VGB POWERTECH
Volume 93 – Issue 3/2013
Page 80 to 83

SPECIAL PRINT

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Kurzfassung

Dreiphasen-Transformatorgleichrichter-systeme – Hochspannungsaggregate für schwierige Stäube in Elektrofiltern

Die Abscheiderate von Elektrofiltern in Kohlekraftwerken, Müllverbrennungsanlagen und ähnlichen Einrichtungen hängt stark von der Beschaffenheit der Rauchgase ab. Unter anderem spielen die elektrische Leitfähigkeit der Staubpartikel sowie deren Fähigkeit, sich elektrisch aufladen oder ionisieren zu lassen, eine Rolle. Innerhalb gewisser Grenzen dieser charakteristischen Staubeigenschaften, der Leit- und der Ionisierungsfähigkeit, liefert ein gängiger Elektrofilter problemlos die gewünschte Reinigungswirkung. Überschreitet die Abgascharakteristik jedoch diese Grenzen, sind anspruchsvollere technische Lösungen gefragt.

Die Standard-Hochspannungsversorgung in einem Elektrofilter besteht aus einer einphasigen 50/60-Hz-Transformator-Gleichrichter-Einheit. Bei schwierigen und hochohmigen Stäuben kann unter Umständen diese Standard-Hochspannungsversorgung an ihre Grenzen gelangen und die gewünschte Abscheiderate nicht mehr sicherstellen. Ein Dreiphasen-Transformator-Gleichrichter-System bietet in diesem Fall eine Alternative zum Einphasensystem, da es eine glatte Hochgleichspannung über einen sehr weiten Spannungsbereich zur Verfügung stellt. Dies hat sich zum Beispiel bei Anlagen mit inhomogenen Brennstoffen, wie in Müllheizkraftwerken eingesetzt, als vorteilhaft erwiesen.

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Introduction

Stack gases, which are generated by coal-fired power plants, waste-to-energy, and biomass combustion plants as well as exhaust gases from steel- and cement factories have a substantial adverse effect on the environment and according to legislation, they have to be purified before they are released into the ambient air. Solid particles, such as fly ash are captured by a filter system through which the exhaust gas stream is flowing. Given the varying compositions of exhaust gases and the solid particles they are transporting, the reliable separation of dusts is frequently a technical challenge; hence the choice of the most compatible filter system and its voltage supply as well as its concise alignment with the respective situation are extremely important.

Fundamentally, a distinction is made between two filter principles: fabric filters that retain dust particles by mechanical means and electrostatic precipitators (ESP), which use a strong electrostatic field to divert the dust particles to separation panels where they are deposited.

The paper at hand describes the power sources and operating modes that work well under difficult ESP conditions.

Exhaust gas streams in ESPs

In an ESP the exhaust gas stream moves through a series of electrostatic fields as consistently as possible. The fields are generated by a system of counter-pole charged electrodes. The so-called discharge electrodes are located in the centre between two electrodes each collecting and are usually connected to the negative pole of the high-voltage power supply. They are structured in such a manner that the negative charges (the electrons) easily emit from their surface and can move around in the exhaust gas stream as available charge carriers (e.g. sharp edged, tipped surfaces easily emit electrons). The collecting electrodes are usually charged positively, i.e. grounded to earth potential and at the same time form the filter pathways. They work as the collection surfaces for the dust particles to be separated (Figure 1).

The dust particles are charged negatively while the exhaust gas containing dust particles moves through the electrodes. The charged particles are affected by the electrical field forces. The so-called Coulomb force diverts the dust particles into the direction of the electrical field lines, until they are stopped by the surface of the collection electrode. The collection electrode is grounded and simultaneously connected with the positive potential of the voltage source. The negative charges, which are located on the dust particles, can therefore flow down to the collection electrode after they have settled. Initially, the dust particles form a more or less firm dust layer on the electrode given that a negative residual voltage is constantly present on the surface of the dust layer. Rapping hammers activated at regular intervals ensure that the dust layer is loosened and falls into the catching and collection devices.

