doi: 10.5937/SimTerm24103M

Optimisation of Electrostatic Precipitators in Pulverised Lignite-Fired Thermal Power Stations

Zoran Marković[a], Milić Erić[b], Aleksandar Milićević[c], Ivan Lazović[d], Predrag Stefanović[e] Ilija Stevanović[f]

[a]*Vinca Institute of Nuclear Sciences – National Institute of the Republic of Serbia - University of Belgrade, RS, zoda_mark@vinca.rs*
[b]*Vinca Institute of Nuclear Sciences – National Institute of the Republic of Serbia - University of Belgrade, RS, milic@vinca.rs*
[c]*Vinca Institute of Nuclear Sciences – National Institute of the Republic of Serbia - University of Belgrade, RS, amilicevic@vinca.rs*
[d]*Vinca Institute of Nuclear Sciences – National Institute of the Republic of Serbia - University of Belgrade, RS, ivan.lazovic@vinca.rs*
[e]*Vinca Institute of Nuclear Sciences – National Institute of the Republic of Serbia - University of Belgrade, RS, pstefan@vinca.rs*
[f] *Electrical Engineering institute Nikola Tesla Joint Stock Company, Belgrade, RS, istevan@ieent.org*

Abstract: The energy transition while maintaining energy security and environmental protection is recognized by the Republic of Serbia and Joint Stock Company Elektroprivreda Srbije (EPS) as a priority in the implementation of the Green Agenda. From 2004, a detailed reconstruction and modernization of the electrostatic precipitators (ESP) of the 15 units of the thermal power plant (TPP) in the EPS system was carried out. The aim was to reduce particulate matter emissions from each unit below the limit value of 50 mg/Nm3. This resulted in a reduction of more than 90% in particulate matter. Over the past ten years, however, periodic measurements of particulate emissions have revealed a decline in the efficiency of many ESP systems, usually due to deterioration in coal quality. The plate-wire ESP achieves maximum dust removal efficiency by simultaneously generating the maximum spark voltage over a homogeneous velocity field of the flue gas between the plates. The consortium consisting of the Vinča Institute of Nuclear Sciences and the Nikola Tesla Electrotechnical Institute successfully diagnoses these new working conditions of the ESP based on the results of periodic measurements of particulate emissions, the results of measurements of flue gas velocity distribution in the ESP channels and chambers and the results of measurements of various electrical parameters of the ESP. Detailed analyses and numerical simulations are used to identify the existing limitations of ESP properties and to investigate suitable measures to improve ESP efficiency. This paper presents the results of the testing and optimization of the ESP of five thermal power units in the EPS system, which was carried out from 2020 onwards. The implementation of the measures proposed by the consortium, both the reconstruction of the mechanical turning and damping elements of the ESP and the installation of the proposed new power control elements, was carried out as part of the annual overhaul of these units. The effectiveness of the measures applied is demonstrated by the fact that the particulate emissions of each optimized ESP were reduced from over 60 mg/Nm^3 to around 30 mg/Nm^3.

Keywords: electrostatic precipitator, particulate emission, computational fluid dynamics simulations, on site measurements.

1. Introduction

Particulate matter emissions are one of the most serious environmental problems that pose a major health risk to people [1]. About 70% of electricity generation in the Republic of Serbia is based on the combustion of low-grade lignite from open pit mines in thermal power plants. Currently, the Republic of Serbia has neither the resources nor the potential to ensure a stable and independent electricity supply without relying on coal. Therefore, taking into account the national circumstances and interests of the Republic of Serbia and EPS, energy transition while maintaining energy security and environmental protection is recognised as a priority in the implementation of the Green Agenda [2]. From 2004, the refurbishment and modernisation of the electrostatic precipitators (ESP) in all 15 thermal power plant (TPP) units of the EPS system was completed with a total investment of around 97 million euros, reducing particulate matter emissions from these units to below the limit value of 50 mg/Nm^3. As a result, particulate matter emissions were reduced by up to 90% (from 66,626 tonnes in 2003 to 6,344 tonnes in 2022). During operation, some of these plants have experienced increased particulate matter emissions compared to the permitted [3] emission limit value (ELV), which is due to the change in working conditions compared to the design conditions, as shown by the results of periodic and continuous measurements carried out in recent years. The most frequent causes of the deterioration in operating conditions are poorer coal quality compared to the design, erosion of turning vanes in the ducts upstream of the ESP and of distribution plates in the ESP [4], increased temperature and flow of the flue gases compared to the design values [5], obsolescence of the equipment, failures of the electrical fields of the high-voltage supply systems, etc. Many factors influence ESP dedusting performance, such as the flue gas velocity distribution and turbulence level [4, 6], the strength and distribution of the electrical field [7], the size, resistivity and charge of particles [8], electrode configurations inside an ESP [9], temperature and compositions of the gas [5], etc. The Matts-Öhnfeldt [8, 9] generalized form of the ordinary Deutsch-Anderson equation gives relation for the ESP collection efficiencu η as the ratio of outlet C_{out} and inlet C_{in} dust concentration via the particle migration velocity, ω_{k}, the ESP colecting area, A, and the gas flow rate, Q:

$$\eta = \frac{C_{out}}{C_{in}} = e^{\left[-\left(\frac{\omega_k A}{Q}\right)^k\right]} \tag{4}$$

with the parametar k allowing to compensate for different particle size distribution of the incoming dust (of the values around 0.5 for coal-fired boilers, while k = 1 coresponds to a uniform particle size, thus to the original Deutch equation). It could be shown that, if we take so called coefficient of variation (CV) as a measure of the uniformity of the cross sectional gas flow profile in ESP, defined as the ratio of the standard deviation to the mean [4, 10]:

