Continuous measurement/analysis of plastic WESP operating currents

M. Kloeckner[1], E. Hoffmann[2], Prof. Dr. N. Grass[3], T. Fischer[4]

[1,2]Siemens AG, Siemens Germany, Power and Gas Division, Energy Solutions,
Freyeslebenstrasse 1, 91058 Erlangen, Germany
[3]Technische Hochschule Nuernberg, Institute for Power Electronic Systems (ELSYS),
Kesslerplatz 12, 90489 Nuernberg
[4]Grass Power Electronics GmbH, Preisslerstr. 11, 90429 Nuernberg
Corresponding author: *Michael.kloeckner@siemens.com*

Abstract Wet Electrostatic Precipitators (WESPs) with collecting electrodes made of plastic are commonly used in industrial and chemical processes. Plastic tubes are resistant against many chemical reagents like sulfuric acid, they are very cost efficient and have a comparable low weight. Unfortunately, they are not very robust against thermal stress, which can be caused by locally concentrated and frequent flashovers. The arcs can cause severe and non-reversible damage in the material of the plastic tubes, therefore, the local flashover distribution needs to be controlled by means of the high voltage power supply. The paper shows a method to detect and analyse the flashover location by measuring and comparing the operating currents of the collection electrode sections of the entire precipitator. Furthermore, the WESP discharges (spark, flashover) cause high frequency current and voltage peaks in the collecting electrode grounding system which can result in disconnection of individual collecting electrodes from ground or in a faulty connection to the outer grounding system. Missing ground connections may result in deteriorated ESP performance and increased risk for damages of the collecting electrodes. Single or several faulty ground connections cannot be detected with the usual measurement of the total DC current and voltage at the transformer rectifier set (TR set).

With additional DC current sensors positioned on the ground cables in between the WESP sections lead outs and the outer WESP grounding system, the currents of the ground connections can be monitored in relation to the total DC operating current. In addition the location of the ESP discharges can be estimated and monitored by analysing the wave shape of each DC current measurement. This enables condition monitoring and providing a warning signal due to faulty ground connections, of unbalanced DC current distribution or frequent ESP discharges at a certain position. With corresponding maintenance measures taken in time, possible damage or excessive deterioration of the ESP collecting tubes can be avoided.

Keywords: WESP, WESP grounding, DC current sensor, WESP fault analysis

1. Basic Operational Requirements

To ensure proper operation of a WESP with collecting electrodes made of plastic, all ground connections of the collecting electrodes shall be carried out with low electrical resistance and low inductance.

During operation all collecting tubes shall be completely covered by a liquid film with sufficient electrical conductance. The TR set supplies the WESP with the maximum possible voltage and current. When reaching the break-down voltage, a flashover is formed. Each flashover must be detected by the TR set controller to prevent continuous arcs, which result in severe damages to the collecting electrodes. ESP flashovers are typically detected by the controller by analysing the break-down of the ESP voltage, the current increase (primary/secondary current) or current flow duration. Each flashover causes high frequency current transients, which result in high voltage peaks at the collecting electrode grounding system. To avoid electrical discharges at the grounding system, the ground connections shall be designed with sufficient conductor surface, regarding skin effect and parasitic inductance.

Faulty or missing ground connections, insufficient wetting or too low electrical conductance of the collecting electrodes increase the overall electrical resistance between the location of a flashover and the outer ground connection. This influences the current distribution on the electrode system and possibly the detection of flashovers by the TR set controller. The voltage break-down, the increase in current signal wave shape can be very weak, therefore the flashover may not be detected by the TR set controller. This leads to the formation of a continuous arc. Undetected flashover/arcs result in thermal destruction of the collecting electrodes or may even cause fire disasters inside the ESP and in consequence severe damage and plant down time.

Theoretical investigations as well as measurements with a prototype of DC current sensor have been carried out and results are presented in this paper.

2. Theoretical aspects

The theoretical investigations are based on the equivalent circuit shown with Fig. 1, following the WESP configuration of the real test unit. The equivalent circuit shows 4 sectors of a precipitator with a grounding connection for each of them. Different to the real precipitator conditions, the supply voltage was selected positive, as it does not affect the results. The sector is modelled by its electrical capacity between the corona electrode and the collecting electrode. Additionally, the inductance was derived by the geometrical dimensions and the conductivity of the sulfuric acid film at the collecting electrode is modelled by the regarding resistor. The boxes N1 in Fig. 1 contains the corona model (V/I characteristics see Fig. 2). The groundings of the sectors are interconnected via platinum wires, which are modelled by the R11 etc. To simulate a flashover in the 4th sector a single collecting/discharge electrode was connected in parallel with a closing switch and an arc voltage drop to about 10 kV. The elements of the equivalent circuit have been calculated by the geometric dimensions of a WESP with 212 collecting tubes, each 4.5 m in length and 240 mm in diameter.

