

Power Electronics Solution to Dust Emissions from Thermal Power Plants

Slobodan Vukosavić^{1,a)}, Nikola Popov^{1,b)}, Željko Despotović²

Abstract: Thermal power stations emit significant amounts of fly ash and ultrafine particles into the atmosphere. Electrostatic precipitators (ESP) or electrofilters remove flying ashes and fine particles from the flue gas before passing the gas into the chimney. Maximum allowable value of dust is 50 mg/m³ and it requires that the efficiency of the ESPs better than 99 %, which calls for an increase of active surface of the electrodes, hence increasing the filter volume and the weight of steel used for the filter. In previous decades, electrostatic precipitators in thermal power plants were fed by thyristor controlled, single-phase fed devices having a high degree of reliability, but with a relatively low collection efficiency, hence requiring large effective surface of the collection plates and a large weight of steel construction in order to achieve the prescribed emission limits. Collection efficiency and energy efficiency of the electrostatic precipitator can be increased by applying high frequency high voltage power supply (HF HV). Electrical engineering faculty of the University of Belgrade (ETF) has developed technology and HF HV equipment for the ESP power supply. This solution was subjected to extensive experimental investigation at TE Morava from 2008 to 2010. High frequency power supply is proven to reduce emission two times in controlled conditions while increasing energy efficiency of the precipitator, compared to the conventional thyristor controlled 50Hz supply. Two high frequency high voltage unit AR70/1000 with parameters 70 kV and 1000 mA are installed at TE Morava and thoroughly testes. It was found that the HF HV power supply of the ESP at TE Morava increases collection efficiency so that emission of fine particles and flying ashes are halved, brought down to only 50 % of the emissions encountered with conventional 50 Hz thyristor driven power supplies. On the basis of this study, conclusion is drawn that the equipment comprising HF HV supplies are the best solution for new ESP installations, as well as for the reconstruction of existing facilities. The paper describes the topology of the HF HV power supply, power management and controls, and brings the most important details of the implementation. It is found that the HF HV solution achieves several significant improvements over the conventional thyristor system. It is possible to provide more precise control of the ESP parameters such as the output voltages and currents. It is also possible to make a rapid increase or decrease in voltage and to effectuate a very fast response to load changes. Due to this advantages it is

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possible to suppress the supply quickly in the case of sparking, reducing the spark energy and the quantity of ionized gasses produced by the electric arc. Reduction in the spark energy is up to 10 times compared to conventional thyristors solution. This means that the erosion of the electrode system is significantly reduced, and that the quality of the collection plates is preserved for much longer periods. At the same time, lower quantity of ionized gasses produced by the spark contribute to much shorter de-ionization intervals, required to quit sparking and evacuate charged particles in order to reinstate the voltage and proceed with the operation. In addition, HF HV power supply provides a significant reduction in size and weight of the complete ESP installation, hence reducing the tons of steel that has to be built in. Therefore, the HF HV power supply may be the key instrument to reducing the cost of the de-dusting ecological equipment. Besides, size and weight reduction leads to cost savings of installation and maintenance. According to estimates, savings in steel may reach 30%, contributing to the overall cost savings of roughly 20%. Within this paper, in addition to describing the AR70/1000 unit topology and principles of operation, the paper presents the results and measurements obtained during extensive experimental investigations wherein performances of 50 Hz based thyristor units with T/R sets are compared to HF HV power supply.

Keywords: Electrostatic precipitator, High-voltage high-frequency supply.

