Achieving Equal Flow Distribution with Flow Control Devices at outlet of Electrostatic Precipitator Using Control Dampers

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Abstract— This paper clearly focuses on the capabilities of CFD tools, which can be effectively used to simulate the gas flow inside the ESP in order to obtain equal flow distribution among all ESP passes at different operating conditions. This is in line with the international ICAC standard which is governed by strict environmental norms. In order to meet this objective, 1:1 scaled three dimensional geometric model is simulated computationally for a typical 500 MW Power plant, which faces this uneven issues of flow distribution as well as high loading of ID fan. The CFD model contains the computational domain starting from the outlet of Air pre-heater to the inlet of ID Fan along with ESP's for simulating the flow of flue gas. Developed 3D numerical model corresponding to the actual site layout is created, meshed and analyzed using ANSYS workbench. The results obtained using CFD are validated against the experimental results evaluated from the typical project site. Flow control in different ESP passes were achieved, along with reduction in pressure drop, which considerably reduces the loading of ID fan. The position of control dampers at each ESP outlet passes are simulated here in order to obtain equal flow distribution among all ESP passes for different cases like, while all ESP's are in operation or during the pass isolation condition. The capabilities of CFD are fully extended here by simulating the actual site conditions, thereby eliminating the need for experimental setup, which involves more trial and error conditions and also being advantageous in simulating various flow parameters in a short time with cost effective solutions.

Keywords— CFD, ESP, ICAC, ANSYS, Control Dampers

Introduction

Electro Static Precipitator, abbreviated as ESP is the commonly used pollution control equipment for filtering the coarse and fine ash particles from the dust laden flue gas flowing from boiler towards the chimney.

The total flue gas flow coming from the boiler via air-preheater has to be divided equally among all ESP's in line with international standard of ICAC (Institute of Clean Air Companies) [1, 2]. As per ICAC standard, EP-7 the total fuel gas flowing towards ESP should be divided equally among all ESP's, in order to achieve equal flow as well as equal collection of ash at ESP hoppers.

In conventional ESP's, there are various flow correction devices located inside the ESP like splitters and gas distribution screens for uniform flow distribution, while flow control devices like guide plates and guide vanes are located outside the ESP at common inlet ducting system before ESP inlet. The requirement of guide plates are decided based on the adequacy of enough flue gas flow required for each ESP. If there are more flow for a particular ESP, enough guide plates are suitably placed, to divert the flow in the other direction, where there is less flow [3, 4]. The objective towards the usage of guide plates at ESP inlet ducting system, serves the same purpose for both greenfield and R&M projects (Renovation & Modernization of Existing ESP'S), for achieving equal flow distribution among all ESP's.

Flow Correction Devices

Existing system

Flow control devices such as guide plates are suitably placed inside the ESP inlet ducting system for the equal flow distribution across all ESP passes. But these guide plates if erected will save as a hindrance during isolation of any ESP due to overhauling operation or during part load condition. Also these guide plates serve as useful only during the case, when all ESP'S are in operation and in full load condition.

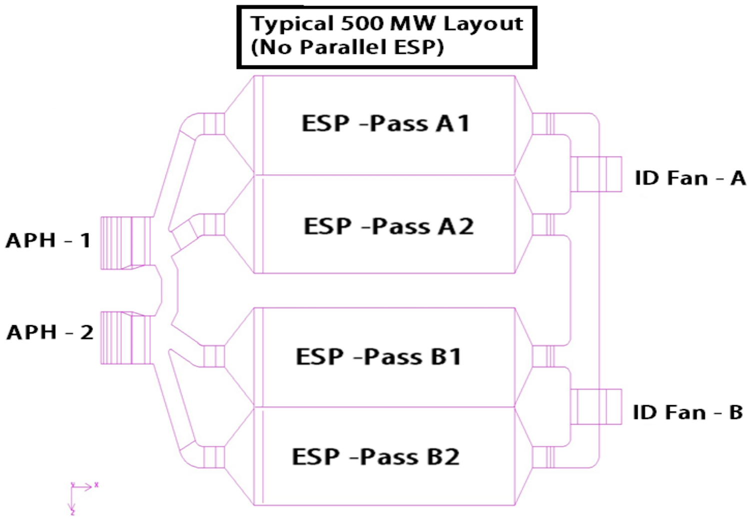
Another major issue highlighted by providing guide plates is erosion caused due to high velocity of gas flow at full load condition. On the other side, at part load condition, the erosion is less, but there might be an ash deposition at low velocity zones formed near guide plate locations. Due to erosion of guide plates, over a period of time, there is an unequal flow distribution across each ESP's, which leads to unequal ash collections. So in order to replace these eroded guide plates, there is a requirement to shut down the entire boiler frequently [5, 6] over a period of time.