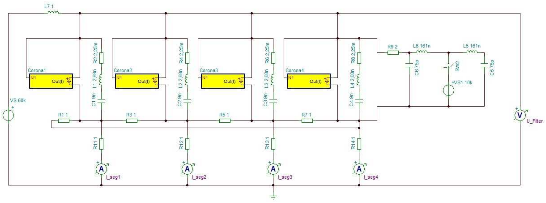

Figure 1. Equivalent circuit WESP with 4 ground connections

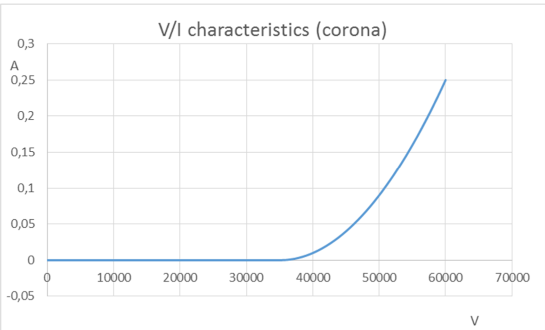

Figure 2. V/I characteristics taken as a base for the equivalent circuit

The simulation results for the operating current values during a simulated flashover can be divided into two parts: the short term (transient) and long term behaviour (short circuit current). The transient chart as shown in Fig. 3 presents the typical voltage and current oscillations, measured in the ground connection of the entire sectors. With flashovers located near grounding of section 4, the current of section 4 starts in positive direction, while the remaining 3 sectors start with negative current after the occurrence of a flashover. This criterion could be used to determine the WESP section of the flashover, but this would require a fast current measurement providing a very high time resolution, which is therefore difficult to realize and at high cost.

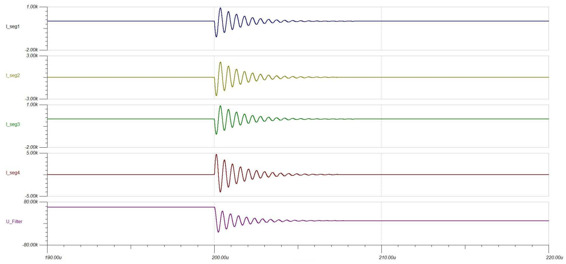

Figure 3. Transient processes during flashover for the 4 grounding currents and ESP voltage

After the decay of the dynamic response of the flashover event, an arc is fed by the current delivered from the high voltage power supply. The arc current increase rate is limited by the inductance of the HV transformer. The long term response to a flashover, which is in the ms range is given in Fig. 4, shows the different current shapes for the 4 sectors.

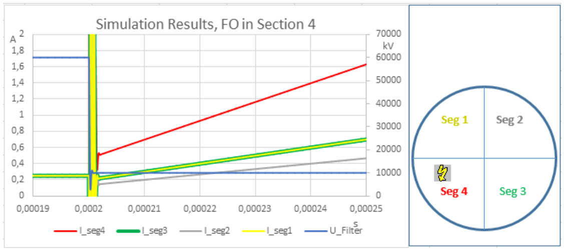

Figure 4. Short & long term operating current values during flashover

The grounding current of sector 4, where the FO occurred, is significantly higher than the other 3 currents. The currents of the sectors next to sector 4 (i.e. 1 and 3) are identical and the current of sector 2 is lower because the distance towards sector 4 is higher. The simulation model is supplied by a DC voltage and does not contain the sinusoidal waveforms as observed with a real SCR high voltage power supply.

However, the simulation results show the possibility to determine the location of the flashover by evaluating the current distribution of the 4 sectors.

3. Test installation

The DC current sensors need to be appropriately for operation under critical electrical and environmental conditions. Particular requirements are but not limited to:

- Isolated sensor (no electrical connection to the existing grounding system)
- Wide gap between sensor core and conductor, minimum 20 mm Ø (to avoid coupling through high electrical field strength between sensor and grounding conductor)
- High isolation capability
- Availability of different measuring ranges (up to 5A)
- High accuracy, low reaction and response time
- High overload capability

A prototype of a DC current sensor has been developed with the following basic parameters:

- Measuring range current transducer type 1: 600 mA; type 2: 1000 mA
- Typical electrical offset current value (4 mA for type 1; 7 mA for type 2)
- Frequency bandwidth 9.5 kHz
- Accuracy 1.5%
- Supply voltage 24 V DC
- Impulse withstand voltage 10 kV
- Isolation amplifier bandwidth 10 kHz, 4-20 mA output

The current transducer with power supply, signal adaption and the isolation amplifier is installed in an insulating casing, which is connected in between one of the 4 existing ground connections (top West/top East; bottom West/bottom East) of a WESP at a chemical plant in Germany.

