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IMPROVEMENT OF EXHAUST TEMPERATURE DISTRIBUTION DURING COMMISSIONING OF GAS TURBINE

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Abstract- During the commissioning of the gas turbine (GT) AE64.3A operated with fuel oil, some problems relevant to the EGT distribution and the very high fuel oil pressure were detected, when switching from diffusion to premix mode. The combustion of fuel oil is a very sensitive issue because it is affected by a lot of internal and external variables. This article aims to show how the problems were addressed and solved and the tools that were used to analyze them. The problems were caused because some burners were clogged for an unknown reason and the GT tripped every time due the high spread of EGT. For analyzing the temperature distribution, the EGT profile was built up, using the data taken from the 24 thermocouples installed in the combustion chamber of the GT and some simulations were performed using the MATLAB. Through the Performance Monitoring, DCS module was evaluated the performance of the GT when the EGT spread was higher than the threshold and was found that the fuel oil consumption was increased. Under investigation was taken the quality of fuel oil and demineralized water (injected in the GT) to understand if they can affect the nozzles clogging. In the end to solve the problem some modifications in the GT logic were carried out. We are aware that the best solution would be to optimize the burner design and the geometry of assembling in the combustion chamber. We hope to give our modest help to the engineers that deal with gas turbines commissioning.

Keywords: Diffusion Mode, EGT Spread, Gas Turbine, Hybrid Burner, Premix Mode.

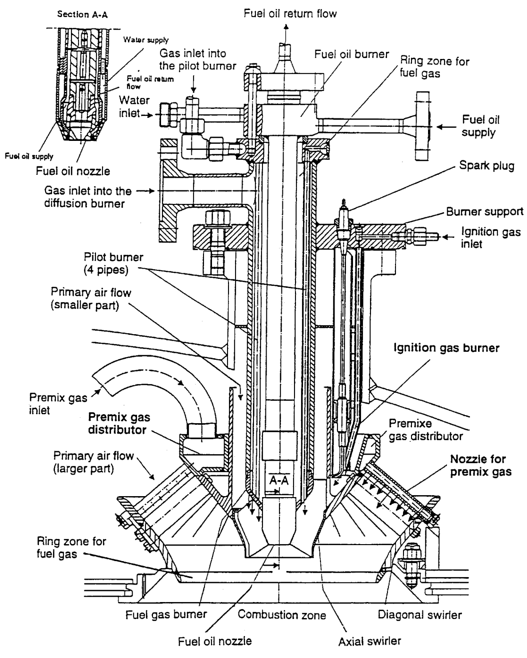
1. INTRODUCTION

The gas turbine (GT) installed in the Vlore combined cycle power plant is a model AE64.3A manufactured from Ansaldo Energia (AEN) [1]. This GT has an annular combustion chamber lined with individually replaceable heat shields and 24 hybrid burners adapted for fuel gas and fuel oil operation. Due to the non-availability of natural gas in Albania, the GT operate only with fuel oil. Air is extracted from three points along with the compressor and is used for cooling turbine internals. The AE64.3A HR3-type burner is shown in Figure 1 [2]. The hybrid burner operates in diffusion and premixed flame and assure good combustion with both gas and fuel oil and very low NO_x and CO emissions. To achieve the aerodynamics features, the burner is composed of two concentric, co-rotating swirlers (axial and diagonal) and it has a central diffusion burner for operation with fuel gas and fuel oil.

The burner has the pilot burner, which is used for premix fuel gas operation. When the GT operates with fuel oil, it is mixed with demineralized water to keep the NO_x emission low. In the dry premix fuel oil operation mode, the fuel oil jet is atomized by the air and the droplets are mixed with the air.

The GT may operate either in diffusion flame or premixed flame. These different flames have different features. Diffusion flame has a low dilution ratio, high flame temperature, and high NO_x production. Premixed flame has a high dilution ratio, low flame temperature, and low NO_x production.