Consider the case (Layout-A), from Figure 1, for the typical R&M 500 MW project, where there are two existing ESP's with four passes. Due to R&M work, new parallel ESP is added to left side of the existing layout to suite the extra flow requirements. The tapping point for new ESP was carried out from centre of existing duct, as indicated in the proposed case (Layout B). This was made in order to obtain the symmetrical design, which improves the flow distribution. In case, if new ESP would have tapped from the side of inlet ducting system, it will end up in un-symmetrical layout which impact the flow, resulting in improper gas distribution. The layout scheme proposed in this paper (Layout B) was implemented in a typical 500 MW project site.

Layout and Scheme

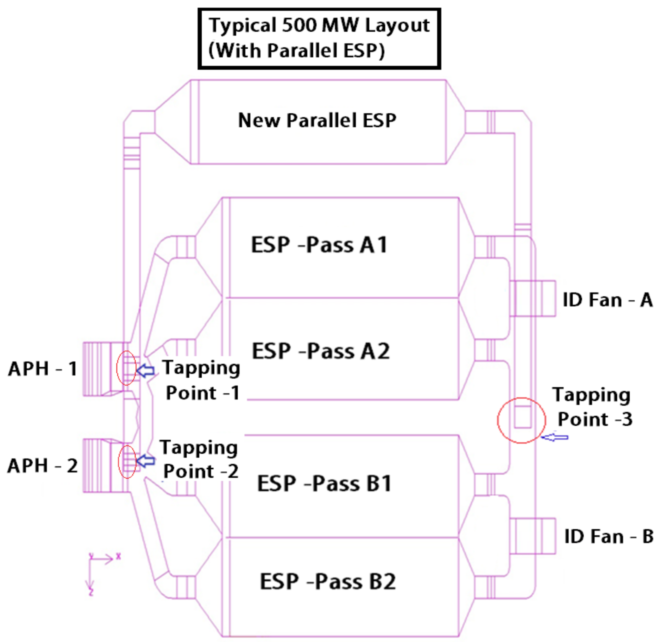
1. Layout A

Fig. 1. Typical 500 MW Layout with No addition of Parallel ESP.



2. Layout B

Fig. 2. Typical 500 MW Layout with addition of Parallel ESP (With tapping Point at centre for both Inlet and outlet)



The entire flow domain of ESP includes tapping point from APH outlet, via ESP chamber till the inlet of ID fan. We can observe from the layout B that the tapping point for new ESP is from the center of the common inlet duct (Tapping point 1&2). Similarly, the tapping point for the new ESP is also midpoint at common outlet ducting system (Tapping point 3), which made the layout symmetrical. To distribute the incoming flow evenly across all ESP's either in full load or half load condition, the guide plates are placed (conventional method) at the inlet of the common ducting system as highlighted in Figure 3. The location of these guide plates are found out by carrying out the experimental study with physical model.