$$CV = \frac{S_{tdev}}{\bar{v}} = \frac{1}{\bar{v}}\sqrt{\frac{\sum_{i=1}^{n}(v_i - \bar{v})^2}{n-1}} \tag{5}$$

with $\bar{v}$ being the average gas velocity in the ESP cross-section $\bar{v} = \frac{1}{n}\sum_{i=1}^{n} v_i$, for the case of relatively small velocity variation and not extremely high value of the collection efficiency, the maximum theoretical ESP collection efficiency results from perfectly uniform gas velocity [4]:

$$\eta \approx e^{\left[-\left(\omega_k \left(1-k(CV)^2\right)^{\frac{1}{k}} \frac{A}{Q}\right)^k\right]} \tag{6}$$

where Q [m^3/s] is gas flow rate, ω_{k} [m/s] – particle migration velocity, A [m^2] - the ESP collecting electrode area. The eq. (3) indicates that maximum theoretical ESP collection efficiency results from perfectly uniform gas velocity distribution over the ESP's chamber cross section (CV = 0).

The migration velocity ω represents the ability to collect particles within a certain ESP and depends on the particle size, the strength of the electric field and the viscosity of the flue gas [9]:

$$\omega = \frac{d_p \cdot E \cdot E_m}{4 \cdot \mu \cdot \pi} = \frac{q \cdot E}{3 \cdot \mu \cdot \pi \cdot d_p} \tag{7}$$

where d_{p} – is the particle diameter [μm], q - charge of a particle [C], E_m - electric field strength [V/m] in charged particles, E - electric field strength [V/m] in the collected particles (normal field near the deposition electrodes, expected values 300-400 kV/m), μ - gas viscosity [Pa·s], π = 3.14. Therefore, the dust removal efficiency also depends on the intensity of the electric field in the ESP chamber. If presents the efficiency of dust removal as:

$$\eta = 1 - \frac{C_{out}}{C_{in}} = 1 - e^{-\left(a \cdot \frac{P}{Q}\right)} \tag{8}$$

where P/Q [$W/1000 \cdot m^3/h$] is the power density of the corona, then high dust removal efficiency could be obtained only for high values of the power density of the corona [11]. A high dust removal efficiency of an ESP is achieved by simultaneously establishing a homogeneous flue gas velocity field in the vertical sections of the ESP chamber, which flows through the optimally regulated electric field inside the ESP chamber [12].

The consortium, consisting of the Vinča Institute for Nuclear Sciences, the Institute of National Importance for the Republic of Serbia, the University of Belgrade and the Electrotechnical Institute Nikola Tesla AD Belgrade, has been successfully developed and applied new measurement euipement [13] and original methodology for diagnosing the working conditions of the ESP. The methodology consists of the following steps:

a) inspection of the electrical and mechanical equipment of the ESP;

b) on-site measurements (distribution of velocity, temperature and flue gas composition in the flue gas ducts, particulate matter emissions, distribution of air velocity in vertical cross-sections of the ESP chamber) and laboratory analyses of coal, fly ash and bottom ash;

c) numerical CFD simulations of various geometric solutions of the structural elements of the ESP (channels, turning and guide vanes, distribution plates) in order to obtain the geometrical solution which enable the best flow homogeinity in the ESP chamber. The most commonly used parameters for assesing flow homogeinity were the dimensionless momentum M_k (Boussinesq coefficient) and energy correction coefficient N_k (Coriolis coefficient) [14]:

$$M_k = \frac{\int v^2 dA}{v_{avg}^2 A_{tot}} = \frac{1}{A_{tot}} \sum_{i=1}^{n} \left(\frac{v_i}{v_{avg}} \right)^2 \Delta A_i, \qquad N_k = \frac{\int v^3 dA}{v_{avg}^3 A_{tot}} = \frac{1}{A_{tot}} \sum_{i=1}^{n} \left(\frac{v_i}{v_{avg}} \right)^2 \Delta A_i \tag{1}$$

where v_i [m/s] is a mean velocity through the elementary surface i of the cross-section of the ESP chamber, v_{avg} [m/s] – mean velocity in the cross-section, ΔA_i [m^2] – elementary surface i and n – number of elementary surfaces i in the cross-section of the ESP chamber. The values of M_k and N_k are equal to unity only under the uniform flow conditions. The further the flow deviates from uniformity, the greater these values become.

d) numerical simulation of the structural and electrical parameters of ESP (gas flow rate, ratio of total length and height of ESP, gas residence time, specific surface area of the specific collection area (SCA), effective migration velocities ω_e, ESP efficiency, etc.) for the various ESP power supply solutions.

The results of the applied methodology enable detailed theoretical and numerical analyses with the aim of identifying the existing limitations and defining the measures to be taken in order to achieve a high efficiency of the analysed EF systems. The effectiveness of the proposed measures is reflected in the fact that, following their application to the ESP of unit A4 of the TPP TENT A4, ESP of unit B2 of the TPP TEKO B and ESPs of units A1 and A2 of the TPP TEKO A, particulate emissions have been reduced from over 60 mg/Nm^3 to around 30 mg/Nm^3, which puts emissions well below the ELV.