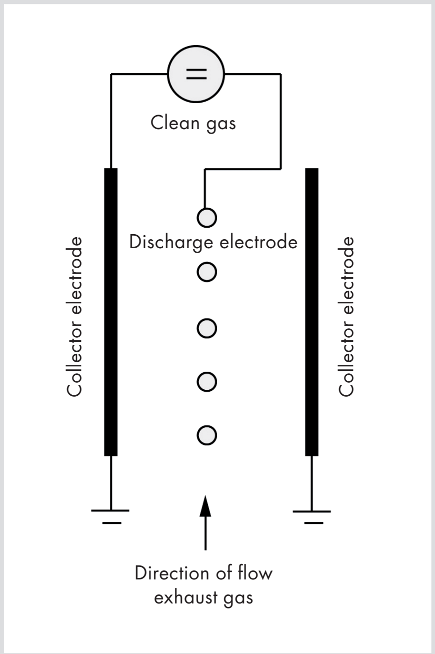


Fig. 1. Principle of ESP with negatively charged discharge electrodes and grounded collection electrodes.

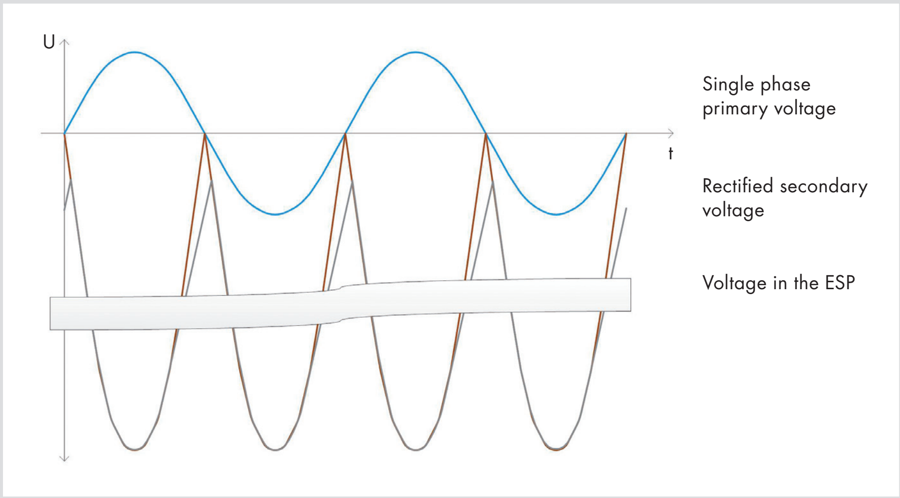


Fig. 2. Electrical filter voltage (gray) from a single phase high-voltage rectifier device when the sinusoidal waves are fully actuated.

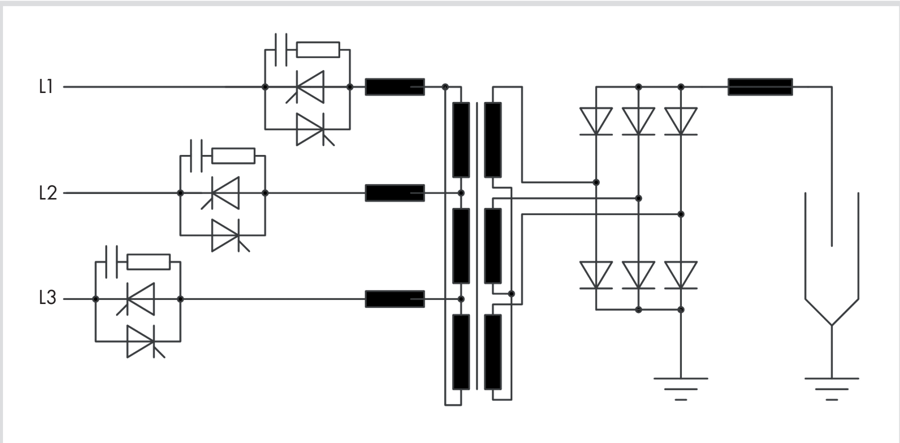


Fig. 3. Principle of a three phase transformer rectifier system with full wave thyristor control and bridge rectifier on the outlet.