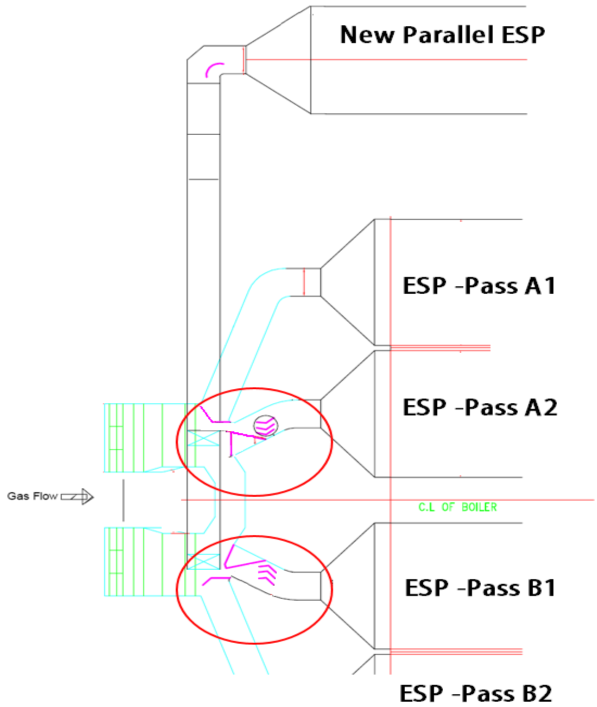


Fig. 3. Guide plates at Inlet ducting System for layout B for Flow Correction (Equal flow for all ESP)

Distribution of required flow for each ESP is studied on a scaled physical model at the ESP laboratory on trial and error basis. These guide plates are required for distributing the equal flow among all ESP passes (New ESP C, A1, A2, B1 & B2). But after a passage of certain time period, these guide plates are eroded, which leads to unequal flow distribution in all ESP passes, not only resulting in emission performance issues, but also leads to high loading of induced draft fan. This problem get further augmented, when there is uneven erosion on guide plates resulting in more unequal flow during normal operation (All ESP's are in operating condition.) or during isolation of any ESP passes.

During continuous operations of ESP there are always some issues related to maintenance, due to which some ESP passes are to be isolated and taken care for a short period or a for prolonged period. During which, other ESPs passes (in operation) are expected to receive equally divided incoming flow. This is not possible with permanent erection of guide plates at inlet of ducting system, whether in eroded or not eroded condition, does not perform well during this pass isolation operation.

The typical project, which considered for this simulation study was also facing similar issues of guide plate deterioration with uneven flow distribution and maximum loading on ID fan. It was then decided to resolve this issue by suitable controlling the flow by placing flow control devices at outlet rather than on the inlet side. As all the big particles associated with erosion are captured by the ESP filter before it reaches the ESP outlet, there will not be any kind of erosion to the flow control devices which are proposed to be located at the outlet side of ESP.

Further it was decided to eradicate the guide plates at inlet side which are static in nature, then replaced with control dampers at outlet side, which are dynamic in nature. The control dampers are used as flow control device, which is operated by varying the opening of duct area more or less depending on the requirement of required flow for each ESP. In the present context, it was decided to remove guide plates completely from the inlet side and providing with control dampers at outlet side for each ESP passes. In this boiler, there are five ESP passes, which leads to the erection of five control dampers at ESP outlet side as highlighted in Figure 4.

Fig 4. Typical 500 MW Project with control dampers at outlet
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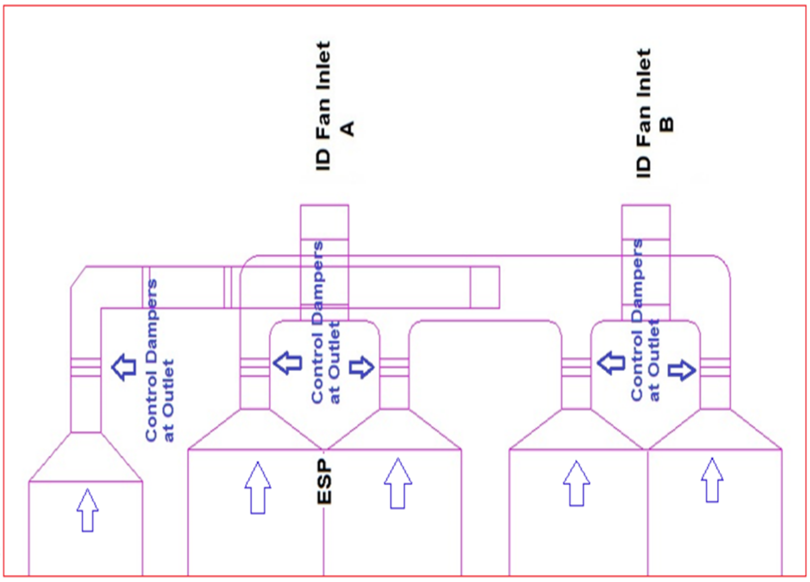


The opening of control dampers at each outlet passes, with respect to different operation conditions (whether all ESP's are in operation or any pass is in isolated state) are to be found out using some methodology. Experimental testing is very costly as well as more time consuming also, while CFD methodology is a standard practice now to apply for any kind of physical problems.