Figure 2 is shown the gas turbine combustion modes and Figure 3 is shown the switch over from diffusion mode to premix mode for both fuel gas and fuel oil. We can easily note how is reduced the NO_x emission when is changed from diffusion to premix mode.



Burner Assembly for Dual Fuel Operation

Figure 1. Typical Hybrid burner assembly HR3 - type, for dual fuel operation

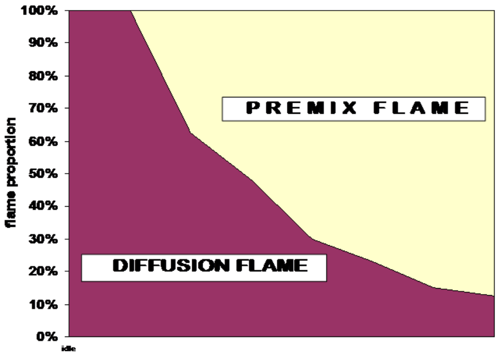


Figure 2. Gas turbine combustion mode

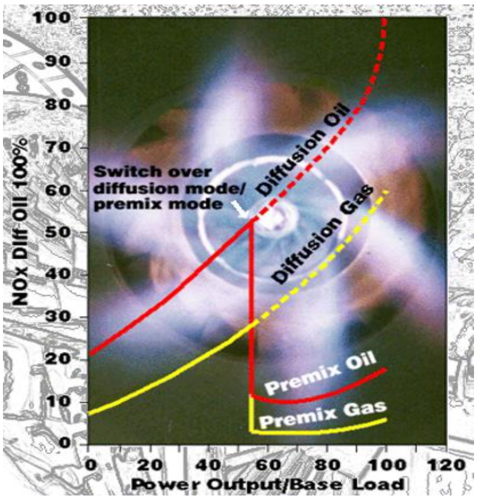


Figure 3. Switch over diffusion mode / premix mode

Figure 4 is taken from DCS during the operation of the GT and shows what happens with GT parameters during the changeover.

The gas turbine has some auxiliary systems related to fuel oil. DeNOX water system is used, when burning fuel oil, to further reduce NO_x emission also in conjunction with fuel oil premix mode. A purge water system is used anytime is necessary to switch from fuel gas to fuel oil and vice versa and when switching from diffusion mode to premix mode (and vice versa) when burning fuel oil. This is done to clean the lines and components from any dirty or oily deposits. Water emulsion system is used when switching from diffusion mode to premix mode (fuel oil) to cool down premix oil lance to prevent fuel oil nozzle clogging [3].

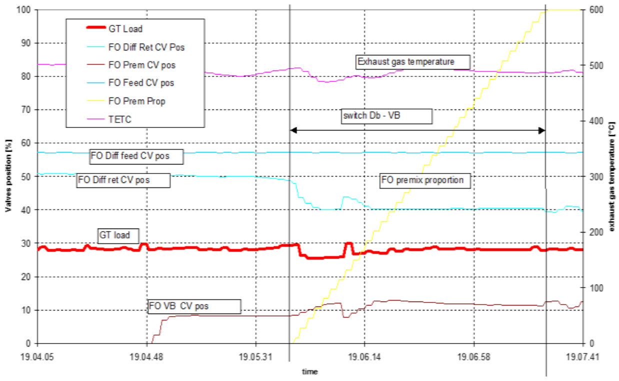


Figure 4. Change over oil diffusion to oil premix mode

Vlore combined cycle power plant has been restarted after almost one year of standstill, firing fuel oil. After the successful start-up and synchronization, the load has been increased up to the conditions for the switch to premix oil operation (exhaust temperature approximately 500 °C). The changeover has been performed successfully and the load further increased.

All the operating parameters have been monitored and it was found that the exhaust temperature distribution (monitored by 24 triple thermocouples) has shown a certain variation between the thermocouples, this indicating that the premix burners are not working homogeneously.

In particular, each premix oil burner is constituted by 18 nozzles of a very small diameter (approximately 0.5 mm) to achieve good atomization (Figure 5).

