Comparison of different power supply techniques for biomass ESP applications

Dominik STEINER
Scheuch GmbH
Austria
d.steiner@scheuch.com

Wilhelm HÖFLINGER
Vienna University of
Technology, Austria
wilhelm.hoeflinger@tuwien.ac.at

Manfred LISBERGER
Scheuch GmbH
Austria
m.lisberger@scheuch.com

1 Abstract

This work gives a power supply manufacturer independent comparison of conventional T/R-sets and High-Frequency (HF-) power supplies for biomass electrostatic precipitator (ESP) applications.

A comparison of the two power supply techniques and also an assessment of HF- power supplies of two different manufacturers were done at a lab setup. In a second investigation, a HF- power supply was setup beside a T/R-set on an ESP at a 30 *MW* biomass power plant to investigate the separation efficiency of both technologies under real conditions.

Total separation efficiency, as well as fractional separation efficiency, spark response regulations and power consumption were measured.

2 Introduction

In recent years HF- power supplies, also referred to as Switch Mode Power Supply (SMPS), developed to a state of the art power system for industrial ESP.

Advantages of this technology can be summarized according to *Parker* [1]:

- low voltage ripple and thus increase of voltage and current into the ESP
- high power factor, high efficiency and less harmonics than T/R-sets
- balanced power input (three phase)
- fast spark response and
- smaller and lower oil volumes than T/R-sets

Many comparisons of HF- power supplies to conventional T/R-sets can be found in literature [2]-[6]. All of those works have been published by power supply manufacturers or at least with their support.

In almost all cases positive results with increasing ESP efficiency were obtained when using HF- power supplies. Also the high power factor of HF- power supplies is given as an advantage of that technology.

Only in one paper data for biomass ESP application is given [6] whereas all other works focus on other fields like fossil power plants or industrial applications.

In [7] a technology screening for conventional T/R-sets and HF- power supplies as well as an assessment at a biomass power plant ESP with a comparison of the results to experiences in other industrial fields can be found. Here the focus was on ESP separation efficiency when using those technologies.

2.1 Aim of this work

The aim of this work is to give a more detailed comparison of the two power supply techniques when used at biomass ESP applications as well as present results of a comparison of HF- power supplies of two different vendors.

So the following tests were performed:

- Determining separation efficiency for a T/R-set and a HF- power supply – direct comparison for different gas conditions in a lab setup as well as at a power plant ESP
- Measurements of the separation efficiency for HF- power supplies of two different vendors
- Measurements of spark response for the different power supplies
- Power consumption and line quality measurements for T/R-sets and the HF- power supplies

3 Experimental setup

3.1 Lab setup

A small industrial ESP was set up at a laboratory as shown in Fig. 3-1.

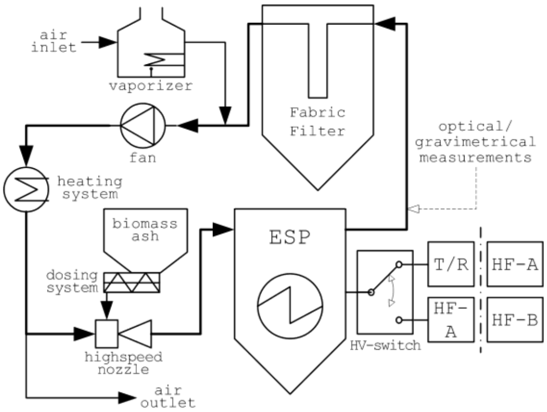

Fig. 3-1: Simplified test setup with main components

Air was circulated via a fan across a heating system to maintain gas temperature and furthermore through a high-speed nozzle where biomass ash was redispersed.

The gas then entered the ESP which was powered either with a conventional T/R-set or a High-Frequency power supply. In a second step two different HF- power supplies were connected to the ESP to do a vendor comparison (HF-A, HF-B). A High-Voltage splitter switch was used to change the ESP power supply within seconds.