Computational fluid dynamics (CFD) is the powerful analysis and design optimization tool used to resolve any complex flow problems with good accuracy [7]. Hence it was decided to use CFD tool like ANSYS workbench for resolving this present problem of uneven flow distribution.

Computational Modeling – Governing Equations

Ansys Fluent software is the CFD tool that used for the present investigation which is based on finite volume method [8]. It is very important to understand the flow physics behind the study, which is governed by the basic governing equations such as mass conservation, momentum conservation and conservation of energy.

The key step of the finite volume method is the integration of the following generic differential equation over a control volume yielding,

$$\underset{(1)}{\int \frac{\partial(\rho\phi)}{\partial t}} + \underset{(2)}{\int div(\rho u\phi)} = \underset{(3)}{\int div(\Gamma grad\phi)} + \underset{(4)}{\int S}$$

Where (1) denotes unsteady term, (2) denotes convection term, (3) denotes diffusion term and (4) denotes the source term [9, 10].

CFD Models for the Proposed Layouts

The computational model was created in three dimensional using Gambit, as a pre-processor and analysed using ANSYS Fluent. All the structural details of ESP was modelled along with both inlet and outlet ducting system, and hybrid meshed containing 12 million cells. The meshing of the ESP components includes flow control devices such as guide vanes, guide plates, control devices and other main components which impacts the distribution of flow.

The meshed model was then exported into Ansys Fluent for processing and the flow parameters were set at the prescribed Boundary condition. The proposed layout containing the computational domain from APH outlet to ID fan inlet are depicted in Figure 5a and 5b for Plan view and Isometric view respectively

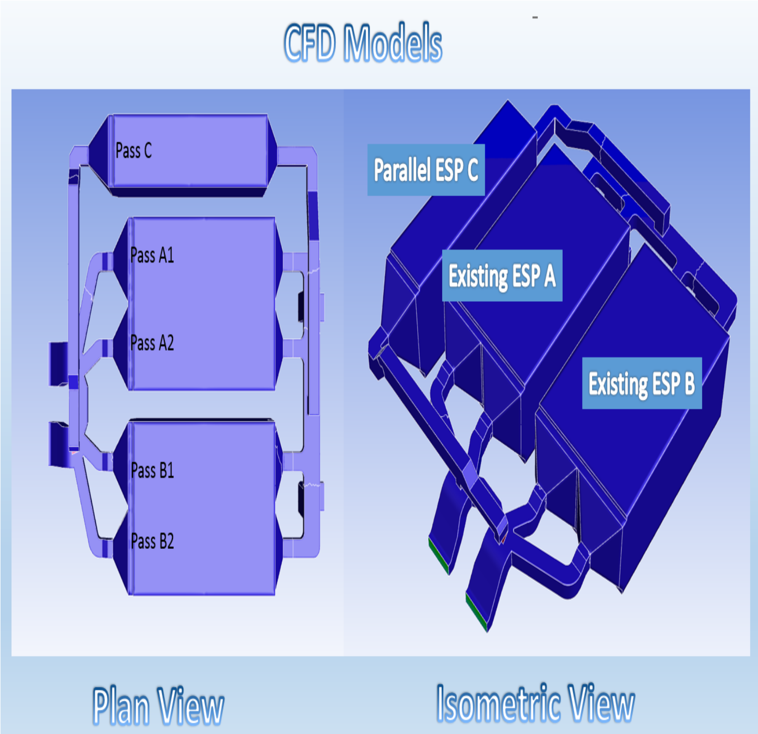


Fig 5. a) Plan View and b) Isometric View of Proposed layout created for CFD analysis, with control dampers

The hybrid meshed CFD model is highlighted in Figure 6, which contain both hexahedral and tetrahedral elements. After the grid independency check, the simulation was carried out till residuals meet the convergence.

