Precipitator Performance Improvement and Energy Savings based on IGBT Inverter Technology

Norbert GRASS[1], Andreas ZINTL[2]
(1 Georg Simon Ohm University of Applied Sciences Nuremberg Institute for Electronic Systems ELSYS, Nuremberg, Germany. Norbert.Grass@ohm-university.de
2 Siemens AG, Dep. I IS IN E&C CIS, Erlangen, Germany. Andreas. E-mail: Zintl@siemens.com)

Abstract: Energy efficiency and energy saving become more important for many technical applications due to the higher cost of energy and environmental impact (e.g. CO_2 emissions). Dust emissions need to be maintained below the emissions limits regardless of the operation mode or fuel type of the process.

Basically, precipitator performance improvements can be achieved by applying higher electrical power to a precipitator. The limitation of a conventional SCR based high voltage power supply is the 50/60 Hz voltage ripple, which leads to flashovers during the peak voltage, while the average voltage is comparably low. High frequency IGBT inverter technology can deliver a DC voltage with a higher average value resulting in significantly higher power. Additionally, the current can be interrupted at any time for faster reaction to flashovers. High space charge density is avoided and therefore shorter wait time for deionisation is required resulting in higher average power. In case of high resistivity dust short superimposed pulses can be applied for increased charge density generation at the spray electrodes.

Existing plants can be upgraded easily by just replacing the control cubicle, while the TR set can be kept in use in many installations. For optimum performance the TR set can be replaced by a high frequency (500 Hz / 10 kHz) type. An advantage of this concept particularly can be found in existing plants, because the cable installation between the cubicle and TR set can be still up to 120 m.

Grid current waveforms of IGBT inverters are different from SCRs. The reactive power demand is much lower due to the diode bridge at the input stage and the voltage link capacitor. The load current is symmetrical for the three phases. The harmonics of the grid current are typical for a standard diode rectifier. This is very common due to the fact that IGBT inverters are used for electrical drives frequently. The low demand of reactive power limits the apparent power to a value very close to the active power. Therefore supply transformers which are rated for the apparent power demand of the connected load can be reused, even if higher electrical power for the precipitator is required. For future requests the input rectifier can be equipped with an IGBT based power factor control to limit the harmonic distortion.

Active Power savings (real savings) can be achieved by a computer based energy management system which calculates the required power for each zone of the precipitator. Due to the high dust load the inlet fields of a precipitator generally require more power than the middle fields or outlet fields. Practical tests have shown that the total power consumption of a precipitator can be decreased significantly, depending on the operation mode and the process conditions 0. Lowering the power of a precipitator results in a higher sensitivity to any process changes, particularly during collection electrode rapping when dust from the plates is being released. To avoid dust emission peaks the high voltage and current control has to be synchronized with the rapping interval of the entire field. Increasing the current during rapping has been proven to keep the emissions low, even during rapping.

The achievable power savings depend on the operating conditions of the precipitator, and they usually vary during operation. The system shown in this paper is designed to keep the emissions within the required range with highest priority. Anytime the emissions range can be reached with lower power, the system will drop down the power as low as possible. In coal fired power stations it has been shown that usually 30%-60% of the electrical energy within a period of operation can be saved. This results in a reduction of CO_2 gas emissions in a coal fired power station due to the resulting electrical usage savings. The power consumed in the precipitators has to be generated additionally in the generation plant.

Keywords: ESP, IGBT converter, Energy saving

1 INTRODUCTION

In comparison to SCR (silicon controlled rectifier) based conventional high voltage power supplies IGBT inverters offer much higher dynamic behavior. Voltage and current can be controlled much more precise and much faster and the efficiency of an electrostatic precipitator can be significantly increased. Unfortunately, better dedusting basically leads to higher power consumption resulting in higher operation cost.

In large industrial precipitators with a high number of parallel and serial fields the dedusting is processed in different ways in the inlet, middle and outlet fields. Optimizing the operational voltage and current in each zone can be done under the constraints of minimum power consumption for the precipitator while operating significantly below the emission limit.

The IGBT inverter (Fig. 1) has a 3-phase mains input rectifier with a power factor (cos φ) near unity. A voltage link capacitor is used as a energy buffer for the H-bridge IGBT-inverter. The switching frequency is typically 10 kHz. The current inversion frequency has been selected at 500 Hz, therefore accurate and fast adjustment of current and voltage is possible. The current frequency can easily be changed to 50 Hz/60 Hz in case of reuse of standard TR-sets.