Single phase and three phase high-voltage power supply

The main energy component of the ESP is a high-voltage transformer rectifier set with a compatible control unit. The high-voltage generators mainly comprise an electromagnetic voltage converter – if grid frequency is used it is called transformer, otherwise a transmitter – and a rectifier set that turns transformed AC voltage into DC voltage. Depending on the technical requirements, several architectures of voltage sources in multiple operation modes are available first and foremost in order to generate the required electrical field in the ESP.

The conventional and most basic method is that of a single phase transformer, which gets variable voltage through the thyristor supported phase controlled modulator. On the secondary end, the transformer delivers a high AC voltage, which is transformed into DC voltage by the rectifier (Figure 2).

In order to obtain DC voltage that is of the highest quality possible, i.e. smooth, and to place a more symmetric load on the phases, a three phase transformer can be used (Figure 3). This system works much like the single phase type, but is distinguished by the residual waves during high voltage, because the three 120° each phase deferred and therefore overlapping sinusoidal waves cover the gaps (Figure 4).

Difficult ESP conditions

Difficult conditions in a filter occur if especially high ohm or especially low ohm dust particles are present, or if dust particles have inhomogeneous resistance or if large volumes of dust occur.

Dust particles with especially high ohm ratings and/or particles that tend to attract only minimal charging or are hard to ionise, are frequently referred to as “difficult ESP conditions”. In multi-zone filter systems, this problem arises primarily in the final filter zone, where the dust is particularly fine just before the outlet. The high ohm content of these dust particles results in the development of an extremely high voltage over the dust layer on the collection electrode, given that the (virtual) capacitor of the dust layer is discharged very slowly over the high resistance of the dust layer. As a result, the voltage in the flow-through channel becomes very low. The electrical field is correspondingly weak and the particles are no longer diverted to the collection electrode with enough force. The different resistance conditions are compared in Figure 5. The left diagraph shows a low-ohm dust layer on the wall electrode; thus the voltage over the dust layer is low, as the dust layer capacitance is quickly discharged over the low-ohm dust resistance; hence the voltage in the gas area is very high with a strong electric field which can divert the charged particles easily. The right diagraph shows a high ohm dust layer which results in a high voltage within the dust layer capacitor and a weak electric field within the gas area; the diversion of charged particles becomes inefficient.

In order to meet the required separation rate even under the latter conditions, it is recommended to use a voltage source that delivers DC voltage that is in general as smooth as possible. This high quality DC voltage, which is provided for example by a three phase transformer rectifier system, creates an electrical field in the flow-through chan-