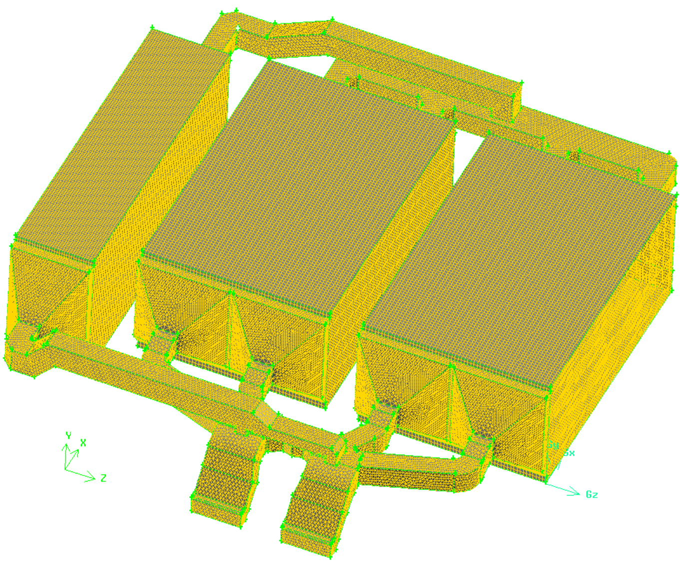


Fig 6. Meshed CFD model for a Typical 500 MW Project

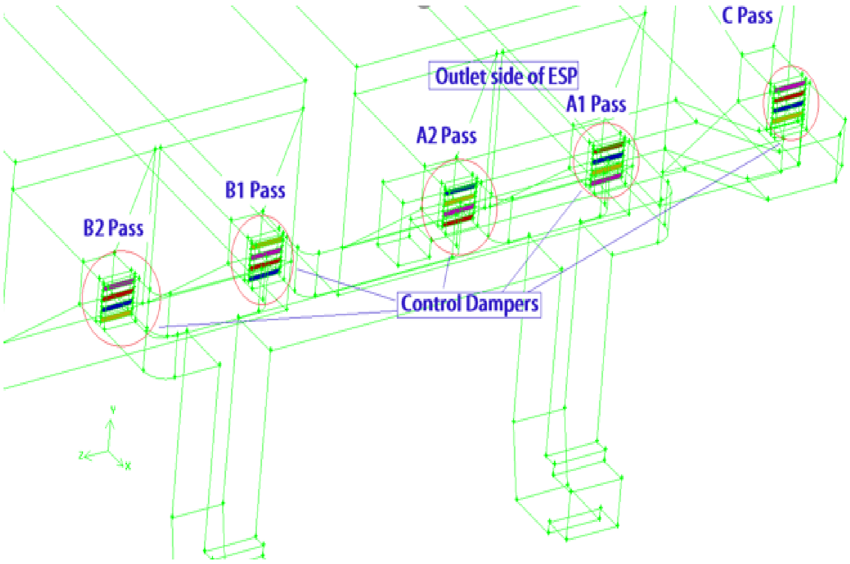
Modifications Using CFD Analysis

The following modifications are proposed, to be implemented at both project site as well as in the CFD analysis.

1) Existing guide plates & vanes at inlet of ESP A and B, as highlighted in Figure 3 are to be cut and removed.
2) Control dampers are to be erected respectively at the outlet of each ESP passes (C, A1, A2, B1 & B2).

The erection of control dampers at outlet of ESP for flow correction is depicted by Figure 7.