Downstream the ESP a fabric filter was installed as a back-up filter to collect remaining particles after the ESP. For all tests 150 m³/h of circulated gas was substituted with fresh air which was heated up and sucked through a vaporizer to maintain constant gas humidity.

Process parameters for the lab tests are given in Tab. 3-1. The specifications of the different power supplies can be found in Tab. 3-2.

gas temperature	150°C ±4K
water dewpoint	15-40°C ±1K
inlet dust concentration	0.6 - 3 g/m³
volume flow	5000 m³/h ±2%

Tab. 3-1: Lab setup process parameters

	T/R-set	HF-A	HF-B
current rating	200 mA	250 mA	121 mA
voltage rating	70 kV_{peak} 50 kV_{ar}	120 kV	70 kV
switching frequency	50 Hz	>20 kHz	>20 kHz
voltage ripple	~30%	< 3%	< 3%

Tab. 3-2: Power supply specifications

All power supplies were operated in automatic mode; the control parameters were set to sparking rates of about 5 sparks/minute.

Biomass ash from a 30 *MW* power plant ESP was used as test dust. The crude gas particle number concentration distribution for 0.6 g/m³ is given in Fig. 3-2.

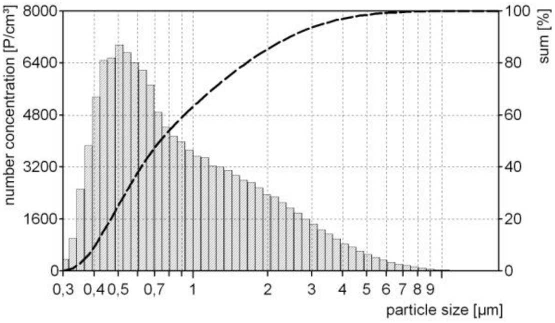

Fig. 3-2: Crude gas particle number concentration, 0.6 g/m³

The ESP used for the tests was a standard type with 300 *mm* spacing, typically applied at biomass combustion plants with about 1 *MW* thermal power. Total particle concentration was determined with the laser scattered light measurement system SICK FW100 which was calibrated via gravimetrical measurements according to VDI 2066, Part 1 [8]. Particle size distribution and concentration was measured with a scattered light aerosol spectrometer Palas WELAS 2000. All concentration measurements were taken at the clean gas side of the ESP; the high voltage-off values were taken as crude gas concentrations.

3.2 Field setup

A High-Frequency power supply was installed beside the existing T/R-set at a biomass fired power plant in Austria. Both supplies were also connected to the ESP via a high voltage splitter-switch to change power supply within seconds. So, the same process, gas and dust conditions for the measurements could be secured.

Both power supplies were set to automatic control mode; the voltage was controlled as closed to the sparking voltage as possible. The power plant was fired with wood chips and bark and operated at constant nominal load of 30 *MW* thermal.

The process parameters are summed up in Tab. 3-3.

gas temperature	~150 °C
water dewpoint	~58 °C
Inlet dust concentration	~300 mg/m³
volume flow	120.000 m³/h

Tab. 3-3: Field setup process parameters

The power supply specifications are given in Tab. 3-4.

	T/R-set	HF
current rating	800 mA	675 mA
voltage rating	85 kV_{peak} 60 kV_{ar}	83 kV
switching frequency	50 Hz	>20 kHz
voltage ripple	~30%	< 3%

Tab. 3-4: Power supply specifications

The T/R-set at the ESP did actually run at ~400 *mA* so only a 675 *mA* HF- power supply was used for the tests.

Total separation efficiency was determined by simultaneous gravimetric dust concentration measurements for ESP inlet and outlet in accordance to VDI 2066, Part 1 [8].

Spark response measurements were done with a 50 *MHz* USB-oscilloscope, TiePie HS3 and power consumption measurements were performed with a power quality analyser, C.A. 8335 Qualistar+ for laboratory as well as field setup.