1 Introduction

Although many readers are already acquainted with the functioning of the ESP, this introduction provides a brief reminder for those who have not come across this topic. ESP are used for removal of ultrafine dust particles from flue gas. The most frequent use is the removal of tiny particles of flying ashes in thermal power plants. In order to achieve this, it is necessary for the flue gas to move in the horizontal direction through a strong electric field established between sets of large, parallel electrode plates. The distance between the plates ranges from 300 mm to 500 mm. The plates extend vertically and along the gas flow. The positively charged electrodes are grounded, while the negative ones are connected to the DC voltage source ranging from 50 kV to 100 kV. The negatively charged electrodes have a number of spikes or small diameter wire, which contributes to corona and creates large amount of ions. The current density due to the corona discharge reaches 1mA/m^2 and it affects a great deal the precipitation and dust collection. Dust particles are being charged by means of diffusion and the field effect and they move towards positively charged electrode, where they are collected. Therefore, the negative electrode is also called the emission plate, while the positive, grounded electrode is also called the collecting plate. Particle migration speed towards the collecting plate is one of most significant parameters of electrofilters. The collecting electrodes are periodically shaken off, i.e. rapped. The rapping process is performed by means of the spinning hammers which periodically knock on the electrode supports and cause mechanical vibration which helps detaching the dust layer deposits

from the plates. The ash being removed during rapping falls into the V-shaped hoppers, located below the ESP chamber. From there, the dust and ashes are transported further by means of water or pressurized air. For the sake of an efficient dust removal, each ESP has at least three series connected sections. The flue gas enters the ESP through the entry section, and then passes through one or more middle sections. Upon leaving these sections, the flue gas passes through the exit section. By passing through the sequence of the serially connected sections the precipitation efficiency (i.e. filtering efficiency) reaches 99.9 %. With this efficiency and with every cubic meter of gas leaving the boiler and entering the ESP with 50 g of flying ashes, the gas leaving the electrofilter and entering into the chimney may have the total of 50 mg of dust per every cubic meter of gas. In order to create the electric field and the corona discharge current, the electrodes should be connected with a controllable DC voltage source which provides voltages from 50 kV to 100 kV. Considering the fact that sparks often occur between the electrodes and the electric arc occasionally appears, the source is exposed to periodic short circuit conditions. In the event of arcing, it is necessary to switch off the power supply for an interval of time so as to allow for recombination or removal of charged particles created by the arc. Premature voltage rise will find residues of conductive, ionized gas between the plates, re-entering hence the short circuit condition. After re-establishing of the dielectric strength of the gas, the voltage between the plates may be increased and the precipitation process may continue. The required DC current depends on the surface of the plates. It is necessary to provide the current of 1 mA for every square meter of the electrode surface. Hence, an electrofilter with 10000 m² requires the current of 10 A. The ESP power supply and controls are traditionally based on one pair of antiparall thyristors which alter the amplitude of the primary AC voltage. The primary supply is usually single-phase, 400 V, 50 Hz. By changing the firing angle, the voltage is being changed in the range from 0 to 400 V and brought to the primary of the line frequency power transformer whose secondary voltage reaches 45 kV to 90 kV (Fig. 1).

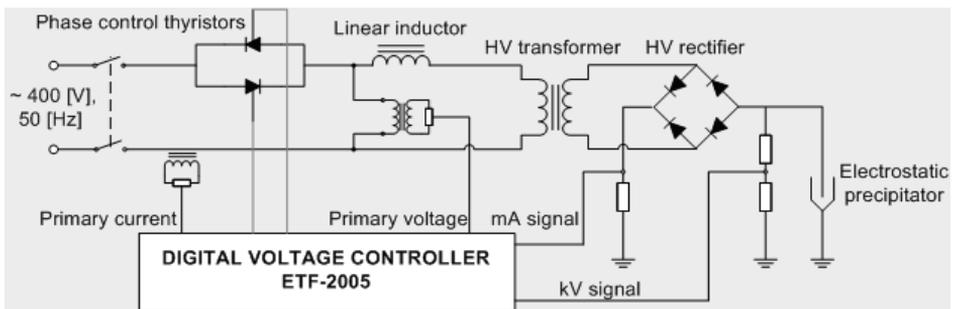


Fig. 1 – The electric scheme of thyristor T/R unit.