2. Results and discussion

2.1. Unit A4 of TPP Nikola Tesla A

The TENT A4 350 MW power unit has two 4-stage, plate-type, dry ESPs, reconstructed and modernized during the capital overhaul made in 2007. The reconstructed ESP consists of two separate chambers with eight hoopers for dust collection. The flue gas duct is long and very complex with a wide-angled, asymmetrical diffuser and confusor (Fig.1). Chambers are electrically divided into four zones, equipped with four 50 Hz transformers of conventional type and with single-phase anti-parallel thyristor bridges. The effective length, width and height of each ESP casing are 17.6 m, 16.24 m and 17.7 m respectively. The total area of collecting electrodes (CEs) in one chamber is 23296 m^2. Each of four electrical zones I-IV contains 40 CEs with 400 mm wide passages beetwen neighboring CEs. A new control and power supply systems were installed, providing primary voltage of 400 V/50 Hz, primary current of 430 A, secondary voltage peak (without load) of 106 kV, average secondary current for the field of 1700 mA. The reconstructive interventions proposed by the INN Vinca – EI Nikola Tesla consortium are marked in red in Figures 1 and 2 and consists of installation of new set of turning vanes in the inlet elbow (I), new set of guide vanes in the difusser (II) and new set of turning vanes in the outlet elbow (III). The fourth proposed intervention was the replacement of two existing single-phase thyristor power supplies (1-T/R) in the first zone of the left and right ESP chambers with three-phase thyristor power supplies (3-T/R) with increased secondary voltage and current values. The results of the numerical simulation for the ESP model with the newly proposed structural elements are shown in Figure 2. The newly established flow has one small dead zone in the center of the ESP chamber, but results in very aceptable homogeinity parameters in the front of each and behind the last electrical field.

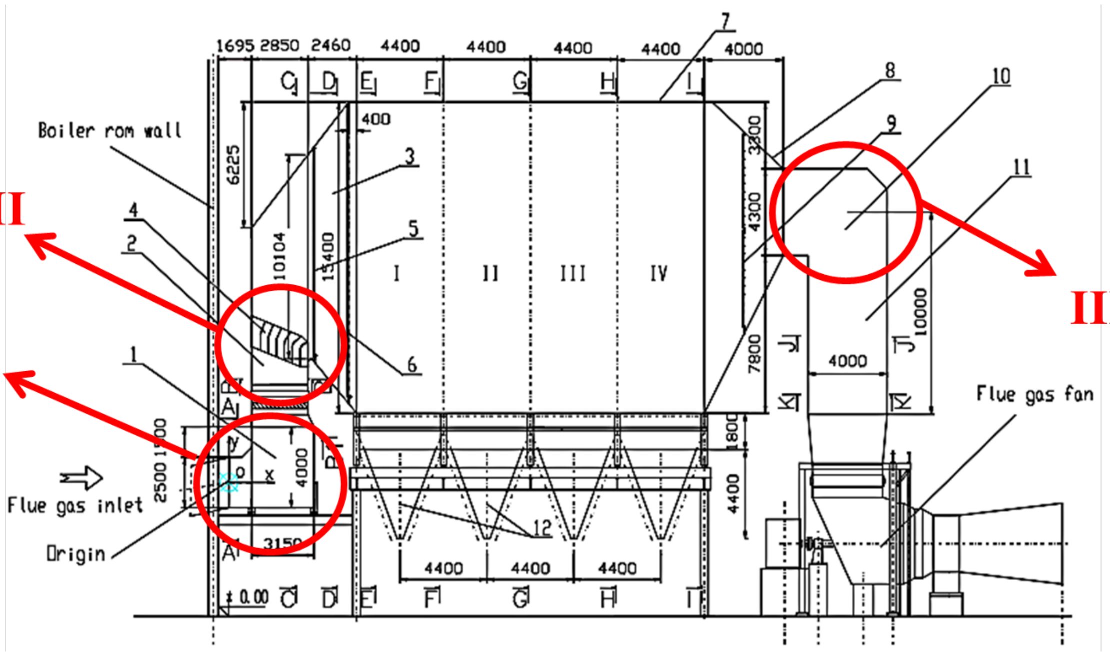

Figure 1. ESP of unit A4of TPP TENT A – side view: 1 - inlet elbow, 2 –inlet channel, 3 – ESP diffuser, 4 – turning vanes, 5 – 1st perforated plate, 6 – 2nd – perforated plate, 7 - ESP casing, 8 – confussor, 9 - outlet screen, 10 – outlet elbow, 11 – outlet channel, 12 – hoppers, I – IV - electrical zones. Red marks for reconstructive intervention: I – new set of turning vanes in the inlet elbow, II – new set of guide vanes in the diffuser, III – new set of turning vanes in the outlet elbow

Applied measures resulted in reduction of PM concentration from 49.5 mg/m^3 and 84.8 mg/m^3 [15] to the level of 33.8 mg/m^3 and 16.2 mg/m^3 [16] for the left / right ESP chamber, considerablly below the ELV.

2.2. Unit B2 of TPP Kostolac B

The TEKO B2 350 MW power unit has two 4-stage, plate-type, dry ESPs, reconstructed and modernized during the capital overhaul made in 2012.