4 Results and discussion

4.1 T/R-set and HF- power supply ESP efficiency comparison

The fractional separation efficiency for T/R-set and HF- power supply HF-A for two crude gas dust concentrations, measured at the lab setup is given in Fig. 4-1.

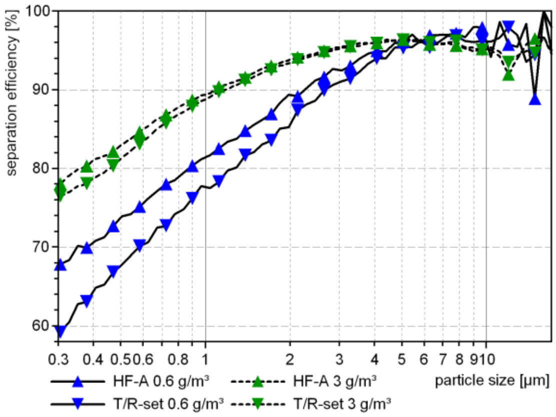

Fig. 4-1: Fractional separation efficiency for T/R-set and HF-A, lab setup

Higher separation efficiencies when using the HF- power supply were determined whereas for small concentrations the efficiency difference for the two power supply was higher than for higher particle concentrations. Total separation efficiency measurements did show similar results.

Also the efficiency improvement was found for smaller particle sizes whereas for particle diameters >5 *µm* efficiencies were about the same.

The results of fractional separation efficiency measurements for the field setup at two different days are shown in Fig. 4-2.

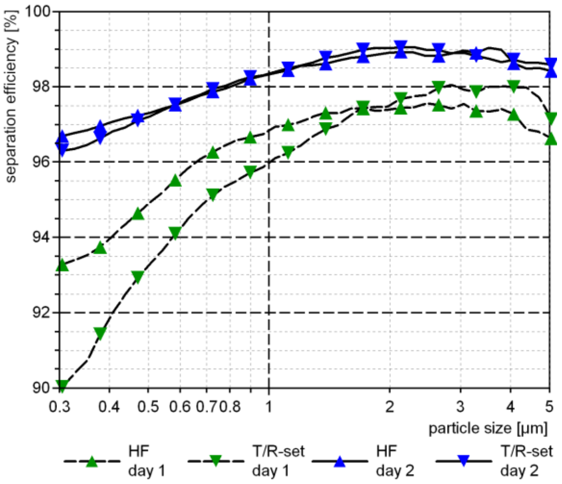

Fig. 4-2: Fractional separation efficiency for T/R-set and HF- power supply, measurements on 2 different days, field setup

The separation efficiency is only shown from 0.3 – 5 *µm* due to very low particle numbers for larger particle sizes and thus varying efficiencies.

The total separation efficiencies for the same two measurement days are given in Tab. 4-1.

		ESP inlet [mg/m³]	ESP outlet [mg/m³]	efficiency [%]
day 1	T/R-set	321.9	25.3	92.1
	HF	317.6	19.1	94.0
day 2	T/R-set	260.5	10.6	95.9
	HF	268.3	9.9	96.3

Tab. 4-1: Particle mass concentrations and total separation efficiency, field setup

From the fractional separation efficiencies as well as from the total separation efficiency measurements a significant efficiency increase was found when switching to the HF- power supply for the first day. On the second day both measurements gave about the same efficiency for both power supply techniques.
An explanation for this could not be found. All monitored parameters (temperature, volume flow, gas humidity etc.) remained constant.

Further results on separation efficiency improvements using HF- power supplies on biomass ESPs including a power consumption comparison can be found in [10].

4.2 HF- power supply of two different vendors
ESP efficiency comparison

The HF- power supplies HF-A and HF-B were connected to the lab-ESP via the splitter switch as given in chapter 3.1, the results again for two dust concentrations are shown in Fig. 4-3.