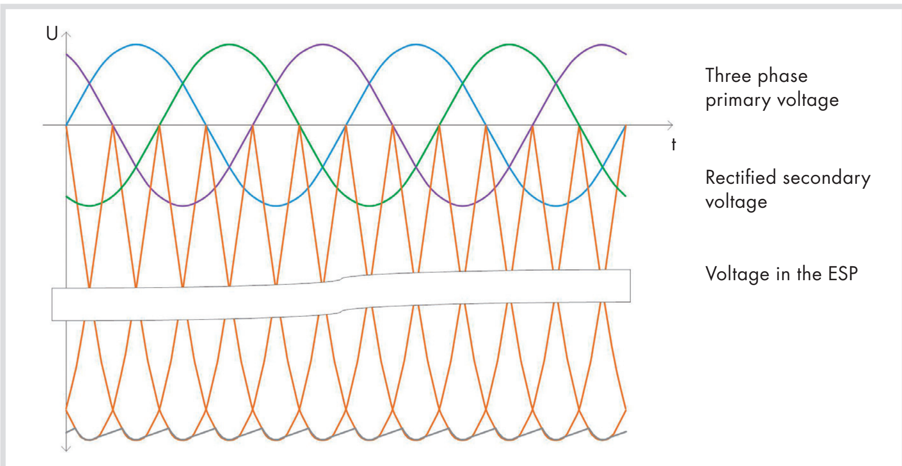


Fig. 4. Electrical filter voltage from a three phase transformer; the effective residual waves of the voltage are contingent upon the situation in the ESP, for instance the capacity and resistance of the dust.

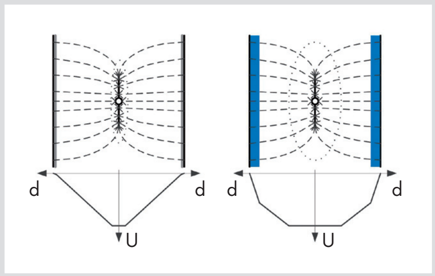


Fig. 5. Two ESP models with different resistance conditions, left: low ohm dust layer, right: high ohm dust layer.

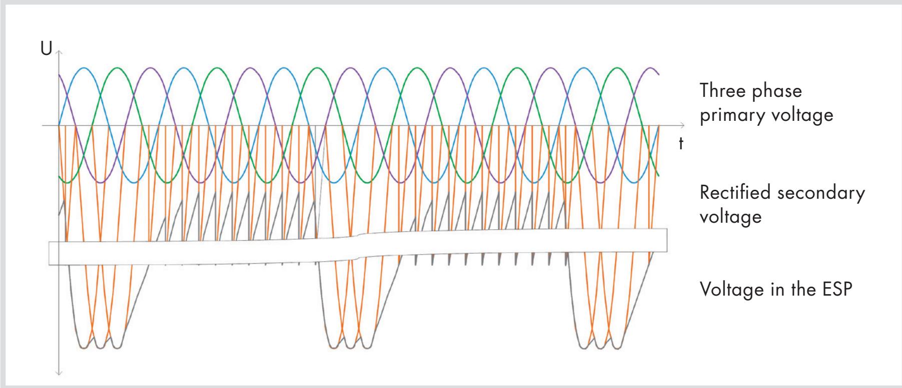


Fig. 6. Pulse operation using a three phase unit; triple the volume of voltage pulses in the gaps results in much lower alternating voltage shares.

nel that remains very consistent and therefore adequately strong over time in order to create the necessary deviation forces. The high voltage is brought as close to the flashover point as possible at all times so that an electrical field that is as strong as possible is maintained for a long period of time.

Continuous and pulse operation

High ohm difficult ESP conditions can trigger so-called back corona effects. If the electrical resistance of the dust layer on the separation electrode continues to increase, the drop in voltage above this dust layer becomes excessive and disruptive electrical discharges occur as a result of the dust layer. Some of the dust particles flow back into the exhaust gas stream and the separation rate drops. The back corona effects can be reduced by using the so-called pulse functions.

Contrary to continuous operation, which results in every half wave of the sinusoidal voltage being ignited by much the same size ignition angle, the pulse operation is limited to ignition with large ignition angles affecting only a small portion, i.e. every third, fifth or seventh half wave, etc. (Figure 6). The other half waves are only charged through with a minimal ignition angle, which leads to a reduced fill in voltage between the pulses. During these time intervals, the voltage above the dust layer has the chance to normalise, i.e. the (virtual) capacitor has the time to discharge and the electrical field in the flow-through channel regains its power. The ignition risk in the dust layer declines. In order to meet dust separation and therefore the separation rate also during the reduction phase, a suitable fill in voltage must be selected. This can be dependably achieved with a three phase transformer rectifier system, given that this system delivers DC voltage that is still of high quality even in the partial voltage range of the outlet and therefore safeguards the presence of the required strong electrical field.