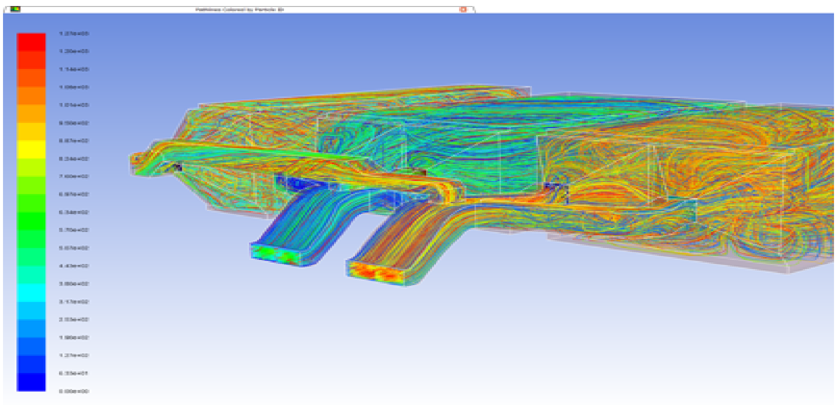
Fig.7. Proposed Modifications with control dampers (at ESP outlet)



Results And Discussion

Processing of CFD model was carried out with the required modifications using ANSYS fluent software. K-omega SST based turbulent model was applied along with other numerical parameters. After the flow convergence, post processing was carried out to analyze the obtained CFD results. Figure 8 portrays the path line contours by particle ID, travelling from APH outlet to ID fan inlet. The simulation was carried out for the following six cases for the purpose of achieving even flow distribution.

Fig.8. Path line contours by particle ID



Case A **– All five ESP's are in operation**

When there is an isolation of single ESP pass, while all remaining four ESP's are in operation, ends up with five cases for simulation

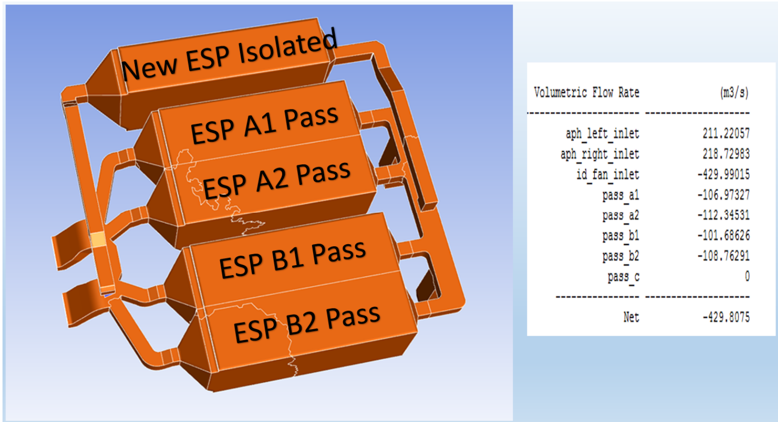
- Case B – Isolation of New ESP
- Case C – Isolation of ESP A1 Pass
- Case D – Isolation of ESP A2 Pass
- Case E – Isolation of ESP B1 Pass
- Case F – Isolation of ESP B2 Pass

While all ESP's are in operation, as per design condition, the total flow rate is calculated to be around 430 m3/s (typical value), out of which one-fourth is required for new ESP pass (ESP C), while remaining flow is to be distributed equally among all ESP's. During pass isolation condition, the required average flow through each ESP Pass A1/A2/B1/B2/C is calculated to be 107.5 m3/s (i.e. one-fourth of total flow, 430 m3/s)

Out of six cases, two cases are demonstrated here. **Case B**, where there is an isolation of new ESP and **Case F**, where there is an isolation of B2 pass. The main objective here is to distribute the flow equally among remaining ESP's which are in operation. As per ICAC standard, the flow can falls within **± 10%** from the average required flow for that particular ESP. The flow distribution pattern for both the cases B and F are highlighted in Figure 9 & Figure 10 as well in the Table 1 & Table 2 respectively.