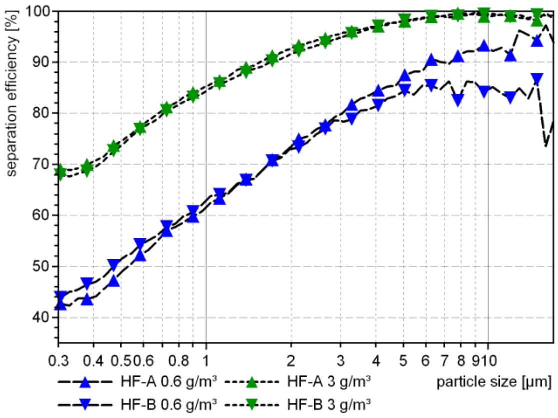

Fig. 4-3: Fractional separation efficiency for HF-A and HF-B, lab setup

Total separation efficiency measurements verified the above given results, no difference in separation efficiency was found when using HF- power supplies of different manufacturers.

4.3 Spark response

In case of a sparking event in the ESP the power supply has to shut down the voltage as fast as possible to avoid dust reentrainment or even damages on the ESP interior due to a continuous arc.

A typical spark response for the T/R-set used in the lab setup is given in Fig. 4-4.

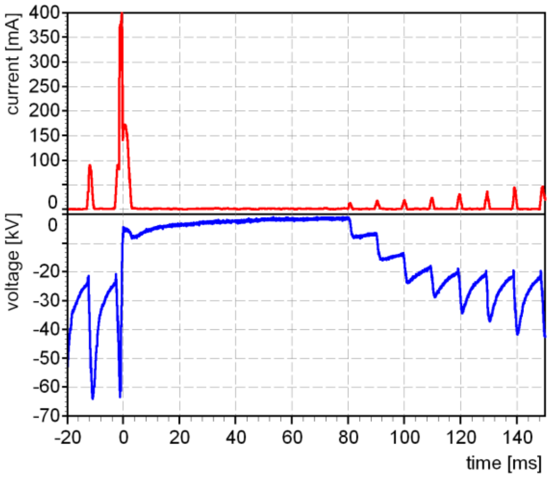

Fig. 4-4: Typical spark response for the T/R-set, lab setup

Shutdown of the voltage can only be done when a zero-crossing of primary current occurs (thyristor control of the primary voltage).

So there is a shutdown delay with high current peaks as shown in Fig. 4-4. The total spark response time, till voltage was again at about 75% of the value prior to the sparking event, was ~160 *ms*.

A typical spark response action for the T/R-set at the field setup is shown in Fig. 4-5. Again the current peak in case of the spark event can be seen. The total spark response time was about 60 *ms*.

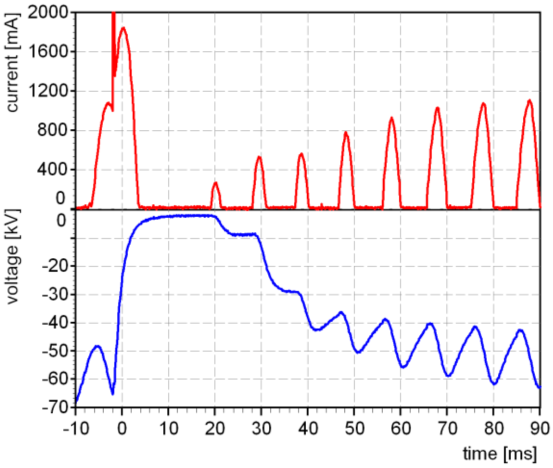

Fig. 4-5: Typical spark response for the T/R-set, field setup

High frequency power supplies do not depend on power grid frequency and can be shutdown in case of sparking immediately as shown in Fig. 4-6.