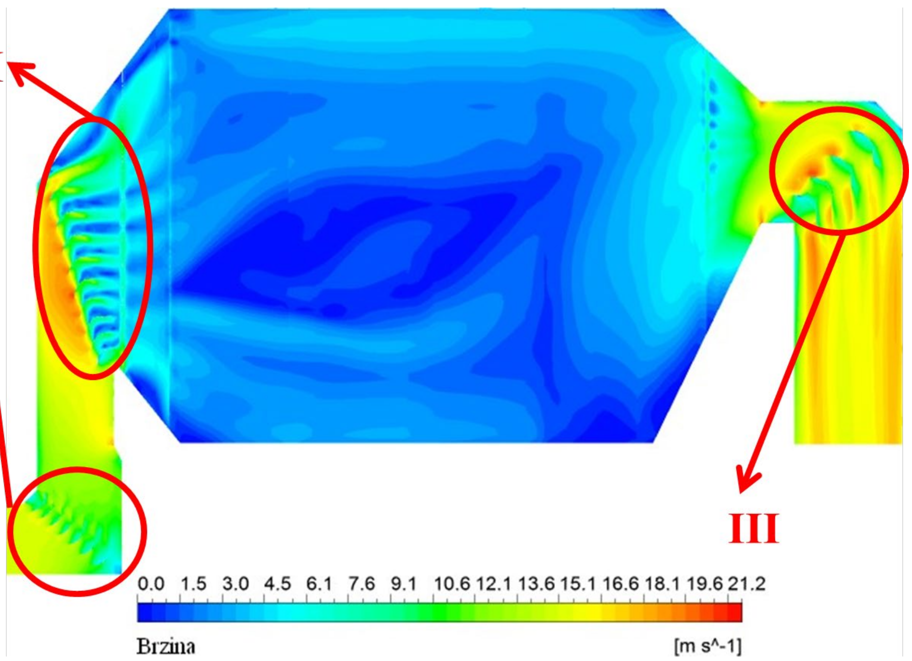

Figure 2. Model of ESP of unit A4 with new proposed set of turning vanes in the inlet elbow (I), new proposed set of guide vanes in the diffuser (II) and new proposed set of turning vanes in the outlet elbow (III), results of numerical simulation, distribution of x-component of the velocity, u [m/s]

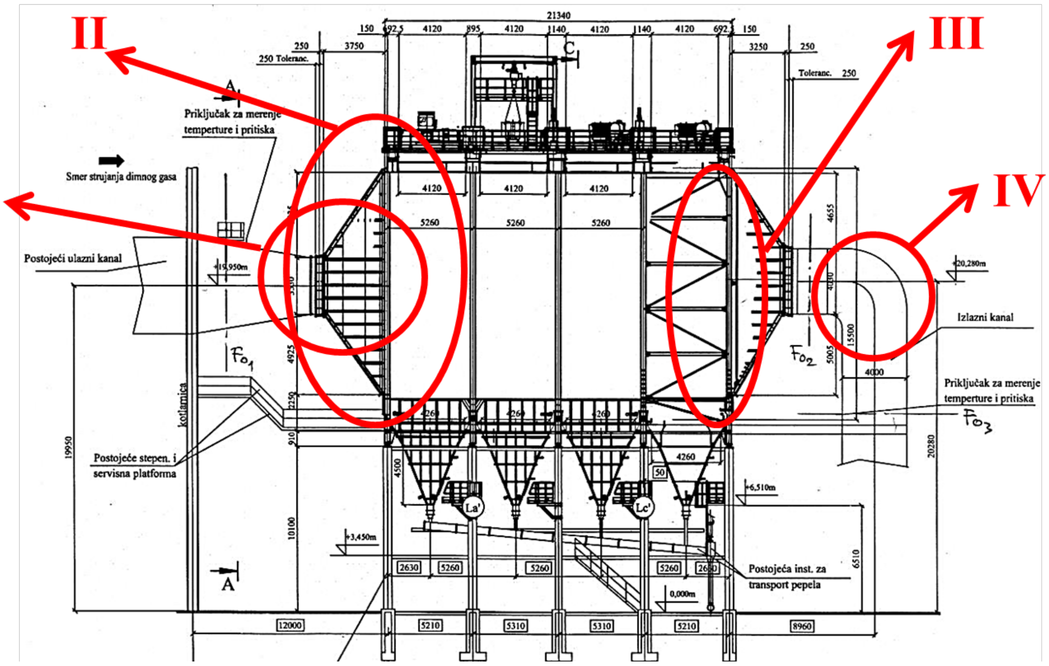

Figure 3. ESP of unit B2 TPP TEKO B – side view. Red marks for reconstructive intervention: I – new set of turning plates in the diffuser, II – new set of guide vanes in the diffuser, III – new distribution plate in the conffusor, IV – new set of turning vanes in the outlet elbow

The reconstructed ESP consists of two units, each with a chamber divided into four mechanical dedusting zones (Fig.3), of which the first two (zones 1 and 2) are divided into two electric fields powered by high-frequency devices (20 kHz), and fields 3 and 4 are fed by transformer rectifier units of the conventional 50 Hz type. In total, there are 6 independent electric fields in the left and 6 in the right chambre. The effective length, width and height of each ESP casing are 21.34 m, 16.87 m and 15.5 m respectively. The total area of collecting electrodes (CEs) in one chamber is 35712 m^2. Each of electrical zones 1 and 2 contains 40 CEs with 400 mm wide passages beetwen neighboring CEs and 32 CEs in the zones 3 and 4 with 500 mm wide passages beetwen neighboring CEs. The reconstructive interventions proposed by the INN Vinca – EI Nikola Tesla consortium are marked in red in Figures 3 and 4 and consists of installation of new set of turning plates in the diffuser (I), new set of guide vanes in the diffuser (II), new design of distribution plate in the conffusor (III) and new set of turning vanes in the outlet elbow (IV).

