Electrostatic precipitator upgrade for stricter emission regulation

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Abstract. Electrostatic precipitator (ESP) is still one of the best dust collecting equipment used in many industries. However, in this modern world, many countries, through their government authorities, make the emission rule stricter in order to achieve healthier and cleaner environment. Original design of the ESP may not comply with the stricter rule resulting in complaints from the neighborhood and fines from the government. Through research and development, the original equipment manufacturer (OEM) of ESP is finding a way to upgrade the ESP without building a new one. Replacing the mechanical parts of the ESP is one of the ways, especially changing the design to a better one, such as rigid discharge electrode (RDE). The performance of the upstream fields will be improved thus bring better performance to the following fields as well. The other way is by replacing the electrical part which is the transformer/rectifier (T/R) set. With the recent technology and development, the new T/R set, which is a switch mode power supply (SMPS) become more sensitive responding to spark or arc and working on high frequency (25000Hz) resulting on better power output of the field and better performance to the whole ESP. This paper will further discuss several case studies which adapt the upgrade options with almost has 50% emission reduction.

1 Introduction

Almost all of coal-fired boiler power plants in the world still utilize electrostatic precipitator (ESP) as their dust collecting device to clean the flue gas. With its performance and reliability, ESP is still believed as the best solution for the emission in many industries. But with recent environmental issues, most of the countries in the world tighten their emission regulation. The ESP built around 20 to 30 years ago cannot comply with the newest regulation as known that ESP is built with particular design parameter and cannot be changed easily.

Research and development have been done continuously by the original equipment manufacturer (OEM) and other parties both in academy and in industry in order to find a way to upgrade the ESP without building a new one. Rigid discharge electrode (RDE) is one of the developed technologies for the ESP with aggressive current-distributing feature [1-4]. Its lower onset voltage provides more current with the same level of secondary voltage output

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(kV), resulting in more power input to the ESP, i.e. more efficient performance of the ESP. It also has more endurance and more efficient in terms of discharging between wires.

While RDE is one of the options for mechanical upgrade, automatic voltage controller (AVC) and power supply upgrade are the other options for the electrical side. It is more sensitive on responding sparking or even arcing with speed recovery and the power supply is working on high frequency (25000Hz) resulting in better power output to the ESP [2].

Several case studies will be further discussed in this paper. RDE will replace the non-rigid discharge electrode. The newest technology of AVC will replace the old one for better response to spark and even arcing. SMPS will replace the conventional transformer/rectifier (T/R) set for better power output to the ESP. All of the latest technologies bring ESP to its maximum capability resulting in better performance and efficiency.

2 ESP upgrade strategy

2.1 Rigid discharge electrode

RDE is widely recognized among other electrodes as the strong corona generating discharge electrodes in the industry. With its tubular design allowing for a larger corona generation area, it can help to encourage the production of very high current densities, in which RDE can produce more mA compared to other type of DE in the same kV due to its spike design. As shown in Fig. 1. At electric field strength of 2.0 kV/cm, the RDEs produce the corona current density that approximately seven times more than standard spiked-type DE (also called saw-band type). It is from 0.05 mA/m^2 to 0.35 mA/m^2. In addition, comparing with spring discharge electrode, corona density increased by 57% from 0.15 to 0.35 mA/m^2 at electric field strength of 2.0 kV/cm. Therefore, it leads to better overall ESP performance; especially when it is installed at inlet field(s) to overcome space charge effect.

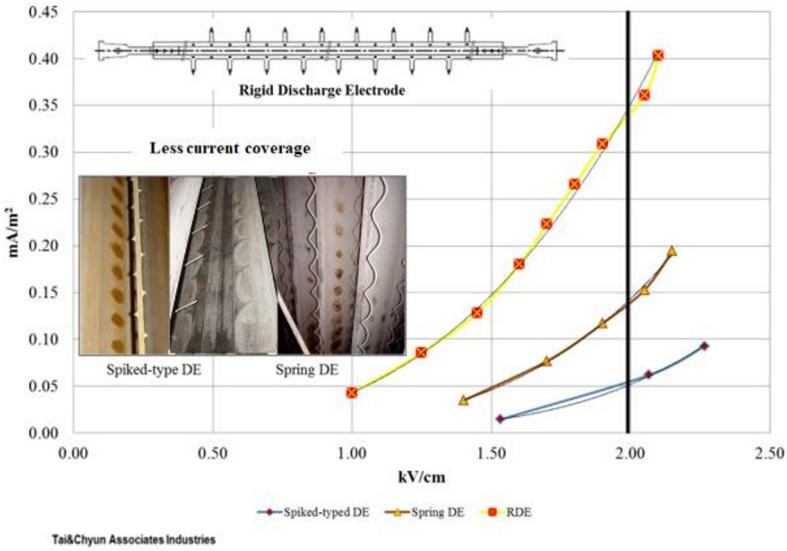

Fig. 1. RDE V-I curve comparison applied in the first field

This is also because RDE has lower onset voltage. As can be seen in the Fig. 1. RDE starts to produce the corona current densities at electric field strength of 1 kV/cm. Spring DE starts to produce the corona current densities at electric field strength of 1.4 kV/cm and