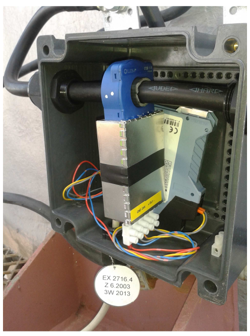

Figure 5. Current sensor prototype for operating current measurement

WESP/TR set data:

- Second stage ESP for sulfuric acid plant
- 2 collecting tube bundles, total 212 collecting tubes
- Length of collecting tube 4.5 m
- Diameter collecting tube 240 mm
- Interconnection of collecting tubes top/bottom section via integrated graphite contact plates
- Interconnection of the 2 collecting electrode bundles (top/bottom section) and section lead through via platinum wire
- Type of TR set: Single-phase thyristor controlled
- TR set nominal average output current 800 mA
- Typical operating current 600–800 mA
- TR set peak voltage 86 kVp
- Typical operating value 43 kV

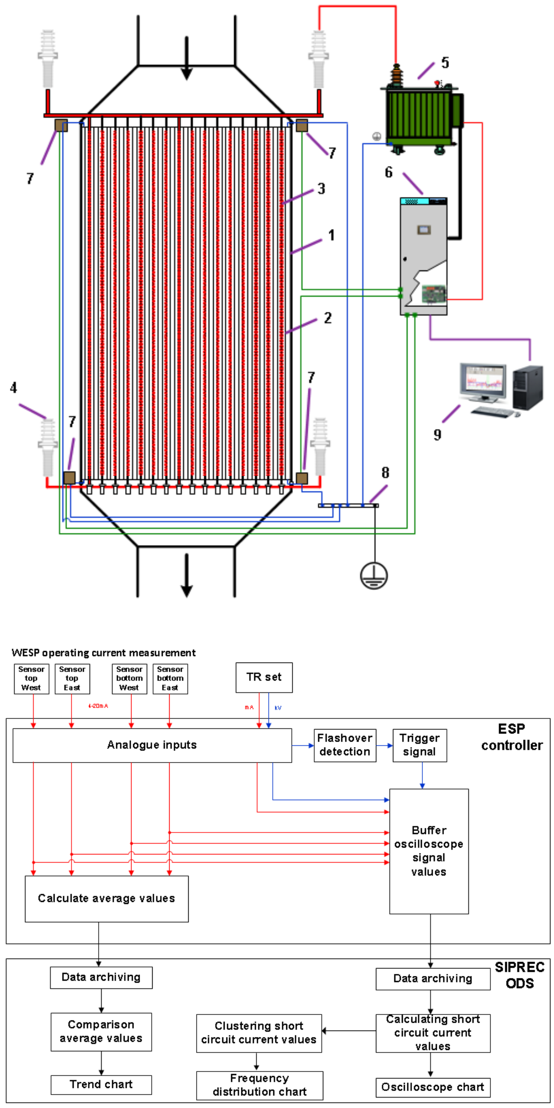

Figure 6. Test equipment WESP test plant

The 4 analogue signals of the WESPs operating currents are transmitted to an ESP controller connected to a PC having the SIPREC ODS ESP software for data archiving, analysing, trend recording and oscilloscope functions installed.

4. Experimental Results

The average values of the operating current signals (top West/top East; bottom West/bottom East), are continuously archived and can be displayed in a trend record window. Comparing the average values of the operating current signals allow the detection of abnormal conditions (i.e. change in current distribution, connection failure etc.). Furthermore comparing the total value of all ESP operating current signals with the TR set current value will show the grade of deviation of each section. However, since the installation of the current sensors no abnormal conditions or deviations have been observed so far.

2 sensors installed on top and 2 sensors installed on the bottom of the WESP allow the separation of values for the 4 different sections. The ESP operating current at the time of a flashover can be clearly differentiated by the shape and value. Highest current values are expected for those flashovers, which occur close to the point of the operating current sensor. Very low current values indicate, that the flashover was not likely to be located in the section of the entire sensor.

The half wave period current values at the time after the occurrence of flashovers were classified into –1 to –10 for decreased current values and +1 to +10 for increased current values compared to normal operation. With subtraction of the top/bottom and West/East values, the estimated position of the flashover is calculated. The example below presents the estimated calculated flashover distribution, found when comparing ca. 250 flashovers.

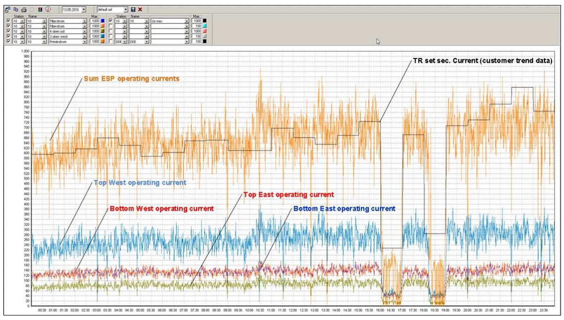

Figure 7. Trend chart for individual and total WESP operating current signals and the total TR set operating current

Flashovers with similar data have been clustered in order to show the number of flashovers within an area by the size of the entire bubble. The diagram shows the flashover distribution with a higher concentration in the center top West/East section.