The flue gas parameters at the inlet of the ESP of unit B2 of TPP Kostolac B in the previous period were lower than the design values in the past period. The actual value of migration velocity ω_{ef} is 36% lower than design value. The area of the CE of about 48000÷58000 m^2 is required instead of the existing 35712 m^2 in order to obtain dedusting efficiency of η = 99.93%. The existing geometry of the electrodes in the ESP chamber allows for much higher values for the secondary current and secondary voltage than the built-in power supply units can realise. The realised values of specific corona current and corona current density are at the lower limit of the recommended for power units of 300÷350 MW. Dedusting efficiency η can be increased by increasing the electrical parameters of the power supply (installation of new power supplies).

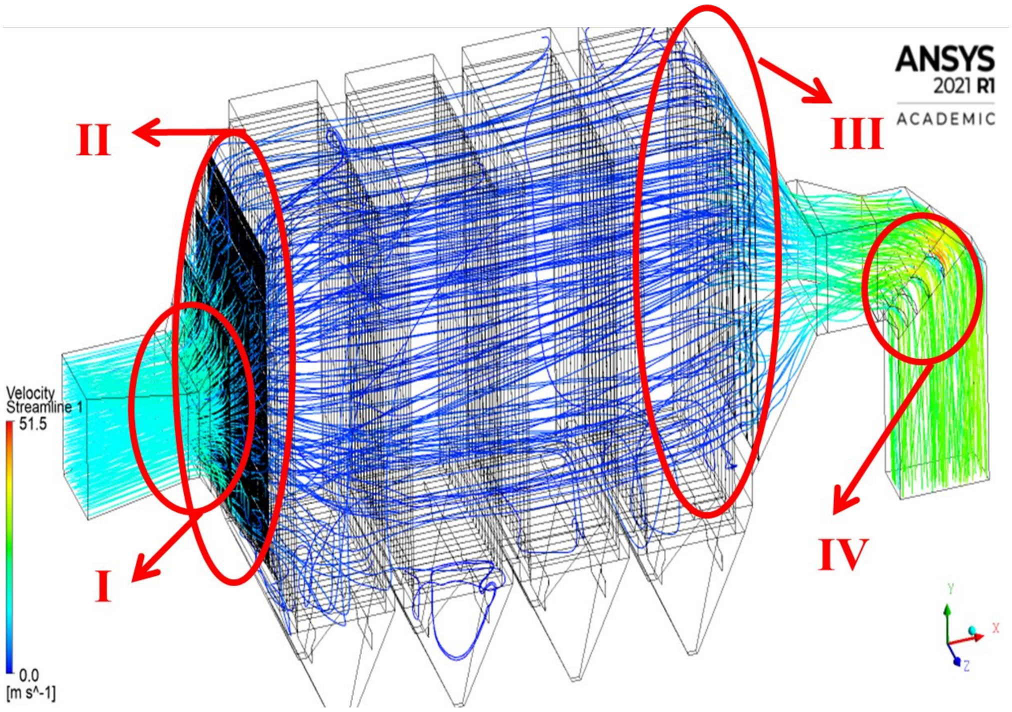

Figure 4. Model of ESP of unit TEKO B2 with new proposed set of turning plates in the diffuser (I), new proposed set of guide vanes in the diffuser (II), new design of distribution plate in the conffusor (III), new proposed set of turning vanes in the outlet elbow (IV), distribution of x-component of the velocity, u [m/s]

Applied measures resulted in good flow homogeinity in the ESP chambers (Fig. 4), with flow homogeinity parameters $M_k < 1.1$ and $N_k < 1.2$ in the cross-sections of theh ESP chamber in the front of the first and behind the last electrical field. The good homogeneity of the flue gas flow was therefore reflected in the reduction of the average PM concentration in three consecutive tests of both ESP chambers from more than 70 mg/m^3 [17] to 29.6 mg/m^3 [18], which is well below the ELV.

2.3. Unit A1 of TPP Kostolac A

Each boiler of TEKO A1 110 MWe power unit has its own ESP plate-type, dry ESP, reconstructed and modernized during the capital overhaul made in 2005.

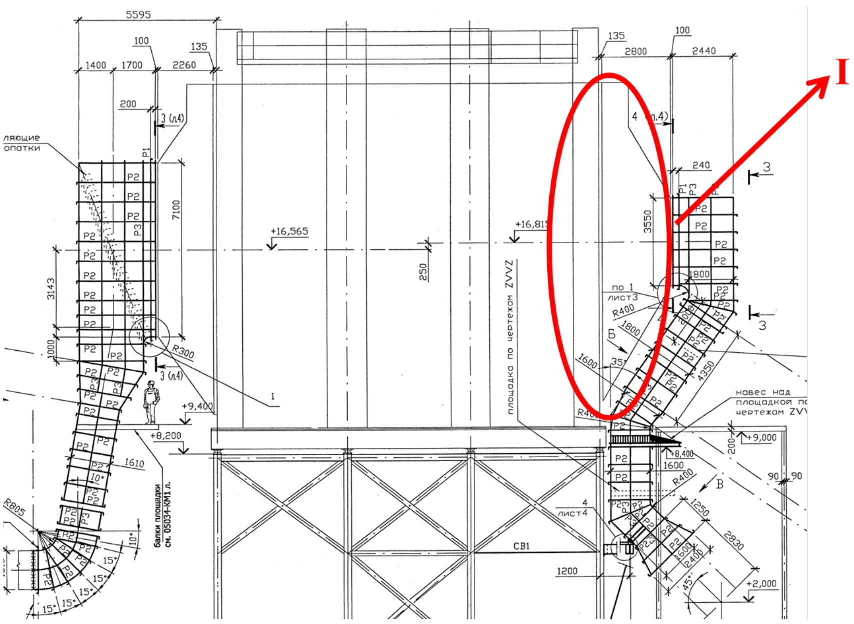

Figure 5. ESP of unit A1 TPP TEKO A– side view. Red marks for reconstructive intervention: I – new distribution plate in the conffusor