Case B – Isolation of New ESP

Fig.9. CFD results (Volumetric flow rate achieved from each ESP's)



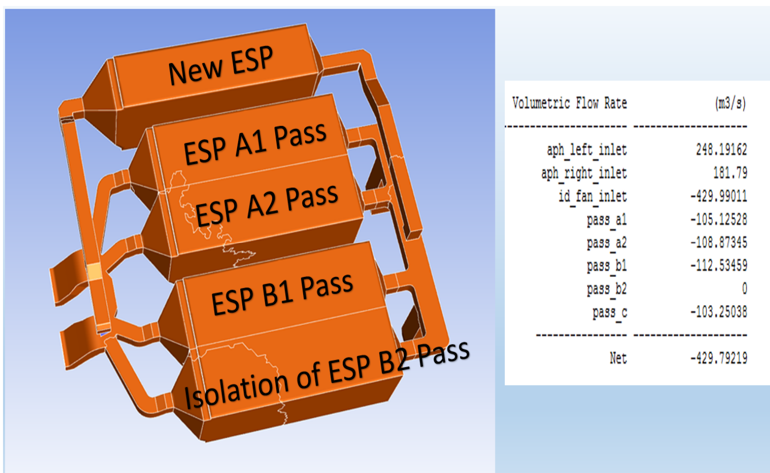
ESP PASSES	Location	Flow Required	Flow Achieved	% of Deviation
Pass A1	Inlet	107.5	106.97	-0.49
Pass A2	Inlet	107.5	112.35	+4.51
Pass B1	Inlet	107.5	101.69	-5.40
Pass B2	Inlet	107.5	108.76	+1.17
NEW ESP	Inlet	ISOLATED		

Table 1. Flow Distribution Pattern for **Case B**

From the flow distribution pattern observed from the Table 1, it is clearly demonstrated that the flow achieved in remaining ESP's which are in operation, meets the ICAC standard of ± 10% from the average required flow.

Case F – Isolation of ESP B2 Pass

Fig.10. CFD results (Volumetric flow rate achieved from each ESP's)



ESP PASSES	Location	Flow Required	Flow Achieved	% of Deviation
Pass A1	Inlet	107.5	105.13	-2.20
Pass A2	Inlet	107.5	108.87	+1.27
Pass B1	Inlet	107.5	112.53	+4.68
Pass B2	Inlet	ISOLATED		
NEW ESP	Inlet	107.5	103.25	-3.95

Table 2. Flow Distribution Pattern for case F

Similarly, for Case F also, flow achieved in remaining ESP's which are in operation, meets the ICAC standard of $\pm$10% from the average required flow. CFD results obtained for the remaining cases (A, C, D & E) also exhibit same characteristics of achieving equal flow distribution among all operational ESP's.

For this to be achieved, there are certain percentage of opening by which control damper positions are to be fixed at all ESP's outlet. For each cases, the ratio of duct opening is varied, by operating control dampers from the ESP outlet side. Control dampers are located outside the ESP and can be operated, either manually or by using actuated motors from the control room. There is no need to wait for boiler shut- down, during pass isolation operation and parallelly achieving equal flow for all the remaining ESP's, without any performance issues. The position of control dampers are to be arrived for each case by using CFD methodology using trial and error method.

The obtained CFD results are implemented in the 500 MW actual project site and control dampers are operated based on the required operating conditions. The site evaluation was also made after the implementation of this control dampers and after the removal of old guide plates from the inlet side. The significant result obtained was in terms of pressure drop reduction. Before this implementation, the pressure drop at ID fan was found to be around 97 mmWC, which is very high during the normal operation. But after this implementation at site, the pressure drop reduced considerably to around 39 mmWC, which is a remarkable difference.

The loading on ID fan correspond to extra power consumption, which is considerably reduced here, also with the achievement of main objective of equal flow distribution. This also results in considerable cost savings due to removal of conventional guide plates which otherwise requires frequent replacement due to high velocity erosion.

Conclusion

Usage of CFD methodology in resolving actual site issues are well demonstrated in this study. The opening ratio of flow control devices such as control dampers are obtained by using this computational tool, suitable employed at 500 MW project site to control flow from outside of ESP without affecting the normal operation for different operating conditions.

Equal flow distribution was achieved as per the ICAC standard in all ESP's which are in operation as well as during pass isolation condition. There is also substantial reduction in pressure drop measured from APH outlet till ID fan inlet after the implementation, resulting in less load for ID fan and leading to more savings and cost reduction. Subsequently, savings in materials consumption through guide plates are also achieved without any performance issues.

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