Spiked-type DE at 1.55 kV/cm. So at higher electric field strength, in this case is 2 kV/cm, RDE have produced more corona current densities compare to the other two types of DE,

With its stronger and unbreakable rigid elements, together with its damping weight design structure, RDE can help reduce the oscillation from rapping impact and it will not be damaged easily by sparks; therefore, providing more stable ESP condition, minimize maintenance and longer lifetime.

2.2 Automatic voltage controller

AVC controls and maximizes the voltage to increase collection efficiency and regulate power to maintain the highest performance to the precipitator. The AVC has the most sophisticated colored touch screen display unit that can access up to 90 transformer-rectifier controllers and it allows for easy monitoring of the ESP.

AVC's benefits are reducing back corona, spark & arc sensing, multifunction support, user-friendly interface, long life span & ruggedness design, economical control solution, and greater safety and reliability.

2.3 Switch mode power supply

A recent development in ESP technology is the usage of SMPS, in which it can enhance ESP's efficiency with shorter quench time. Accordingly, it has an insulated gate bipolar transistor (IGBT) to step up the frequency and because of its three phase power supply, it can also reduce ripple rate to convey high power factor and to achieve faster spark-response as shown in Fig. 2.

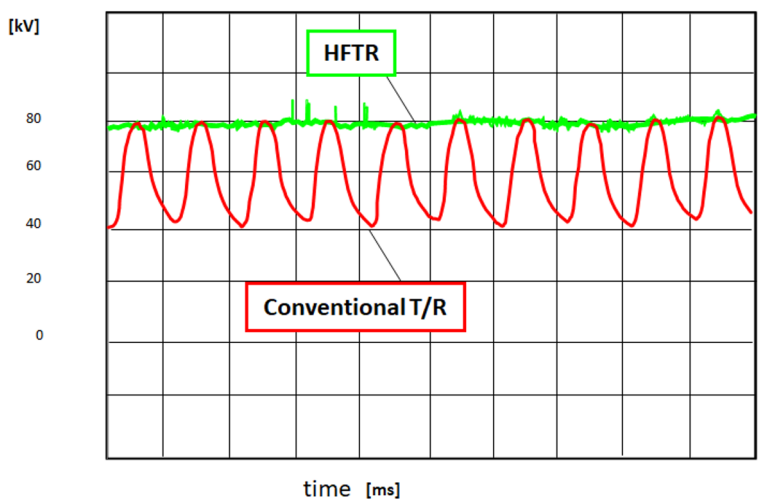

Fig. 2. SMPS versus conventional T/R set voltage waveform

From Fig. 2., the voltage waveform of the conventional T/R set still can be seen clearly as it is worked at 50/60 Hz only. The average voltage may be somewhere at 50kV while the peak voltage is somewhere at 80kV. There is around 37% difference between average and peak value which is called the power loss. For the SMPS (HFTR in the graph), due to IGBT mentioned earlier, it is worked at 20000 – 25000 Hz so the voltage waveform is so closed to each other (there are 20000 – 25000 wave in 1 second). The difference between average and peak voltage value will be very less (3 – 5 % only) so the power loss will be very less as well.

So, SMPS can produce more power output (kW) compared to conventional T/R in the same primary power input (kVA). Therefore, it can create higher power factor and lower power consumption with higher collecting efficiency. Due to this fact, it is always recommended for upgrading conventional T/R to SMPS in the inlet fields of ESP where they receive higher dust concentration.

3 Results and discussion

3.1 Coal-fired boiler ESP upgrade

The ESP is a quadruple-chambered ESP with six fields in each chamber so in total there are 24 fields. The ESP is designed to handle flue gas from a 550MW boiler with the efficiency of 99.29%. The outlet dust concentration at this efficiency is 28 mg/Nm^3 @6%O_2. The ESP has been operating for more than 20 years and due to stringent government regulation which is for Taiwan, the required outlet dust concentration should be below 20 mg/Nm^3 (new regulation set by Taiwan government in 2016 as shown in Table 1.). With this motivating factor, customer expect to lower the emission below 15 mg/Nm^3.

