Industrial Applications of Three-phase T/R for Upgrading ESP Performance

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Abstract: This paper reports one of our recent ESP upgrading activities. It was performed with a 600 MW coal fired boiler equipped with a four-channels and four-fields ESP. The dust collection efficiency was around 98.69% and the emission was in the range of 200 mg/m^3–300 mg/m^3. The upgrading include replacing the four traditional single-phase T/Rs used for inlet fields with four three-phase ones. The new HV system has been in operation for over one year. Dust emission keeps to be below 200 mg/m^3 with more than 400 kW energy saving.

Keywords: Three-phase T/R, ESP upgrading

1 INTRODUCTION

Today, many used ESP needs to be upgraded for either reducing dust emission or saving energy consumption in order to meet latest regulation. Retrofitting usually includes ESP itself, HV- and/or low-voltage power sources, coal switching and/or conditioning. A number of literatures are available for details of individual applications. Among them, the most cost effective technique is to replace old HV power sources by using the latest AVC and/or power techniques. Moreover, many industrial applications have shown that a poor ESP performance is always related to either back corona or insufficient charging at the inlet ESP field, or both of them.

In this paper, we report one of our recent ESP upgrading activities with a 600 MW coal fired boiler. The equipped four-channels and four-fields ESP has been used since 2003. Its collection efficiency was used to be around 98.69% with dust emission in the range of 200 mg/m^3–300 mg/m^3. The upgrading is to replace the four power sources used for the inlet fields by using four three-phase T/Rs. The new HV system has been in operation for over one year. Dust emission always keeps below 200 mg/m^3 with saving more than 400kW power consumption.

2 ESP AND FLUE GAS

Table 1 lists main specifications of the ESP. The four channels are referred by A, B, C and D. It is a 400mm gap ESP with SCA of around 83 m^2/m^3/s–86 m^2/m^3/s. Gaseous velocity and temperature inside ESP are around 1 m/s and 130℃, respectively. Typical ash compositions and resistivity are listed in Table 2 and Table 3. Fig.1 illustrates the ash size distribution. Its average diameter is 22.55 μm. As far as considering its compositions and resistivity, it is not a very difficult ash for ESP. We anticipated that by replacing the single-phase T/R by using three-phase T/R the collection efficiency can be greatly improved.

Table 1 ESP's specifications

Name	
Gas flow rate (m^3/s)	2×423.1
Inlet gas temp (℃)	120 (max145)
Inlet dust (g/Nm^3)	31.49
ESP efficiency (%)	99.6
Total cross area (m^2)	2×408
Total ESP length (mm)	4×4500
Length to height ratio	1.2
Plate-plate distance (mm)	400
Collector surface (m^2)	73440
Length of corona wire (m)	146880
Gas velocity inside ESP (m/s)	1.06

Table 2 Ash compositions

Name	%	Name	%
SiO_2	51.44	MgO	1.04
Al_2O_3	31.88	K_2O	1.09
TiO_2	0.91	Na_2O	0.52
Fe_2O_3	6.48	SO_3	0.15
CaO	6.06	MnO_2	0.006

Table 3 Ash Resistivity

Temperature (□)	Resistivity (Ω·cm)
19	2.50×10^{10}
80	8.20×10^{11}
100	1.35×10^{12}
120	2.20×10^{12}
150	3.10×10^{11}
180	5.20×10^{10}

