate of insulation ; To verify if the conduct is hot	To repair the floodgate
	Very low temperature vapeur admission turbine	To verify temperature steam admission turbine	
	Very low efficiency HP turbine	To verify the efficiency of the HP turbine	

The tree starts with the description of the main problem and every box of the branches can be the root cause.

The representation based on the causal tree permits to determine the zone where the equipment suspected of losses without bending to sometimes do expensive specific performance tests. Preventive and corrective actions of maintenance have been hired at the time of the yearly revision of the TPP.

An excellent question when analyzing around change is 'why?' Causal Analysis seeks to identify and understand the reasons why things are as they are and hence enabling focus of change activity.
This perspective is based on practical experience in implementing causal analysis in industry.

Staring from the application of the causal analysis discussed in this paper, work is in progress to develop a supervision system of the different equipments of the TPP using Bond Graph and external models [25]. Then, we focus particularly, on the application of the systemic design [26].

6. Conclusion

In this paper, we presented an exploration of the ways permitting the improvement of the plant heat rate. This is why we present two methods for the boiler efficiency calculations on the one hand and an analysis of the different losses at the level the boiler using the causal analysis, on the other hand.

Calculating the boiler efficiency by the Input-Output method is desirable because of the simplicity of the method but is subject to the inaccuracies of all of the measurements needed.

The method of heat losses increases the accuracy of the calculation but, while the number of measurements is decreased, the difficulty of obtaining accurate measurements is increased.

Finally, it important to determine the possible causes generating the losses and provoking the deterioration of the plant heat rate while using the causal analysis.

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