The ESP was built after 1985, so the expected emission by the new regulation must be less than 20 mg/Nm^3. Before this new regulation, the emission standard was determined by the air volume only which ESP has more than 70000 Nm^3/min air volume, the emission must be less than 25 mg/Nm^3. This power plant is very important for the country's electricity supply, so they really take good care of this plant. And this plant always become the pilot project for other power plant in the country which are smaller capacity. By this stricter regulation, the country also hopes for better air quality and better environment.

Table 1. The emission regulation in Taiwan

Old Regulation (2011)		New Regulation (2016)	
Air volume above 70000 Nm^3/min	< 25 mg/Nm^3	Installed before year 1985	< 40 mg/Nm^3
		Installed after year 1985	< 20 mg/Nm^3
		Installed after year 2015	< 10 mg/Nm^3

ESP inspection and assessment are done in order to decide what should be done to the ESP to achieve the goal. Then it is concluded the ESP should be upgraded by replacing the existing discharge electrode (DE) to the RDE and replacing the existing conventional T/R set to the SMPS. These upgrades should be applied in the first and second field of each chamber so in total there will be 8 units of SMPS and 16128 pieces of RDE which will be distributed and installed on those 8 fields as shown in Fig. 3. Project duration is one of the constraints as customer requests to have no delay since it will affect the electricity distribution throughout the country. It is planned to have shutdown for two months (sixty days) but in the end the project can be finished in fifty-two days including preparation, installation and

commissioning. Fig. 4. and Fig. 5. show both the installed RDE inside the ESP and installed SMPS on the ESP rooftop.

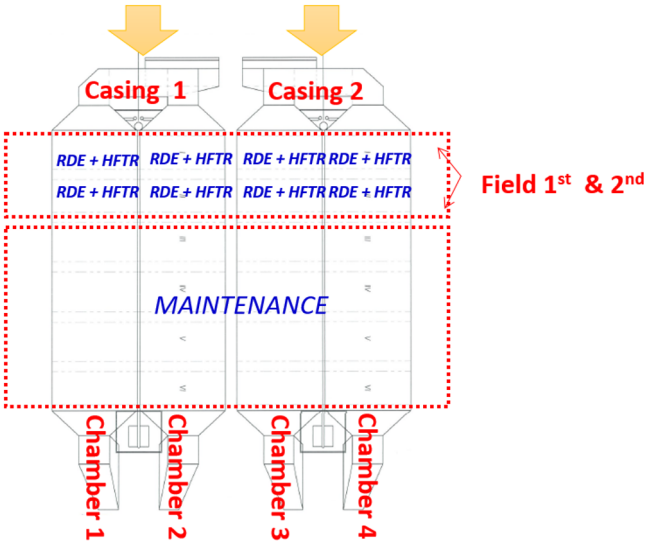

Fig. 3. ESP layout

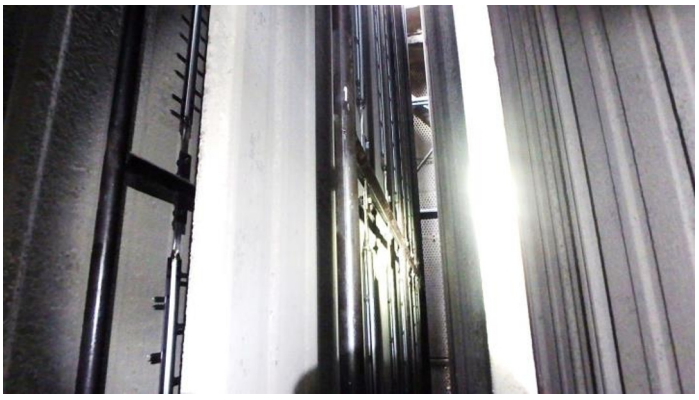

Fig. 4. Installed RDE inside the ESP

Fig. 5. Installed SMPS on the ESP rooftop

In order to prove the result of the upgrade, emission test is done both before (baseline test) and after (acceptance test) the upgrade. The condition for both tests are tried to be maintained as close as possible to really see the improvement made by the upgrade. The baseline test result shows 19.3 mg/Nm^3 while the acceptance test result shows 10.9 mg/Nm^3. This result is much better than what customer expects. They are satisfied with the result and consider the project as a pilot one to be followed by the other units for the following years. There are in total 10 boilers with the capacity of 550MW each so the whole plant capacity is around 5500MW.