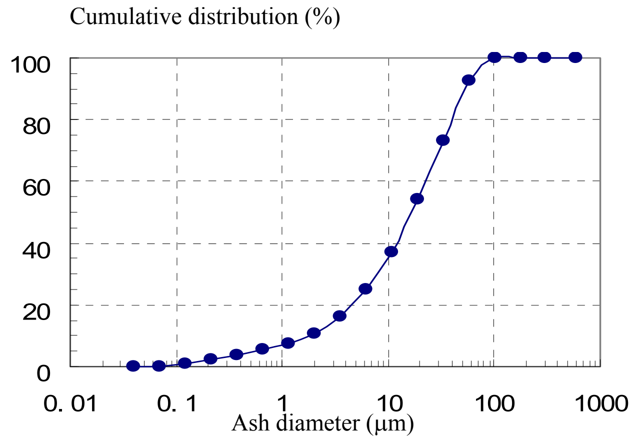

Fig.1 Cumulative ash size distribution with averaged diameter of 22.55 μm

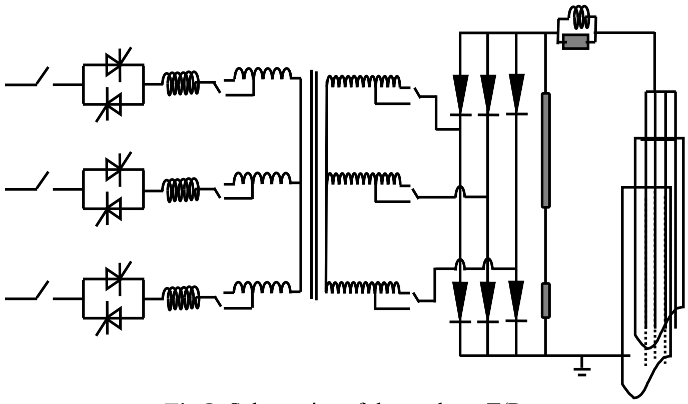

Fig.2 Schematics of three-phase T/R

3 CHARACTERISTICS OF THREE-PHASE T/R

In additional to a series of publications at ICESP conferences, two recent excellent books give very comprehensive review on modern ESP technologies [1] and the related power sources [2]. With regard to high-frequency switch power sources, Alstom and NWL have demonstrated their leadership in both techniques and marketing [3,4]. For Chinese ESP, however, it is often need to have a source with 72 kV–84 kV and 1.6 A–2.2 A, which is beyond present solid-switch source techniques. Boyle and Paradiso conducted detailed investigation on effects of using three-phase T/R as indicated in Fig. 2 in order to improve the ESP efficiency and save power consumption [5]. Unfortunately, to our best knowledge, no commercial activities about their sources were reported.

Since 2005, we have been involved in developing three-phase T/R for upgrading ESPs. Within the past three years, we have performed a series of industrial demonstrations with 125MW, 300MW and 600MW coal-fired power boilers. In additional to reported remarks by Boyle and Paradiso [5], we can conclude that in contrast to using single-phase T/R, the main characteristics of using a three-phase T/R for a 300 mm–400 mm gap ESP can be summarized as the following:

1. For a given secondary current, the secondary voltage is about 5kV–10 kV higher;
2. For a given secondary voltage, the secondary current is about 20% lower;
3. The applicable voltage multiplication factor of VaVp can be significantly improved;
4. A relatively higher voltage source can be applied for the inlet field, such as 84 kV for 400 mm gap, and a lower voltage one for the outlet field, such as 66 kV for 400 mm gap.
5. The power factor can be improved from roughly 60% to 90%.
6. A much larger arc current may exist if the AVC can not correctly control the V-I characteristics.

4 RESULT AND DISCUSSION

In order to evaluate the applicability of the three- phase T/R, a number of energization methodologies were designed to study both energy consumption and dust emission. With regard to applying both single- and three-phases sources at the same time on a single ESP. We proposed the following energization principle to improve the efficiency and the energy consumption:

1. Using three-phase T/R at the inlets to achieve intensive charging. For a 400 mm gap ESP, the maximum applied voltage and current can be increased from 72 kV to 80 kV and from about 500 mA to about 1000 mA, respectively;
2. Using intermittent energization (I.E.) and/or other methods for other fields to save energy consumption.

Table 4 lists typical energization methods used for this study. Spark-rated limited, I.E, secondary current or voltage limited and simple-pulsing are adopted to conduct series of experiments. Experiments took a few months to reach present status. Table 5 lists typical results in terms of power consumption and dust emission for both 600 MW and 480 MW generation. According to our experience with 125 MW and 300 MW coal-fired boilers, we always apply the largest input power at the inlet field for improving charging under high dust concentration. For the last field, however, I.E mode is very effective for saving energy consumption. We also noticed that either secondary voltage or current limited AVC methods are also effective. Spark-rate limited AVC are not recommended at all for either improving the collection efficiency or saving the energy.