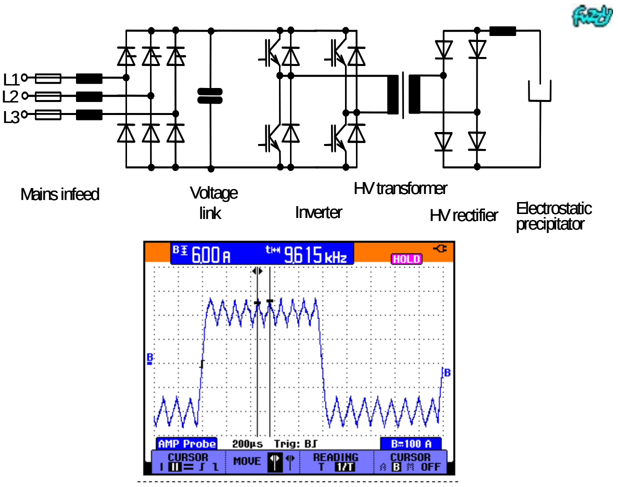


Fig. 1 IGBT inverter circuit diagram and inverter current shape

Compared to a standard SCR the average precipitator current can be increased significantly due to the flat V/I characteristics of a precipitator the electrical power could be increased by up to a factor 2 or 3 in many applications.

2 EMISSION IMPROVEMENTS

Fig. 2 shows the dependency of the Emission on the corona power. In respect to Fig 2 higher corona power due to the constant DC voltage leads to a significant reduction of the emissions. The electrical power is limited by the flashover voltage of the precipitator. Flashing usually occurs at the peak voltage, while the de-dusting depends on the average voltage applied to the precipitator. IGBT inverter based power supplies deliver a flat DC voltage, while conventional SCR based power supplies show a high voltage ripple. Therefore, the average voltage can be increased with the IGBT inverter up to the peak voltage of the regarding SCR supply.

Each time a flashover occurred the voltage drops down and the current has to be turned off for deionization of the flashover space. Due to the high space charge generated during the flashover in case of a SCR power supply the deionisation period needs to be in the range of some tens of milliseconds (e.g. 50 ms). During this period of time there is no current flow in the precipitator and therefore, no gas is being cleaned. IGBT inverters can deliver a DC voltage without a ripple and the current can be turned off immediately after the occurrence of a flashover. Only a small space charge remains in the area of the flashover and the deionization period can be much shorter. The result is a significantly higher average voltage which leads to a better operation of the precipitator, but results in higher energy consumption.

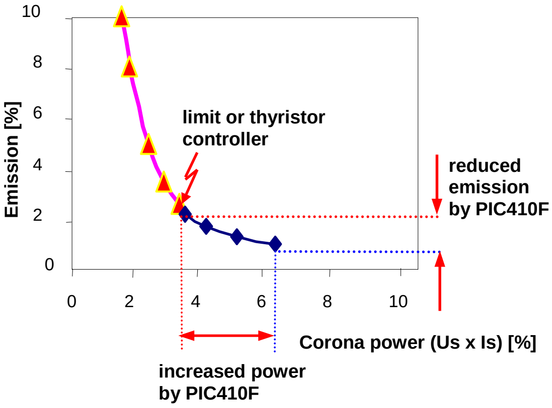


Fig. 2 Emission versus electical power

With IGBT inverters and the fast flashover processing the system can be operated with significantly higher flashover frequency in order to increase the average power further. If the flashover rate is driven too high the precipitator responds with an avalanche of flashovers which drives down the electrical power. Therefore, the power is to be kept below the occurrence of the uncontrollable high local space charge to avoid this critical state of operation. Fuzzy logic based control has been proven to operate a high voltage power supply successfully under these critical conditions. Further information can be found in 0 0.

3 ENERGY SAVINGS

Basically, emission improvements and energy savings are contrary goals. Frequently the maximum electrical power may not be required to match the emission setpoints depending on the process conditions. It has been found that increasing the power in the first fields often results in a much lower power demand in the following fields and the total electrical power consumption can be reduced. The system determines online the differentials of emission versus electrical power of each field. This measurement is difficult because of overlaid events in the other zones, and process changes. The long response time of the resultant dust emission due to electrical power changes in the precipitator is an additional complication. Rules were defined for a coarse, but fast response power adaptation of all zones. Fine tuning the running system after the coarse optimization increased the accuracy and reliability. When installed on a 4 by 5 zone precipitator in a power station significant results were obtained. The power savings over 3 months of operation were in the range of 40% to 60% depending on the load and fuel characteristics. Data was recorded over the test period of 3 months. The details are explained in 0.