Figure 5. Premix oil burner

Due to this small diameter, it must always be ensured that the oil supplied is properly cleaned and there is no trace of impurity inside the piping, to avoid any risk of clogging which may cause cracking of the injected fuel and finally the complete damage of the nozzles.

Before the start-up, the piping has been flushed and the microfilters on the connection between the fuel oil collector and the burners have been installed. Nevertheless, it was found that the exhaust temperature associated with some burners was slightly lower than the average and on the other hand, some other burners were burning more fuel to compensate. For example consider Figure 6.

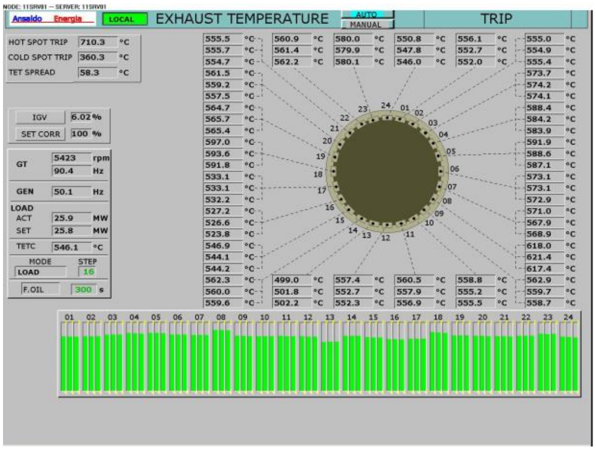


Figure 6. Nonhomogeneous exhaust temperature

It can be seen that at approximately 26 MW the exhaust temperature distribution shows some difference between thermocouples.

To improve this distribution, it has been executed a "backflow" of the premix burners, by pressing the air at the compressor outlet (approx. 10 bar) to the collector through the nozzles [4]. Thanks to this operation a large part of impurities has been removed from the burners and the piping. The following temperature distribution was much better, even at the maximum load.

During the combustion chamber inspection, the cleanness of the burners has been checked and it was decided to replace two burners (number 14 and 18). The burner's cleanliness was checked by the flow test. Simultaneously the microfilters installed on the piping were removed to allow a more efficient backflow at the following change over to premix operation.

After these activities the engine has been started and operated in premix mode, the exhaust temperature distribution was more uniform, Figure 7.

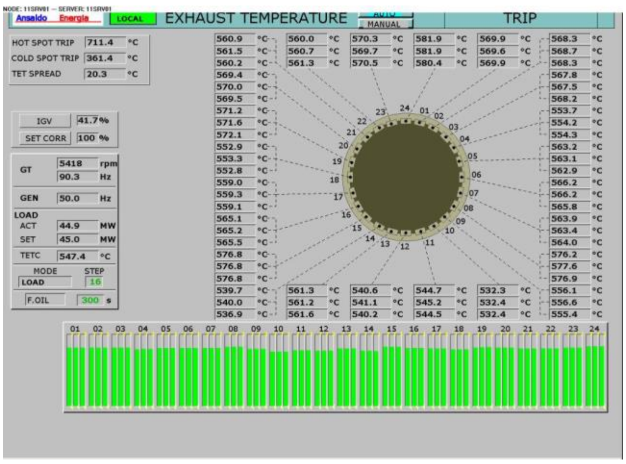


Figure 7. Uniformization of the exhaust temperature

Immediately after the replacement of the premix oil burners the turbine exhaust distribution results improved. The clogging of the existing burners was probably due to the exposure of the fuel oil nozzles to impurities during the long standstill.

Anyway, during further operation, the spread of the exhaust temperature during the switch from diffusion to premix mode was observed again and the data collected from the site were analyzed, to solve this problem definitely.

Also, a review study was carried out based on previous experience and the international literature which treat the temperature spread when is changed from diffusion to premix mode [5], [6]. The experience was very limited because it was just one GT V64.3A in Ballylumford, Northern Ireland, which operated with fuel oil all the time. The other installed GT operated with fuel gas.