Use of inhomogeneous fuels in explosive environments

One of the challenges an ESP has to master in power plants is the wide range of dust particles in flue gases. Even if only "one" fuel, such as lignite or hard coal is used, the different levels of moisture contained in the fuels result in significantly heterogeneous exhaust gas streams, whereby the diversity in the composition of fuels such as "lignite" or "hard coal" is also substantial in itself. This complexity is further amplified by the procurement of fuels from the international market.

Waste incineration plants using an extreme variety and inhomogeneous fuels make the conditions for ESP even worse. In these cases, a high-voltage system also proves beneficial, if it has a more expansive voltage range to create a strong and consistent electrical field. If the system offers as much voltage as possible over the time, a consistent and strong electrical field is also available for the same period of time and ultimately current flows are needed and all particles are charged effectively despite their different consistencies.

At this point the importance of a quickly responding control unit has to be born in mind. This control unit also activates pulse operation, which has an additional positive influence on the separation rate if the respective ESP conditions arise.

The advantages of a strong electrical field with high-quality DC voltage also make a difference if the gas particle combinations in the exhaust gas stream are such that they pose an explosion risk. These conditions can be found primarily in the chemical and process technical industry. Any spark over in the filter must be avoided in explosive environments. In this case, it is best to opt for three phase transformer rectifier systems as high-voltage supply systems that deliver the required smooth DC voltage over a wide range and create a consistent electrical field even if the loads in the ESP should change.

Comparison of voltage sources

Single phase transformer rectifier systems offer a range of advantages that made them the preferred choice in practical filter applications. Among them are their simple design, budget priced installation accessories, easy scalability, which can be used depending on the filter characteristics. Overall, this technology has proven itself in operations and meets the requirements of most applications. Nevertheless, if the aforementioned difficult application conditions arise, this technology frequently meets its limits. The reason is its measurable voltage ripple in continuous operation or its large ripple in pulse operation. Difficult dust scenarios require – as described earlier – DC voltage that is as smooth as possible and has minimal residual ripple, and is, as needed, overlapped by high voltage pulses to ensure the presence of a consistently strong electrical field in the flow through channel. Three phase based transformer rectifier systems offer the optimum alternative for such cases. However, three phase systems are not only able to deliver high quality DC voltage. Modern high-frequency voltage generators are increasingly appearing on the market. They increase the switching frequency of the voltage to be transferred significantly. Commonly used high-voltage systems with high-frequency transmission offer frequencies ranging from 400 to 1,000 Hz or 30 to 50 kHz. Advantages of these systems are their compact and lightweight design – contrary to the substantially heavier three phase systems – and the symmetric load on the in-feed phases that go hand in hand with the low ripple. However, the lightweight design of these systems also involves some inherent disadvantages. The highly complex devices and their expensive components require special installation equipment. More specifically, the connection between the performance control cabinet and the high voltage transmitter requires special cabling in order to limit the stray, coupling and wave losses and to bring the high frequency performance to the transmitter. This is further compounded by the fundamental disadvantages of limited scalability of the voltage and the limitation of the voltage and current values at the secondary end.

Example of a waste incineration plant in Scandinavia

A waste incineration plant in Scandinavia is to be introduced as positive example of a three phase system. The facility, which was delivered turnkey ready by the manufacturer, was dimensioned with an ESP with three zones that can handle a flue gas volume 67,000 Nm^3/h_{moist}. Based on a projected raw gas dust content of 4.0 g/Nm^3 and max. 8 g/Nm^3 for "soot bubbles", the design pure gas dust content was 10 mg/Nm^3.

Initially, the ESP was equipped with three single phase systems rated at 111 kVs and 400 mAar each. During commissioning of the plant and start-up of the ESP, some irregularities were observed. Among other things, the voltage and current values fluctuated considerably while the pure gas dust content temporarily exceeded the limit values massively (20 to 40 mg/Nm^3 with peaks exceeding 100 mg/Nm^3 during rapping).