4 CONTROL SYSTEM

To operate large industrial precipitators on low emissions and minimum energy consumption a new two stage control system has been developed. The first stage is a controller dedicated to each field. It contains a fully functional independent control system for each field. The second stage is a computer based superimposed control system targeting the optimized operation of the precipitator plant. Fig. 3 is showing the structure of the control system which uses an inference free fiber optic network for data transmission. Optionally, a PLC system (e.g. Siemens SIMATIC) or a plant control system (e.g. Siemens Teleperm) can be linked to the data network. Even in case of a fault in the second stage of the control system the first stage will be fully functionally and the operation of the precipitator can be ensured, but with increased energy consumption.

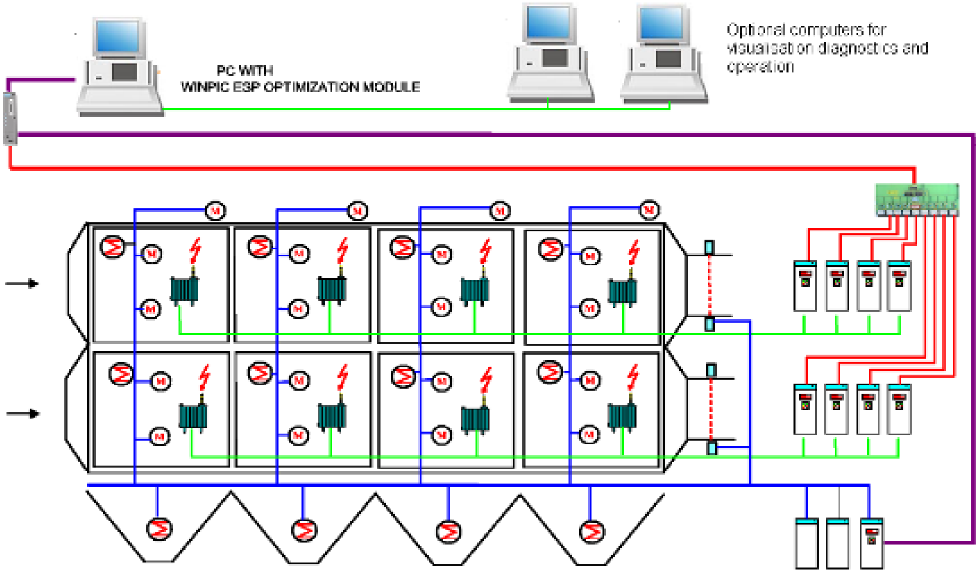


Fig. 3 data network structure of the control system

Siemens has developed a new controller for precipitator fields (see Fig. 4) with the following features:

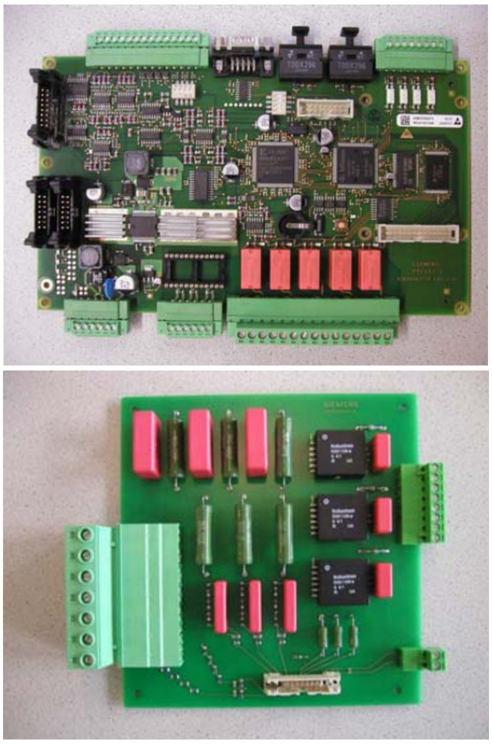


Fig. 4 New controller for each field of a precipitator

- **Control of the high voltage generation** (control of the power electronics (IGBT/SCR), optimization of current/voltage, flashover processing (conventional and fuzzy logic);
- **Data acquisition and processing** of voltage/ current signals (sample and average values, filtering);
- Different programmable and recallable **operating modes** (e.g. startup, shutdown, full load etc.);
- Control of **electrode rapping**, calculation of rapping intervals for collecting and spray electrodes, adaption of field current during rapping intervals;
- Data **acquisition of process signals,** e.g. stack/ flow emission, boiler load, gas temperature;
- **Internal diagnostics** (power electronic status, TR-set status, controller self check);
- **Safety functions:** CO gas interlock, HV switches, door contacts;
- Optical data interface for **PROFIBUS** network;
- New comfortable operator panel with **graphical user interface** (see Fig. 5);
- Due to the digital signal processing unit (DSP) of the new controller the precision, stability and robustness of the system could be improved compared to the preceding version of the controller. Additionally, size and number of cards could be reduced.

Fig. 5 Operator panel with graphical color display

The second stage (superimposed) control and optimization is processed as a “Fuzzy Power Management” software module of the Siemens WINPIC package on an industrial computer. In normal operation it runs as a taskbar application on a Microsoft Windows™ operating system. The WINPIC server module is providing the data communication between all WINPIC software modules and the field controllers via PROFIBUS industrial network. Additional software modules process rapping optimization, data storage, visualization, monitoring and operation. The data communication between the software modules is based on standard TCP/IP communication (see Fig. 6). Therefore they can be executed even on different computers. Generally it makes sense to execute the server, database and optimization modules on a dedicated computer. The visualization module can be executed on any computer which can access the server via network (e.g. office computer of the maintenance engineers).

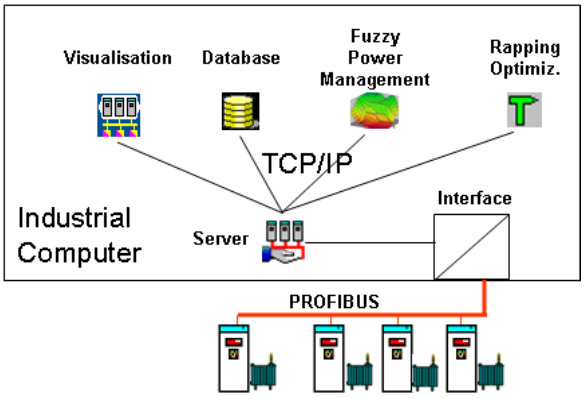
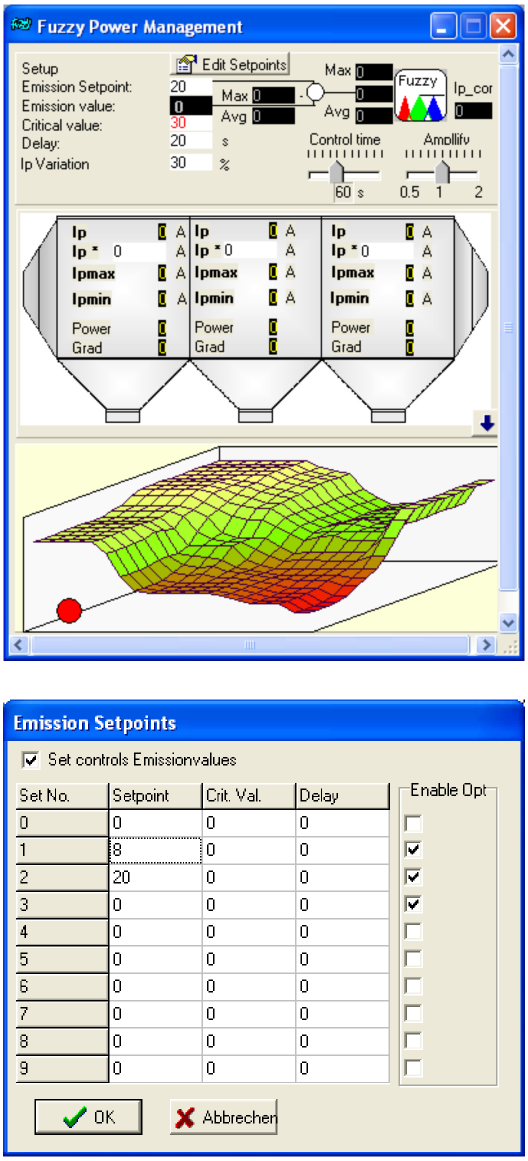


Fig. 6 Data communication structure

The “Fuzzy Power Management Module” (see Fig. 7) offers the independent optimization of up to 10 precipitators. Each precipitator may contain up to 10 parallel and 10 serial fields. The user needs to set following parameters:

- Emission setpoint: expected emission at the stack. The software tries to optimize the power of all power supplies in order to match this value in average;
- Critical emission value: In case of emission exceeds that value the power / current of all fields will be increased fast in order to avoid to high emissions;
- Delay: The time the gas flow needs from the precipitator to the emission measurement;
- Some additional parameters to adapt the control to the process dynamics.