2. DATA COLLECTION AND ANALYSIS

After the replacement of the burners, the gas turbine has been therefore operated for some days without any anomaly of temperature distribution.

Due to commissioning reasons the gas turbine has been shut down and operated on turning gear for two days. During the next cold startup, after the changeover to premix, it was found a very high fuel oil pressure and a bad temperature distribution.

The burners have been manually cleaned and the purging time increased to improve the cleaning of the nozzles. During the inspection in the provisional filters, some residuals were found.

Then the gas turbine has been started and operated for several days (with two load rejections during these days) until when the power plant has been shut down. At the next startup at the premix oil connection a very high increase in the pressure was found and also the spread was found higher than at the stop. The back purge procedure has been performed several times and a good reduction of pressure was attained (at baseload around 30 bar) but it was still evident a cold spot zone therefore the engine has been stopped and the burner (again number 18) was replaced. Before the start-up some modifications to the purging logics have been implemented, in particular, the repetition of the purging when reaching turning gear operation.

After such modification to the purging logics the gas turbine has been started and operated for two days during which it has been found that no degradation on the nozzles has taken place (spread and fuel oil pressures constant at constant conditions).

On the next gas turbine shut down, after the purging another flushing has been selected, during which the gas turbine tripped due to incongruence on the drains set-up. When turning speed was reached the second purging started and it was found an increase of the water pressure which indicated a probable occlusion of the nozzles.

At the following start-up the back purge, sequence has been performed several times but it was found that the water pressure was always high and when the premix oil has been connected an increase of oil pressure and exhaust temperatures spread has been found. Therefore, the gas turbine has been shut down for inspection and nozzles cleaning.

At that moment was thinking to increase the threshold of the EGT temperature spread. This action usually affects the performance of the GT, fuel oil system; oil pressure and consumption and, also the performance of the hot components [7]. For this EGT profile were built up, using the data are taken from the 24 thermocouples installed in the combustion chamber of the GT.

It was found that the exhaust temperature associated with some burners was lower than the average and on the other hand, some other burners were burning more fuel to compensate. The temperature profile is shown in Figure 8.

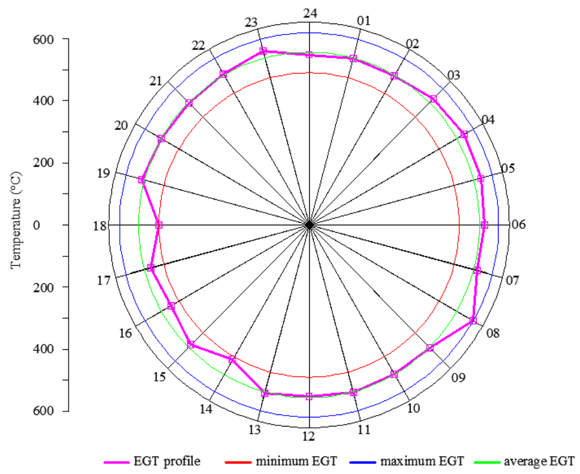


Figure 8. EGT profile

In that time was build up a CCPP Performance Monitoring DCS module [8]. The module was used to evaluate the CCPP performance and the performance of all components GT, ST and HRSG. We used this module to evaluate the performance of the GT during the operation in partial and full load when the spread of the EGT was over the default threshold. It was found that the GT global efficiency was negatively affected by the higher spread of the EGT. In Figure 9, there is a CCPP performance overview, where the GT power output and fuel oil consumption are shown.