In a first step, the ESP was examined and it was revised as needed, e.g. the rapping intervals were adjusted, the flue gas flow was optimised etc. Moreover, the high-voltage control was eventually optimised, i.e. the parameters for voltage reduction and the times for fast and slow ramp were adjusted. All these measures resulted in an improvement of the separation rate achieved by the ESP, however, the values were still above the limits for cleaned gas.

Subsequently, for testing purposes, a three phase system with nominal values 111 kVs/500 mAar was installed in the first zone of the ESP. This measure resulted in a sudden reduction of the dust content in the pure gas to < 20 mg/Nm^3. Most importantly, the trend line of the cleaned gas dust content appeared to be much smoother than it had been with the single phase unit. By converting the next two zones to the three phase technology, the dust content behind the ESP could be reduced to approx. 10 mg/Nm^3.

Summary

ESP systems boast a very broad spectrum of applications. The volume and composition of the exhaust gas in the filter do largely determine the selection of the special application, i.e. the filter structure and the voltage source as well as the related operating mode. Single phase and three phase high-voltage systems as well as high-voltage generators are used, each according to its respective special strengths. If difficult ESP conditions have to be expected in the exhaust gas flow and/or if the fuel is a highly inhomogeneous mix, the three phase transformer rectifier system is a particularly effective as voltage source. Three phase based high-voltage DC generators in grid frequency technology boast robust and dependable technology on the one hand, similar to that of the single phase systems, which have a long time proven success rate, however, they also have the benefits of modern high frequency systems. Sophisticated tasks to be handled by ESP can be addressed efficiently and reliably by these systems.

Rico-Werk: Power Boost IPA2® for high precipitation rates in electrostatic filters

Rico-Werk from Toenisvorst releases an ignition pulse amplifier for thyristor controller bridges which can be used as well in systems with semi controlled as with full controlled technology. The Power Boost IPA2® is designed for the installation in high voltage direct current power supplies as they are used in electrostatic precipitators.

To maximize the precipitation efficiency of an electrostatic waste gas filter, the high voltage has to be set as close to the flash over voltage as possible. Therefore the Power Boost IPA2® includes an innovative power stage, which allows a very precise controlling of the modern thyristors within micro seconds. The power can be adjusted extremely sensitive over the whole ignition angle range.