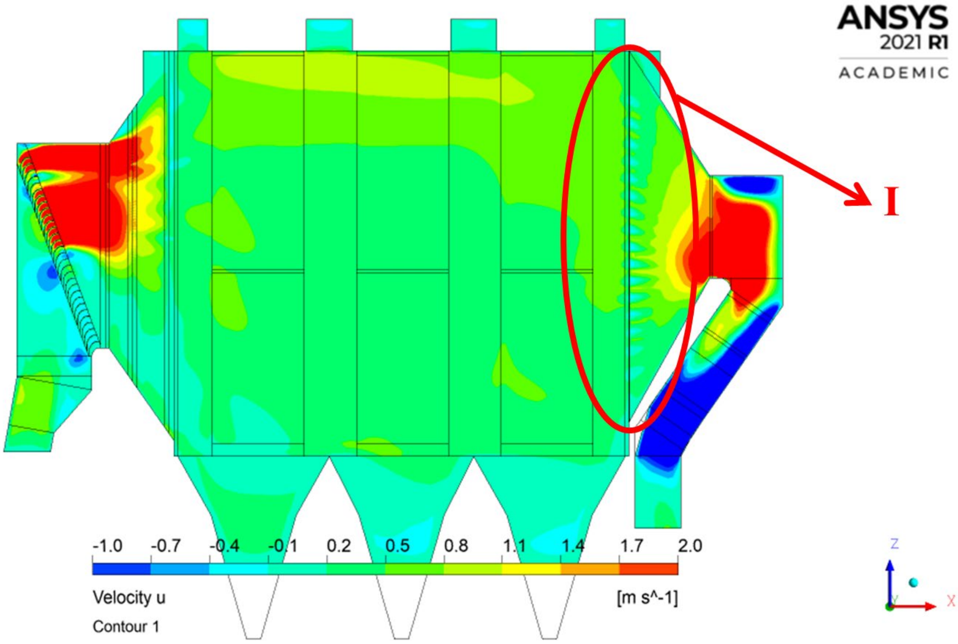

Figure 6. Model of ESP of unit TEKO A1 with new proposed design of distribution plate in the conffusor (I), distribution of x-component of the velocity, u [m/s]

The flue gas duct is long and very complex with a wide-angled, asymmetrical diffuser and conffusor (Fig.5) with a strong conffusor suction effect. The reconstructed ESP consists of two units, each with a chamber divided into 3 mechanical dedusting zones, with 24 CEs with 500 mm wide passages beetwen neighboring CEs. The effective length, width and height of each ESP casing are 15.56 m, 12.2 m and 13.5 m respectively. The total area of collecting electrodes (CEs) in one chamber is 35712 m^2. The reconstructive interventions proposed by the INN Vinca – EI Nikola Tesla consortium are marked in red in Figures 5 and 6 and consists of installation of new design of distribution plate in the conffusor (I).

Maximum design value of the effective migration velocity ω_{ef} = 0.2456 m/s. Minimum specific surface area of the CE is SCA = 29.2 m^2/(m^3/s). Maximum design values of the specific corona current of 0.593 mA/ m^2.

The corona current values were below the design value of 1250 mA in all electrical zones, especially in zones 1 and 2. The temperature and oxygen content in the flue gas were above, while the flue gas flow was approximately equal to the design value and the PM concentration at the inlet of the ESP was below or close to the design value. During the annual overhaul of the ESP TEKO A1 in 2022, the single-phase thyristor-controlled (1-T/R) supplies of the first electrical fields were replaced by improved three-phase thyristor power supplies (3-T/R). Periodic emission measurements carried out after the modernisation showed that the corona current in the first zone had increased to 1035÷1135 mA, i.e. ~90% of the design value. In addition, the installation of a new distribution plate in the conffusor significantly improved the flow homogeneity in the ESP chamber by elimination of conffusor suction effect, which overall helped to increase the efficiency of the ESP above the design value of 99.923% and reduce particulate emissions from more than 75 mg/Nm^3 to level of 27.8÷42.2 mg/Nm^3.

2.4. Unit A2 of TPP Kostolac A

The ESP of unit TEKO A2 210 MWe has two 4-stage, plate-type, dry ESPs, reconstructed and modernized during the capital overhaul made in 2006. The flue gas duct is long and very complex with a wide-angled, asymmetrical diffuser and conffusor (Fig.7) with a strong conffusor suction effect. The reconstructed ESP consists of two units, each with a chamber divided into four mechanical dedusting zones, with 36 CEs with 400 mm wide passages beetwen neighboring CEs. The effective length, width and height of each ESP casing are 17.28 m, 14.59 m and 15.23 m respectively. The total area of collecting electrodes (CEs) is 37897 m^2. The reconstructive interventions proposed by the INN Vinca – EI Nikola Tesla consortium are marked in red in Figures 7 and 8 and consists of installation of new set of turning plates in the diffuser (I), new design of distribution plate in the conffusor (II) and new set of stop plates in the dust collecting hoppers (III).