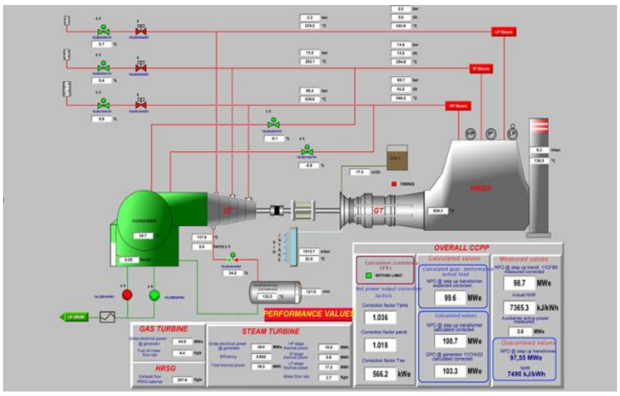


Figure 9. CCPP performance overview

To detect the problems of the fuel nozzles some pressure–measuring instruments were installed in the fuel oil system. These sensors were installed downstream and upstream of each nozzle. It does exist an excessive temperature spread and at the same time a fuel–pressure maldistribution, the problem can be detected for every fuel nozzle.

The EGT spread causes burner damage, which usually are local burns, structural problems and, distortion due to heat excess [9]. Control of EGT spread is important to prevent turbine blade failure due to fatigue because uneven combustion produces a circumferential distortion of the gas flow into the turbine section. Such distortion gets the form of circumferential variations of temperature and as a result of pressure and velocity, which produce variations of the aerodynamic load on the turbine blades while they are rotating around the flow path ring. These distorted models of loading are composed of sine waves or harmonics of all orders (numbers of complete sine waves feels by a blade while it passes through one rotation). Usually, the lower orders (1, 2, 3 and 4) should be stronger in such a model of distortion [10].

Under investigation was taken the quality of Fuel Oil and demineralized water (injected in the GT) available at the site, since it has to be pointed out that the anomaly of clogging has started after the long still period of the GT, while before this period, this anomaly, despite several shut down and restart never occurred.

After all the above considerations, it was decided to restart the GT and to perform step by step all the corrective action needed for the EGT spread improvement.

During the outage, the sealing air valve, the drains and, the fuel oil lines have been inspected to search for any anomaly or leakage to explain the clogging of the nozzles. Furthermore, the purging sequence has been analyzed once again but all the steps appeared to be configured properly. From the combustion chamber the nozzles appeared clean without any trace of cracking outside the nozzles, the occlusion is therefore inside the nozzles from the annulus connection.

In Figure 10 are shown two nozzles extracted from burner 18 and it can be seen that the internal part of the nozzles is filled with residual from oil.

Figure 10. Clogged nozzles

The nozzles have been cleaned once again and some other modifications to the purging sequence – in particular, the opening of the drains prolonged and the fuel oil premix nozzles back purging automatically started at 15 MW and 3 minutes after the switchback.

The gas turbine was therefore, started after one day of fuel oil daily tank flushing. The conditions after the changeover to premix appeared good, both for the fuel oil pressure and the exhaust temperature spread.

On the first day of operation after the corrective actions the following test has been performed:

1. Startup and premix lines blowing.
2. Synchronization.
3. Diffusion operation, premix lines back purge.
4. Premix operation, load to 40 MW for 1 hour. Check of spread and operating parameters.
5. Switch back to diffusion, back purge. Load to 15 MW.
6. Load increase, back purge and, change to premix operation.
7. Load increase up to baseload.
8. Baseload operation for 3 hours.
9. Load decrease, switch back to diffusion, back purge.
10. Diffusion operation at 15 MW.
11. Load increase and switch to premix mode.
12. Load increase up to 50 MW.
13. Shut down of GT.
14. GT on turning gear and start up the day after.

After the above tests are carried out, the gas turbine was started up and at the fuel oil premix connection, the condition of the burners appeared very good. The plant has been set to baseload for the rest of the day. At base load, the situation is shown in Figures 11 and 12:

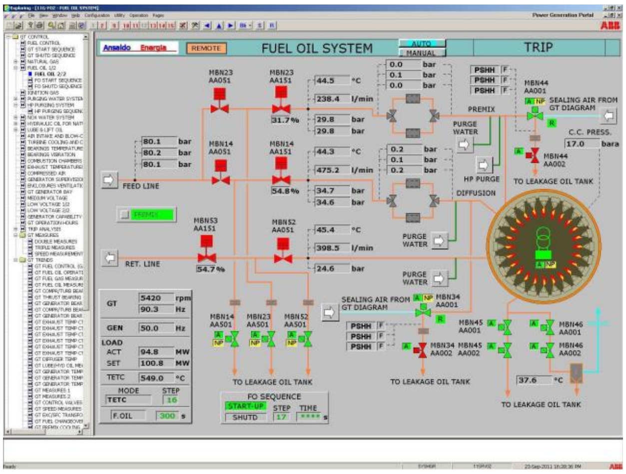


Figure 11. Fuel oil system parameters at baseload

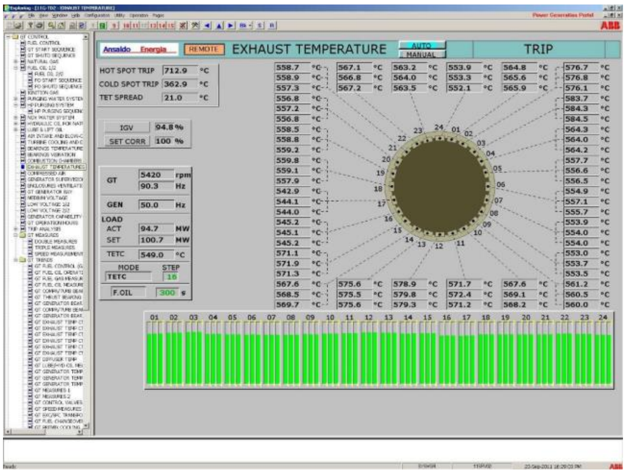


Figure 12. Exhaust temperature distribution at baseload

The gas turbine was shut down in the evening; during the steam turbine shut down a load rejection took place due to the opening of the circuit breakers.

After the purging, the gas turbine was stoped. Then the power plant has been started again and operated all day at baseload. During this period no anomalies on the burners have been found.

The engine has been stopped in the evening without any anomalies. In Figure 13, purging sequence is shown (data taken from Tenore^{TM} as .csv and plotted by Excel).

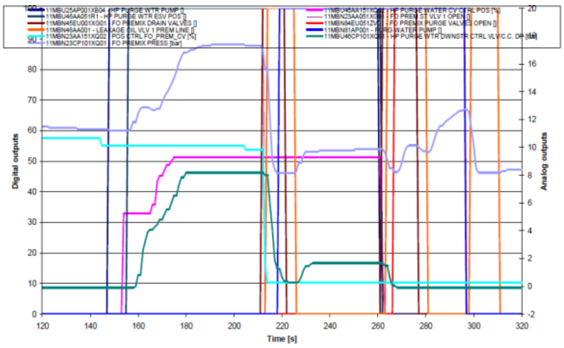


Figure 13. Purging sequence of the GT

Before the start-up of the GT, the control system has been put into the configuration in order to transfer some modification (a pop up in the control panel). Due to this configuration, the preselection of the back purge has been deleted and it has not been selected before start-up, therefore during run-up and at the premix cooling the drains remained closed. At the premix connection, an increase in fuel oil pressure was detected and therefore immediately combustion has been selected to diffusion.

After some back purge the premix oil has been connected again and this time the pressure was around the normal values (slightly higher). When the plant reached the baseload, the spread was higher than before but still on acceptable values. Furthermore, the lower temperature is found on adjacent thermocouples, this means that the anomaly is only on one or two burners. Figure 14 shows the situation of the temperature spread in the burners.