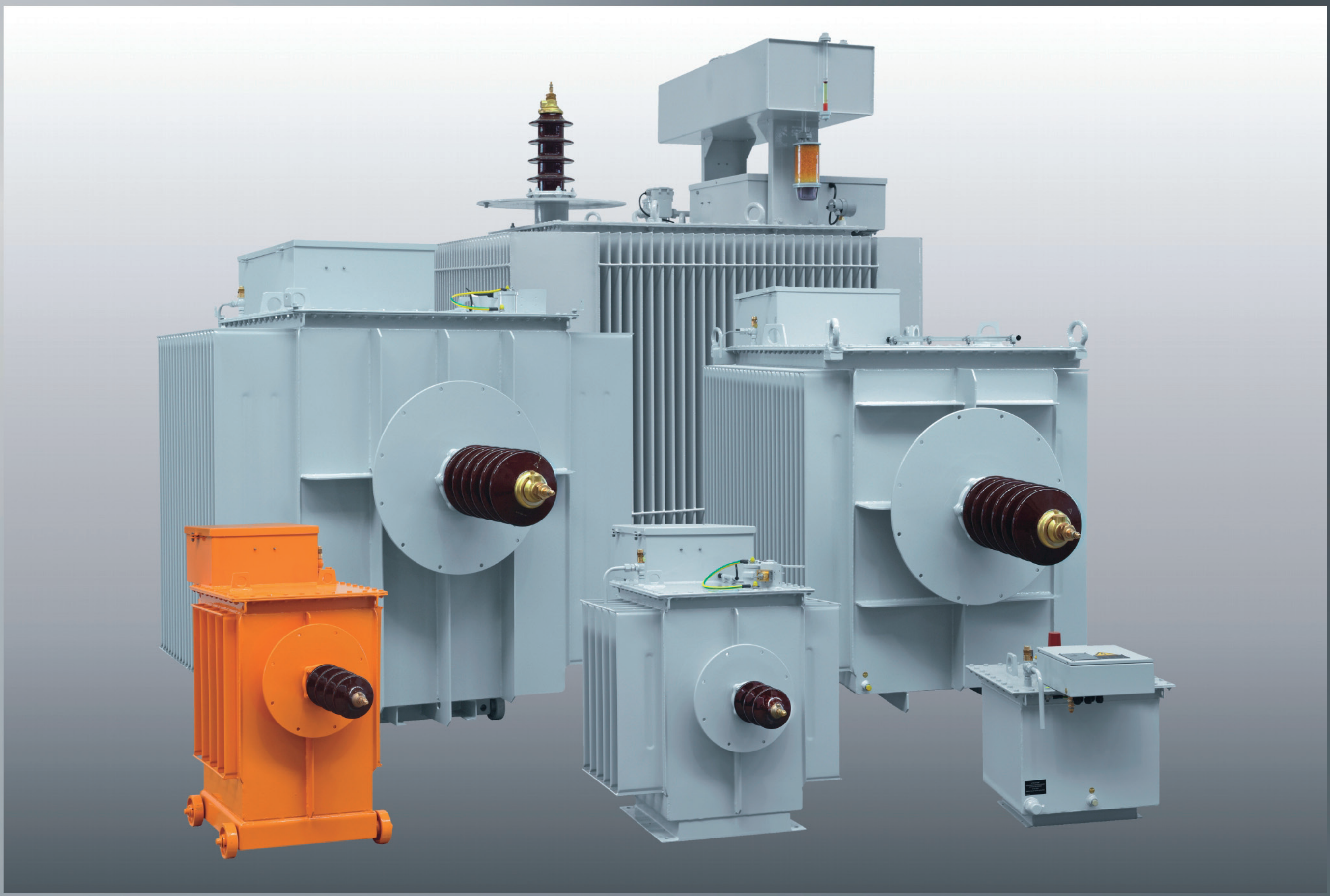
The potency of electrostatic precipitators is evaluated by the grade of separating particles from the waste gas. The precipitation rate can be kept as high as possible by the sensitively tuned power control which adapts the high voltage inside the filter housing to the permanently changing waste gas characteristics. Thyristors are an essential component in this control loop as they adjust the power for the high voltage direct current supply. Modern versions of the thyristors need a very strong and well defined current pulse to ignite exactly and reliably in the desired moment. The strong power stage of the Power Boost IPA2® enables this strong current pulse over the full ignition angle range.

Driven by the Power Boost IPA2® a full controlled three phase current thyristor bridge works with a dynamic range of 75 %, which the high voltage direct current power supply provides a low rippled high quality voltage with. The regulation of the Power Boost IPA2® is based on glass fiber cables.

The ignition pulse amplifier can be used for single phase and for three phase current systems.

Rico-Werk was able to gather a lot of experience with the upgrading of electrostatic precipitators, where the semi controlled bridge technology was the standard equipment. With the Power Boost IPA2® the company indicates that it also masters the full controlled technology without limitations. The Technical Director of Rico-Werk, Dr. Josef von Stackelberg, considers lots of potential in the new Power Boost IPA2®: „With the Power Boost IPA2® and together with our three phase current systems we can provide high voltage power supply systems for electrostatic precipitators which combines the advantages of the conventional single phase technology with the amenities of the switched mode power supplies. This means robust technology for a reasonable price for high quality direct current voltage."
(www.rico-werk.com)

Ignition pulse amplifier Power Boost IPA2® in the version for full controlled thyristor bridges with diagnostic unit IPA-D (Foto: Rico-Werk).



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