3.2 Coal-fired boiler ESP refurbishment

The ESP is a quadruple-chambered ESP with three fields each chamber so in total there are 12 fields. The ESP is designed to handle flue gas from a 300MW boiler. The ESP has been operating for more than 10 years. During annual shutdown, the plant find abnormal condition of discharge electrode (DE) and its support frame which are detached, broken and eroded. This condition encourages sparking during operation. The plant has done many maintenance activities on both the DE and the DE support frame until the DE seat is really in the worst condition due to many DE replacement done.

The ESP has adapted the rigid discharge electrode (RDE) but it is found that the thickness is less than 1 mm. It is recommended to have RDE with at least 1.2 mm thickness. Then it is recommended to replace the RDE in the first field for all chambers (Fig. 6. shows the ESP layout) and also replace the DE support frame to renew the DE seat. Instead of replacing the whole set of DE system, the DE support frame is replaced piece by piece. The replacement will not need to open the rooftop thus minimizing the down time. All replacement parts are sent inside the ESP through the manhole. Fig. 7. and Fig. 8. show the installed new DE support frame and RDE inside the ESP.

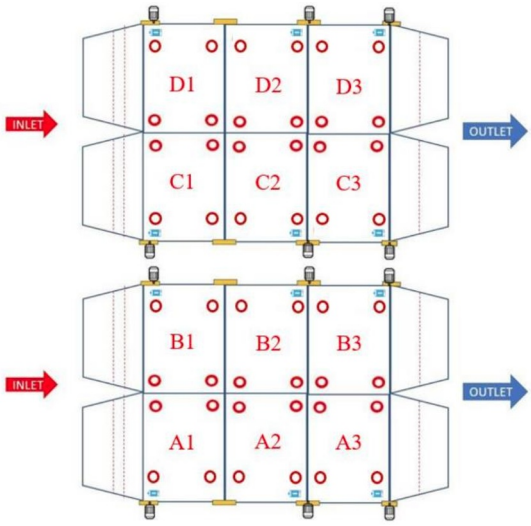

Fig. 6. ESP Layout

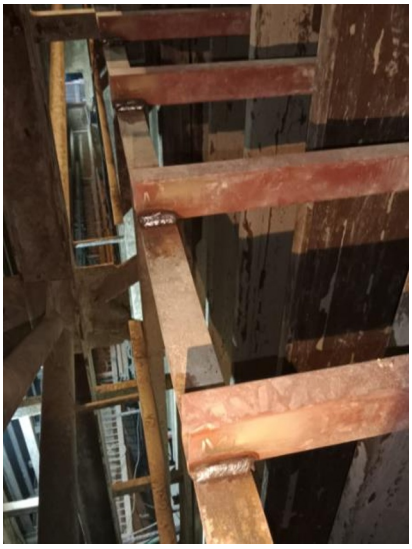

Fig. 7. Installed new DE support frame

Fig. 8. Installed new RDE

No-load test is done after the replacement and the results show all front fields can be energized until its full secondary current (mA) rating, i.e. the alignment for the replacement is good. The plant also records the operating parameters before and after the replacement to see the improvement. Table 2. shows the operating parameters comparison. The plant is satisfied with the replacement and will continue the replacement for the other unit. There are two boilers with the capacity of 300MW each so the whole plant capacity is 600MW. But the plant limits the capacity only up to 150MW. The mA is also limited to 400mA only which is 50% of T/R set mA full rating (800 mA).

Table 2. Operating parameters before and after the replacement

Field	Before		After	
	kV	mA	kV	mA
A1	49	302	45	399
B1	49	302	42	399
C1	49	19	36	400
D1	47	292	37	399

4 Conclusions

The upgrades options are proven to bring great improvement on the ESP performance. The RDE, AVC and SMPS are able to bring the ESP to its maximum capability resulting in remarkably emission reduction of 44%. It may be different story for other plants but for sure it will bring better performance and efficiency to the ESP. The refurbishment of the RDE also brings the ESP back to its design operating parameter.

The RDE is manufactured with high quality material and the thickness is made sure to be 1.2mm thickness. It can be customized to fit any kind of ESP, varied from 2000mmL to 14000mmL. The AVC and SMPS are American brand products which are engineered with the purpose to operate ESP easier in mind. Its ability to automatically control the output power to the ESP is able the ESP to perform on its highest efficiency. As the results show, when these two upgrade options are brought together, many benefits can be achieved without having a major overhaul on the ESP itself. It saves a lot of time and money.

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