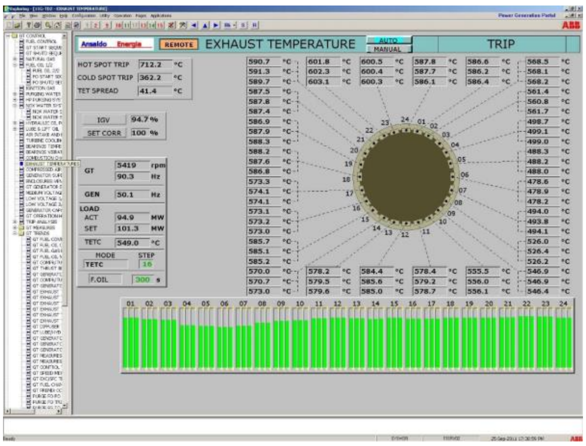


Figure 14. The temperature spread in the GT burners

The plant has been therefore operated at baseload for all the day and shut down in the evening. On the next morning, the gas turbine has been started again and the operation conditions were almost the same that the ones the day before.

The plant was still operated for two days without any evident degradation of the nozzle's cleanliness. Before the shutdown still was increased the purging time to try to clean better the burners which appear to be clogged, but due to a monitoring time, before the end of the purging, the engine tripped.

At the following start-up at the premix connection, an increase in pressure and exhaust spread has been detected and the engine reset to diffusion mode. After some back purge the changeover to premix has been performed and even the fuel oil pressure wasn't increased and the spread was reduced, it was decided to stop the engine for cleaning and further modification of the GT logic.

3. RESULT AND DISCUSSION

1) The analysis of the events shows evidence that the deposit on the nozzles takes place after the shutdown, due to the warming of the burners and residual presence of fuel oil film inside the burners.
2) The analysis of the Fuel Oil and demineralized water quality didn't show any anomaly to be taken into consideration relevant to the EGT spread.
3) The study carried out shows that during the operation of the GT, when the EGT spread is over the threshold, the GT global efficiency was decreased, meaning the increment of the fuel oil consumption.
4) No optimization of the burner design and the geometry of assembling in the combustion chamber was possible in that stage of the Project.
5) The analysis of the events show that remedial actions implemented, i.e. modification to purging logic, sequence and, purging time, is minimizing hence eliminating the clogging phenomenon that appears at the start of the GT. This is demonstrated by the evidence that in the cases in which the purging is executed properly clogging was virtually absent. On the contrary, in the cases when – due to causes explained above - the purging was not executed as required, minor or major clogging of burners was evidenced.
6) During the operation of the GT, detergent was added to the water, to improve the cleaning of the internal part of the burners. This gave good results.
7) Another improvement implemented, was to send air (extracted from the blow-off vessel) during the first minutes of the standstill, to avoid the formation of residues on the nozzles.

4. CONCLUSIONS

During the manufacturing stage, when the assembling of the burners in the combustion chamber was carried out a slight misalignment was verified. To correct the angle was proposed to install a plate with a certain thickness, which wasn't part of the original design. Such a proposal was accepted in order to avoid the reproduction of the combustion chamber and the 24 burners accompanied with added cost. But probably this modification affected the proper operation of the burners. No optimization of the burner design and the geometry of assembling in the combustion chamber was done to solve the problem during the commissioning stage.

As explained in this paper the solution of the problem was checked in the modification of the GT logic and the improvement of the burners cleaning. After the implementation of the corrective action in the GT logic and adding more procedures for the nozzles cleaning, the behavior of the machine during the operation was reasonably good. No more trips due to high EGT spread were verified during the operation of the GT.

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BIOGRAPHY

Klodian Gumeni was born in Tirana, Albania, in August 1968. He completed the studies at Polytechnic University of Tirana, Tirana, Albania as a Mechanical Engineer in 1991 and then he made the postgraduate school from 2003 to 2006 and completed the Ph.D. degree in 2012, in the same university. Currently, he is working in the TSO (Transmission System Operator) and he is a Professor at Mechanical Department, Faculty of Mechanical Engineering of Tirana, Albania. He used to work as a commissioning engineer for Power Plants and has a long experience as a designer and commissioning engineer in field of the energy production, thermal power plant and, hydropower plant. His research interests are in the area of turbomachines. He is an editorial board member of "American Journal of Engineering Research and Reviews" and "Global Journal of Energy and Environment".