Ditailed analysis concluded that effective migration velocity ω_{ef} = 0.1229 m/s was correctly assumed. Also, it was faund that ESP has a high specific CE surface area of SCA = 57.42 $m^2/(m^3/s)$ and low design flue gas velocity through the chamber of 1.5 m/s, a long length of the active electric fields of 17.28 m and long residence time in the zone of active electric fields of 11.5 s. Actual corona current were below the design value of 4100 mA/chamber. The temperature and oxygen content in the flue gas were above, while the flue gas flow was below or around the design value. PM concentration at the inlet to the ESP were around the design value. Low dedusting efficiency in previous period was the result of a combination of unfavourable electrical parameters and flue gas parameters, but after reconstruction proposed by the INN Vinca – EI Nikola Tesla conzortium the flow field in the ESP chamber has improved significantly (Fig.8), eliminating conffusor suction effect and dust reentrainment from hoppers, thus leading to a reduction in PM emissions.

3. Conclusion

A complex methodology was developed and successfully applied to define a technical solution for increasing the dedusting efficiency of ESP unit A4 of TPP Nikola Tesla A, unit B2 of TPP Kostolac B and units A1 and A2 of TPP Kostolac A. The methodology is based on complex on-site measurements of flue gas temperature, composition and velocity distribution in the ducts and chambers of the ESP, as well as on the analysis of the measured operating parameters of the ESP and the TPP unit, the properties of coal, fly ash and bottom ash determined in the laboratory, the results of numerical CFD analyses and the results of the calculation of the complex electrical parameters of the ESP.

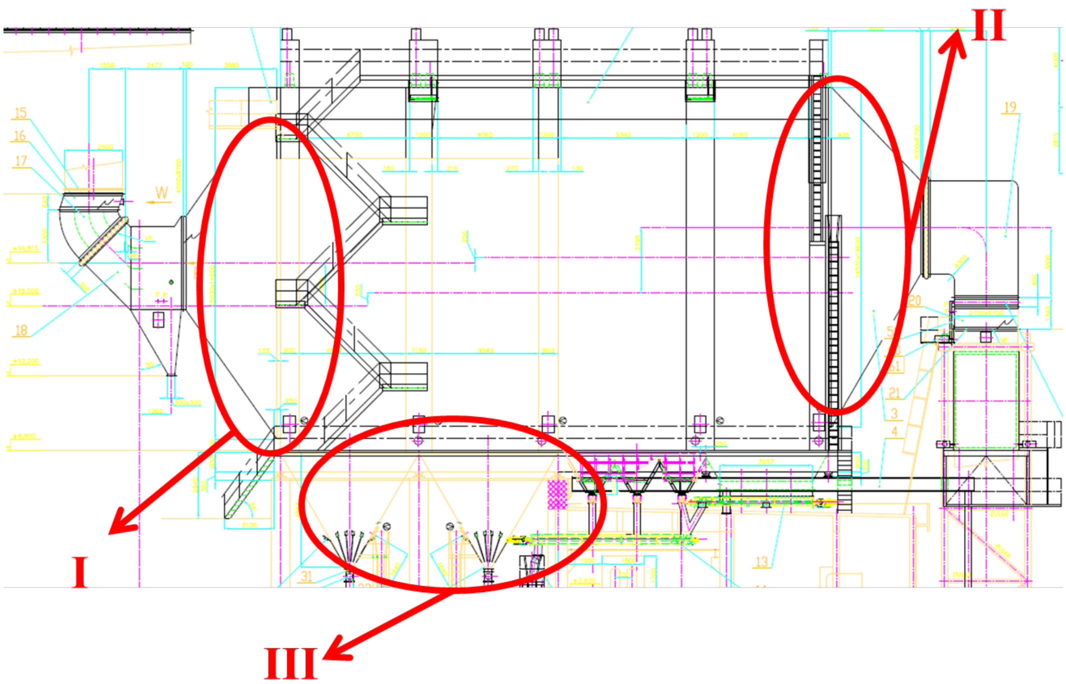

Figure 7. ESP of unit A2 TPP TEKO A– side view. Red marks for reconstructive intervention: I – new set of turning plates in the diffuser, II – new distribution plate in the conffusor, III – new set of stop plates in the dust collecting hoppers

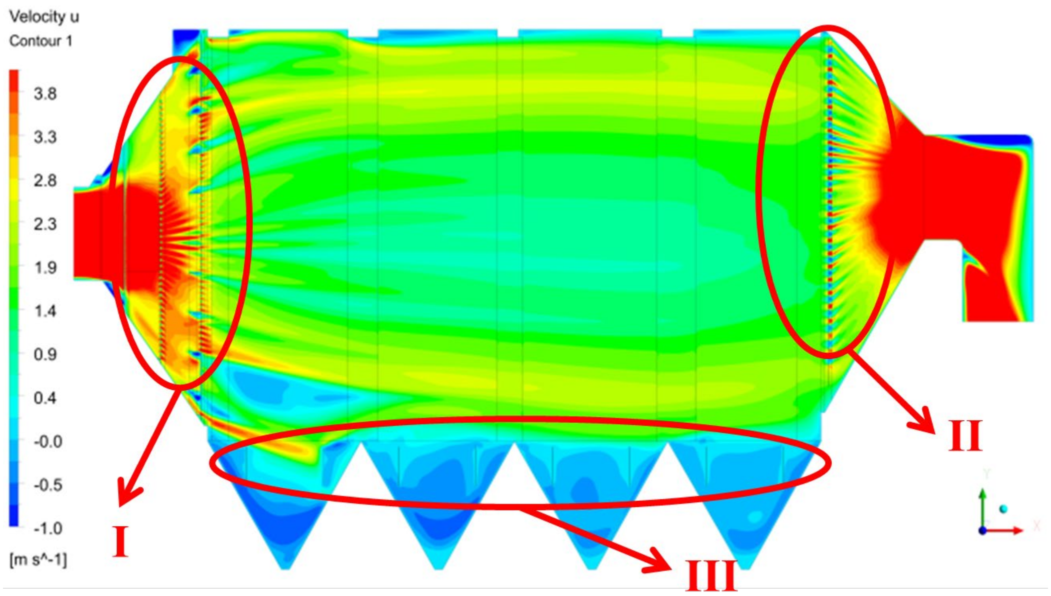

Figure 8. Model of ESP of unit TEKO A2 with new proposed set of turning plates in the diffuser (I), new proposed design of distribution plate in the conffusor (II) and new proposed set of stop plates in the dust collecting hoppers (III), distribution of x-component of the velocity, u [m/s]