Setup
Emission Setpoint: 20
Emission value: 0
Critical value: 30
Delay: 20 s
Ip Variation 30 %
Control time 60 s
Amplify 0.5 1 2

Emission Setpoints

☑ Set controls Emissionvalues

Set No.	Setpoint	Crit. Val.	Delay	Enable Opt
0	0	0	0	☐
1	8	0	0	☑
2	20	0	0	☑
3	0	0	0	☑
4	0	0	0	☐
5	0	0	0	☐
6	0	0	0	☐
7	0	0	0	☐
8	0	0	0	☐
9	0	0	0	☐

Fig. 7 User interface and parameters of the fuzzy power management software

It is possible to use up to 10 parameter sets per precipitator for different operation modes (e.g. plant startup, different coal types, process conditions). They can be recalled by operator access through the WINPIC software or by an automation system.

The user interface offers transparency of the control and optimization operation and status. Additionally, an expert can access more parameters and the control system can be fine tuned.

Besides the energy minimization the WINPIC rapping module realizes the co-ordination of collecting electrode rapping. Rapping control is very important in case of low power operation to avoid emission peaks. Additionally, the ESP diagnostics tools are realized e.g. integrated oscilloscope, I/V characteristic scan and data archiving/trend graphics in the visualization module. All information is on one view by the clear ESP visualization, which was continuously extended after customer's request by several graphical layouts.

Fig. 8 gives an example with the system described above in operation. The emission is maintained fairly constant while the currents of the fields are slowly decreasing. Rapping does not lead to dust peaks due to the rapping control module.

Depending on the process conditions the energy savings may vary. There may be conditions were the maximum possible power is required to maintain the emissions. But Energy savings can be achieved on average during a longer period of time. Experimental measurements on a number of different precipitator plants showed improvements in power consumption in the range of 30%- 60%.

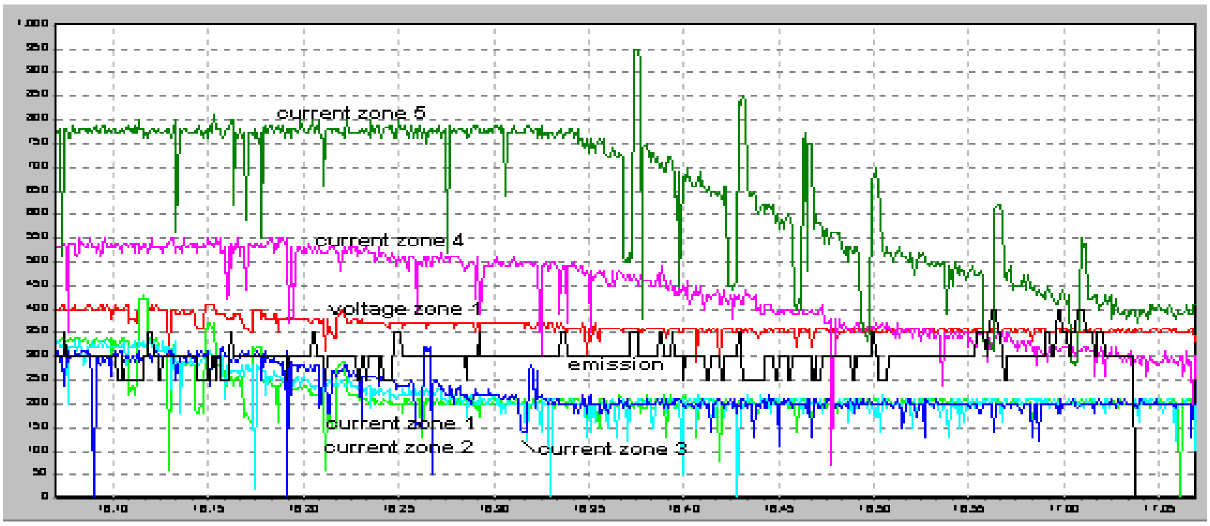


Fig. 8 Example showing the shutdown of a coal fired power plant

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