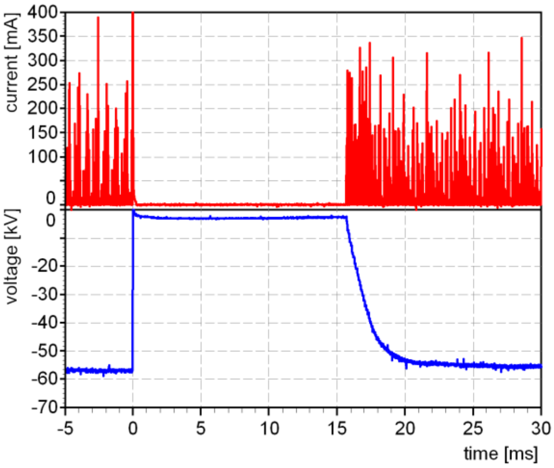

Fig. 4-6: Typical spark response for the HF-B, lab setup

Arc shutdown was done within about 15 *µs*, as other measurements showed, and total spark response time including 15 *ms* quench time was about 18 *ms*.

Similar results were found for HF-B and the HF- power supply used at the field setup. For all HF- power supplies spark response time till voltage was on again (with 15 *ms* quench time) was less than 20 *ms*.

4.4 Power consumption and line quality measurements

Efficiency measurements in terms of input power to output power were done only at the field setup due to very low loads for the power supplies at the lab setup.

Within the T/R-set switchboard space was limited so the current clamps could only be mounted after thyristor control. At this position, voltage and current disturbances due to the thyristor switching were not captured so only real power for efficiency comparison was used.

The input real power P_{prim} was measured with the power quality analyser whereas output power was calculated by using secondary current and voltage values [*mA* x *kV*]. The results are given in Tab. 4-2.

	P_{prim}	U_{sek}	I_{sek}	P_{sek}	P_{losses}	η
	[kW]	*[kV]*	*[mA]*	*[kW]*	*[W]*	*[%]*
T/R-set	34.07	59.59	453.1	27.00	7072	79.2%
HF	49.57	72.43	631.5	45.74	3835	92.3%

Tab. 4-2: Power measurement values, field setup

The power supplies did run with 68% and 82% respectively of their nominal load. For those operational statuses the HF- power supply showed significantly higher efficiency.

At the lab setup the total harmonic distortion for primary voltages and current were measured, an overview is given in Tab. 4-3.

	T/R-set	HF-A	HF-B
operating point [$\%_{nominal\ power}$]	14%	9%	17%
THD U_1	2.7%	3.5%	2.2%
THD U_2	2.8%	3.2%	1.9%
THD U_3	2.9%	3.3%	2.0%
THD I_1	68.1%	107.1%	35.8%
THD I_2	0.0%	109.2%	31.7%
THD I_3	68.3%	108.9%	30.4%

Tab. 4-3: Total harmonic distortion (THD) for all power supplies, lab setup

As also given in Tab. 4-3, the measurements were performed at very low loads of the power supplies. Similar measurements for a T/R-set were found in [9] whereas in this work voltage THD factors were about 3.4% and current THD factors between 10 and 25%, only given as one number for all three phases. Calculating a single THD factor from above measurements, voltage THD factor is 2.8% and current THD factor ~22% which is in the same range than given in [9].

The voltage THD factors do not vary much for all three power supplies. Current THD factors are very high for HF-A and for the two charged phases of the T/R-set. Moderate values where measured for the HF-power supply B.

In Tab. 4-4 the results of the distortion power factor (DPF) and power factor (PF) measurements for the lab power supplies are summarized. The distortion power factors for both HF-power supplies were closed to 1 whereas the DPF for the T/R-set was only 0.52. The power factor did remain on a high level of 0.94 for the HF-B while PF for HF-A was 0.64. The power factor for the T/R-set was only 0.43.