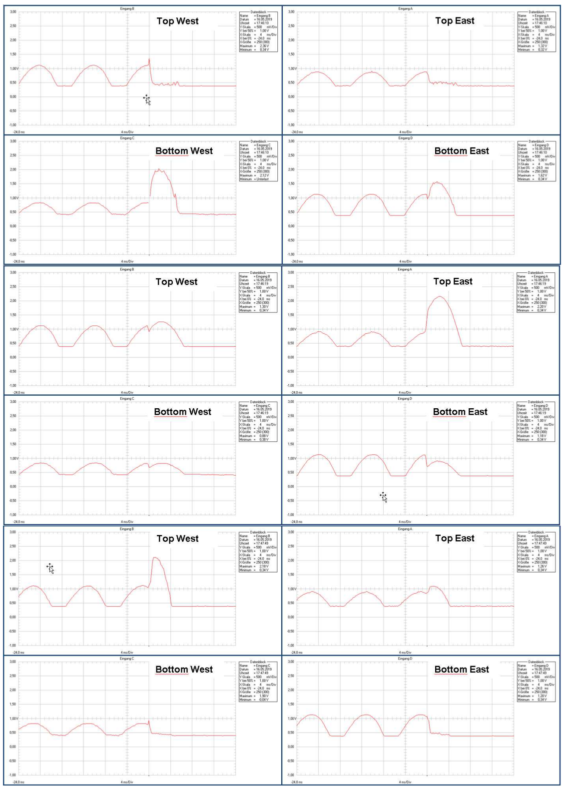

Figure 8. Example ESP operating current signals at the time of flashover (signal 0.4 -2V; 0-808mA for West and 0-1667mA for East)

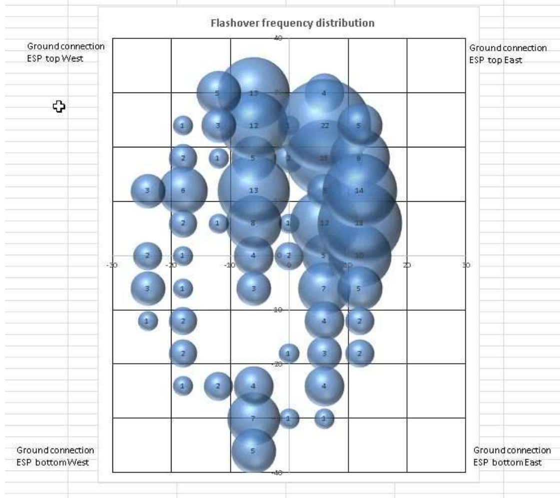

Figure 9. Flashover frequency distribution calculated for a relative short operation period

For WESPs with more than 2 operating current sensors at the top or bottom, information will be also available to calculate the estimated position of the flashovers into the third axis.

With analysis done on the WESP operating current wave forms, as presented above (based on thyristor controlled high voltage power supply), the calculated distribution of the flashovers is monitored and graphically presented in order to allow the detection and reporting of abnormal conditions.

5. Conclusions

The continuous measurement and analysis of the WESP grounding currents average as described above, provides the detection of missing ground connections and the change in the operating current distribution.

The results of the theoretical analysis done by simulation of the ESP configuration, the operating currents and presence of flashovers within a collecting electrode show, that the transient waves and short circuit current wave forms are depending on the location of the flashover within the electrode system. This was confirmed by measurements with a current sensor prototype installed at a real WESP.

The analyses of the operating current wave forms enable the estimation of the frequency distribution of the flashovers.

Abnormal conditions with unequal concentration of flashovers to one location can be detected and reported. With measures taken in time, possible damage to the WESP can be avoided.

A long term evaluation is required to reflect the results of the continuous measurement with the findings of WESP inspections.

In addition, further investigations are required to check the usability of the current sensor and analysis for WESPs supplied by HFPS (IGBT inverter systems).

References

[1] Dr. Miller J., Patent WO 01/08804 A1, Ground conductor for a grounding system, (2001).

[2] Hausmann M., Grass N., Piepenbreier B., Power Electronic Modelling & Emulation of an Electrostatic Precipitator, ICESP XII conference proceedings.

[3] Neamtu V., Stochita A., Dascalescu L., High-voltage monitoring in electrostatic separators, IEEE Transactions on Industry Applications Volume:43, Issue: 1, 29 Januar 2007.