Table 4 Details of energization methods

No	Details of the AVC energization methods
1	● All ESP fields are spark rates limited. ● All secondary voltage and currents are below 72 kV and 1800 mA, respectively.
2	● All ESP fields are spark rates limited. ● The secondary voltage and current for inlet ESP field are controlled to be below 78 kV and 2000 mA, respectively. ● The secondary voltage and current for 2nd, 3rd and 4th fields are below 72 kV and 1800 mA, respectively.
3	● All ESP fields are spark rates limited. ● The secondary voltage and current for inlet ESP field are below 78 kV and 1200 mA, respectively. ● The secondary voltage and current for 2nd, 3rd and 4th fields are below 72 kV and 1800 mA, respectively.
4	● Inlet and 3rd ESP fields are spark rates limited; and 2nd and 4th fields are I.E. mode with duty cycle ratio of 2:2 and 2:4, respectively. ● The secondary voltage and current for inlet and 3rd ESP fields are below 72 kV and 1800 mA, respectively.
5	● Inlet ESP and 3rd fields are spark rates limited; and 2nd and 4th are I.E. modes with duty cycle ratios of 2:2 and 2:10, respectively. ● The secondary voltage and current for inlet ESP and 3rd fields are below 72 kV and 1800 mA, respectively.
6	● Inlet and 2nd ESP fields are spark rates limited; and 3rd and 4th are I.E. modes with duty cycle ratios of 2:4 and 2:10, respectively. ● The secondary voltage and current for inlet ESP field is below 72 kV and 1800 mA, respectively.
7	● Inlet field is spark rates limited; and 2nd, 3rd and 4th are I.E. modes with duty cycle ratios of 2:4, 2:2 and 2:10, respectively. ● The secondary voltage and current for inlet ESP field is below 72 kV and 1800 mA, respectively.
8	● Inlet and 3rd fields are spark rates limited; The 2nd and 4th are I.E. modes with duty cycle ratios of 2:4 and 2:10, respectively; ● The secondary voltage and current for inlet ESP field is below 72 kV and 1800 mA, respectively;
9	● Inlet field is spark rates limited. Its secondary voltage and current for inlet ESP field is below 72 kV and 1800 mA, respectively. ● 2nd, 3rd and 4th are I.E. modes with duty cycle ratios of 2:8, 2:2 and 2:10, respectively.
10	● Inlet field is spark rates limited; and 2nd is off; the 3rd and 4th are I.E. modes with duty cycle ratios of 2:2 and 2:8, respectively. ● The secondary voltage and current for inlet ESP field is below 72 kV and 1800 mA, respectively.

Table 5 Optimization of energization and dust emission

	600 MW		480 MW	
Inlet	23.21 g/Nm^3		23.80 g/Nm^3	
Methods	Total Power (kW)	Outlet (mg/m^3)	Total Power (kW)	Outlet (mg/m^3)
1	829	108.3	760	57.69
2	781	100.0	802	52.88
3	774	110.4		
4	467	116.0		
5	411	105.9	364	52.68
6	370	121.3	385	66.56
7	208	150.2	361	82.10
8			164	83.40
9			170	91.90
10			179	143.6

Note: The total ESP power is for channel A plus channel C.

Table 6 lists typical voltage and current characteristics of the two-type power sources together with the dust emission, where the No refers to the inlet, the second, the third and the last field, respectively. One can easily conclude that the primary line current significantly drops for three phase T/R. In other words, the power factor is greatly improved due to its balanced input. Based on the tests at two generation capacities of 600 and 480 MW, one can conclude that optimal energization can be achieved by considering both generation capacity and AVC methodology. A supervisory system including all AVCs and the generation capacity is under development to match industrial demands.

Table 6 Typical ESP performance under spark rate limited control mode

	ESP fields	Primary voltage	Primary current	Secondary voltage	Secondary current	Inlet	Outlet	SCA
		V	A	kV	mA	g/Nm^3	mg/Nm^3	m^2/m^3/s
A	1	399	109	72	1185	23.05	88.32	85.41
	2	299	354	70	1124			
	3	279	393	65	1287			
	4	304	416	65	1567			
B	1	396	97	72	1066	23.05	164.3	83.51
	2	Off						
	3	291	428	65	1426			
	4	304	416	65	1690			
C	1	414	151	72	1320	23.33	128.3	83.54
	2	286	476	64	1808			
	3	275	419	64	1340			
	4	300	433	64	1815			
D	1	412	179	72	1590	22.94	115.4	83.84
	2	251	434	64	1610			
	3	274	446	65	1400			
	4	293	427	65	1780			

5 CONCLUSIONS

With a series of industrial demonstrations, we confirmed the applications of three-phase T/Rs at coal-fired power stations and can give the following remarks:

1. When applying the three-phase T/R at the inlet field, the secondary current can be increased by a factor of two and at the same time the secondary voltage rises by 5 kv – 10 kV.
2. As a result, the I.E. or current limited energization methods for the successive ESP fields can be used for saving energy consumption.
3. Integration both three-phase T/R for inlet field and single-phase T/Rs for other fields will provide the most cost effective method for upgrading ESP performance. A supervisory system based on both AVCs and generation capacity will improve the system effectiveness.

REFERENCES

1. Applied Electrostatic Precipitation, edited by K.R. Parker, Published by Blackie Academic & Professional, ISBN 0751402664, 1997.
2. K. Parker. Electrical operation of electrostatic precipitatiors. IEE Power and Energy Series 41, ISBN 0852961375, 2003.
3. ALSTOM: http://www.power.alstom.com/.
4. NWL: http://www.nwl.com/.
5. Philllip D. Boyle and Giovanni Paradiso. Demonstration of three phase power supply for electrostatic precipitators. Proceedings of the American Power Conference, Vol. 61-1, Illinois Institute of Technology, Chicago, IL. 1999.