A mathematical algorithm was developed to calculate the parameters of the ESP and increase the efficiency of its operation. Special measuring devices were developed and successfully used to measure the air velocities in large vertical cross-sections of the ESP chamber. The need for regular, periodic measurements of particulate matter emissions is once again evident and proves to be a reliable source of information on the operating parameters of the ESP. Regular inspections and measurements of the velocity distribution in the ESP chamber during the periodic overhaul of the TPP unit and the ESP are necessary to determine mechanical elements that are damaged by erosion and need to be replaced in order to improve the flow homogeneity and thus the efficiency of the ESP.

Acknowledgements

The research was funded by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract Annex: 451-03-66/2024-03/200017). The authors are very grateful for the support of this work by the Joint Stock Company Elektroprivreda Srbije.

References

[1] Cliff I. Davidson , Robert F. Phalen & Paul A. Solomon, Airborne Particulate Matter and Human Health: A Review, *Aerosol Science and Technology*, 39:8, (2005), pp. 737-749, DOI: 10.1080/02786820500191348
[2] EUROPEAN COMMISSION, Guidelines for the Implementation of the Green Agenda for the Western Balkans Accompanying the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions An Economic and Investment Plan for the Western
[3] Balkans, COM(2020) 641 final, pp. 1-22, https://www.mei.gov.rs/upload/documents/eu_dokumenta/2020/green_agenda_for_the_western_balkans_en.pdf
[4] Directive 2001/80/EC of the European Parliament and of the Council of 23 October 2001 on the limitation of emissions of certain pollutants into the air from large combustion plants
[5] A. Bäck, Relation Between Gas Velocity Profile and Apparent Migration Velocity in Electrostatic Precipitators, *International Journal of Plasma Environmental Science & Technology*, Vol.11, No.1, (2017), pp. 104-111
[6] Bao-YuGuo, Ai-BingYu, JunGuo, Numerical modeling of electrostatic precipitation: Effect of Gas temperature, *Journal ofAerosol Science* 77 (2014), pp. 102–115
[7] Munnannur A, et al., Development of Flow Uniformity Indices for Performance Evaluation of Aftertreatment Systems, SAE Int.J.Engines, 4 (1), (2011), pp. 1545 – 1555
[8] Jaworek, A., et al., Two-stage vs. two-field electrostatic precipitator, *Journal of Electrostatics* 90, (2017), pp. 106–112
[9] Arkadiusz Świerczok, Maria Jędrusik, The collection efficiency of ESP model - Comparison of experimental results and calculations using Deutsch model, *Journal of Electrostatics,* 91 (2018), pp. 41–47

[10] Ning, Z., et al, Electrode configurations inside an electrostatic precipitator and their impact on collection efficiency and flow pattern, *Eur. Phys. J. D* 70: (2016), 126
[11] Dazhou Zhao et al, Flow Field Simulation and Optimization Design of SCR of 660MW Power Unit Based on CFD Study, 2018 *IOP Conf. Ser.: Earth Environ. Sci*. 170 (2018), 042031
[12] Ken Parker, Electrical Operation of Electrostatic Precipitators, Institute of Engineering and Technology, London (2007), p. 74, Figure 4.10
[13] Marković Zoran J., Erić Milić D., Stefanović Predrag Lj., Jovanović Rastko D., Lazović Ivan M., Optimization of the flue gas flow controlling devices of the electrostatic precipitator of unit 4 in TPP "Nikola Tesla", Thermal Science, (2023), OnLine-First (00):24-24.
[14] Lazović, Ivan; Marković, Zoran; Erić, Milić; Jovanović, Rastko; Tasić, Viša; ''Transport trolleys for anemometers for testing the air velocity profile in the chambers of electrostatic precipitators of large emitters'', Petty Patents, Intellectual Property Gazette 2022/11 (12/12), published 30.11.2022., Republic of Serbia, ISSN 2217-9143 (Online) Intellectual property office (in serbian)
[15] Zhou, J., et al., Energy and momentum correction coefficients within contraction zone in open-channel combining flows, Water Science and Engineering, 14(4), (2021), pp. 337-344
[16] Test report no. E-28/16/JPEPS/TENT-A 456, December 2016, Laboratory for work and environment protection, Mining Institute Belgrade (in serbian)
[17] Test report no. E-05/20/JPEPS/TENT-A 456, February 2020, Laboratory for work and environment protection, Mining Institute Belgrade (in serbian)
[18] Erić, M., Marković, Z., Periodic Measurement of Pollutant Emissions in the Air of Units B1 and B2 of the Kostolac Power Plant in Kostolac, Technical Report NIV-LTE-662, Vinča Institute, July 2020, Belgrade-Vinča (in serbian)
[19] Erić, M., Marković, Z., Periodic Measurement of Pollutant Emissions in the Air of Unit B2 of the Kostolac Power Plant in Kostolac, Technical Report NIV-LTE-682, Vinča Institute, December 2021, Belgrade-Vinča (in serbian)