	T/R-set	HF-A	HF-B
operating point [$\%_{nominal\ power}$]	14%	9%	17%
PF_{L1}	0.813	0.643	0.928
PF_{L2}	0.0	0.618	0.929
PF_{L3}	0.476	0.656	0.947
PF_{sum}	0.430	0.639	0.935
DPF_{L1}	0.996	0.981	0.995
DPF_{L2}	0.0	0.98	0.981
DPF_{L3}	0.573	0.981	0.996
DPF_{sum}	0.523	0.981	0.991

Tab. 4-4: Power factor (PF) and distortion power factor (DPF), lab setup

It can be clearly seen that power factors for HF- power supplies were much higher than for the T/R-set but also between different HF-power supplies values did vary. Also the very low loads of 9 – 17% of the nominal load have to be taken into consideration and might influence the values, especially for the T/R-set.

5 Conclusion

In this work a comparison of conventional T/R-sets and HF- power supplies powering ESPs at biomass applications were done. It was shown that using HF- power supplies ESP separation efficiency can be increased in some cases. The largest efficiency improvement was found for particles <2 *µm* in diameter. It was also shown that efficiency increase does depend on process parameters whereas for some process conditions no improvement was found.

Comparing power consumption and line quality HF- power supplies do have major advantages due to high efficiency values and very good power factors. Also spark response is much faster for HF- power supplies due to their power grid frequency independent control.

The comparison of two HF- power supplies of different vendors showed same separation efficiency. Also no major difference was found in terms of spark response.

In terms of line quality the two HF- power supplies showed different behavior whereas HF-B produced moderate harmonic distortion as HF-A created high harmonic distortion.

A general recommendation to use HF- power supplies for ESPs on biomass application can not be given. For that decision also other aspects like

- Economic considerations
- Cooling issues (convectional air, forced air or water cooling)
- Noise emission issues in urban areas

have to be taken into consideration.

Nevertheless, HF- power supplies are reliable and state of the art power sources for ESPs at biomass applications.

6 Literature

[1] Parker, K.; Electrical operation of electrostatic precipitators; Institution of Electrical Engineers, London. xii, 270 p. ISBN: 0852961375; 2003

[2] Herder H., Guenther B., Klemm G.; Performance Enhancements Achieved with High Frequency Switch Mode Power Supplies, 11th International Conference on Electrostatic Precipitation, Hangzhou, p. 264-269; 2008

[3] Grass N., Hartmann W., Klockner, M.; Application of different types of high voltage supplies on industrial electrostatic precipitators, Conference Record of the Industry Applications Conference, 37th IAS Annual Meeting, vol.1, p. 270-276; 2002

[4] Parker K., Haaland A. T., Vik F.; Enhanced fine particle collection by the application of SMPS energisation, Journal of Electrostatics 67 (2009), p. 110-116; 2009

[5] Looney B. M. et al.; High Frequency Power Supply Operation on Hot-Side ESP, 11th International Conference on Electrostatic Precipitation, Hangzhou, p. 270-275; 2008

[6] Ranstad, P. et al.; On experiences of the application of high-frequency power converters for ESP energisation; 9th International Conference on Electrostatic Precipitation, Mpumalanga, South Africa, 2004

[7] Steiner, D., Höflinger, W., Lisberger, M.; Using HF-power supplies for ESP’s at biomass power plants compared to other industrial applications; European Conference on Fluid-Particle Separation, Lyon, France; 5. -7. October 2010

[8] VDI; VDI 2066, Blatt 1: Gravimetrische Bestimmung der Staubbeladung; Verein Deutscher Ingenieure; 2006

[9] Nikolic, A., Stevanovic, I.; Power Quality Measurement Analysis of the Electrostatic Precipitator; XIX IMEKO World Congress, Lisbon, Portugal; 2009

[10] Steiner, D.; Höflinger, W.; Lisberger, M.; High frequency power supplies for ESP's at biomass applications; 6th European Meeting on Chemical Industry and Environment, Mechelen, Belgium: "EMChIE 2010 Conference Proceedings (Vol.2)" p. 709 – 719; 2010