The high voltage rectifier made out of the great number of series connected diodes is placed in the oil-filled container, along with the transformer itself. The transformer and the diode rectifier are denoted as T/R, Transformer–Rectifier set. One T/R set provides the DC output voltages from 50 kV to 100 kV and currents from 1 A to 2 A. The supply of larger filter section is achieved by putting several T/R units in parallel.

2 T/R Units Characteristics

Considering the occurrence of sparks and short circuits, it is necessary to foresee the short circuit current limitation measures. The switched on thyristor cannot be switched off before the expiration of the current half-period of the mains. Hence, the short circuit current is limited by the series reactance only. The short circuit reactance of single phase transformers rated several tenths of kVA is relatively small and insufficient for the proper limitation of the short circuit current. Eventual design of dedicated transformer with increased leakage flux would increase the losses as well as the size and weight of the transformer. One of acceptable ways for reactance increase is the HV and LV coil fabrication with increased axial “apertures” between the coil sections in order to increase the leakage. This leads to a fairly complicated insulating structure which should withstand relatively high voltage spikes. Instead, practical T/R sets use the standard, concentrated HV/LV construction and employ a separate external inductance. Transformers are usually put into mineral oil in the common tank with the rectifier and are frequently located on the top of the filter, thus minimizing HV connection length between the transformer and electrodes.

The dielectric tests of T/R units as well as the limitations concerning the upper oil temperature are different from the tests foreseen for conventional HV transformers. The induced overvoltage test is commonly performed at 1.5 rated voltage during one minute. Dielectric strength for short pulses are not performed, since there is no risk of lightning strikes. Considering that the transformer and rectifier share the same container (housing) and the same oil, it is necessary to ensure that the increase in the upper oil temperature does not exceed the values that can damage the rectifier. Hence, the ESP transformer losses should be measured with a great care. Among other things, a salient feature of the transformer is the capability to resist frequent short circuits which occur due to sparking between the electrons. Hence, one part of these transformers testing is the repetitive occurrence of short circuits with the analysis of thermal and mechanical robustness.

Although T/R units are reliable and guarantee a long operating life, they have a very poor power factor and unfavourable waveform of electric currents and voltages (Fig. 2).

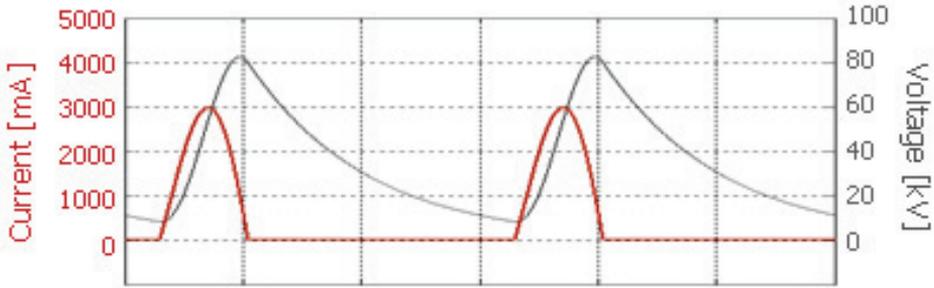


Fig. 2 – *The characteristic voltage and electric current waveforma obtained with the T/R power supply.*

The thyristor commutation creates harmonic distortion, while the presence of relatively high series reactance along with phase delays due to thyristor firing angle create substantial reactive power. In addition, electrode voltage has a large pulsating component at the fundamental frequency of 100 Hz, which causes a decrease in the average voltage. Namely, the peak voltage must not be higher than breakdown voltage U_{bd} . For that reason, the average voltage must be significantly lower. If the voltage waveform is such that the pulsing component at 100 Hz has an amplitude of ΔU , the average voltage across the electrodes must be less than or equal to $U_{bd} - \Delta U$. As a consequence, the electric current density is lowered as well as the precipitation efficiency. Hence, for the given gas flow and specified precipitation efficiency, it is necessary to foresee the electrode system with increased surface and weight. Such an increase raises the weight, size and cost of the ESP.

The short summary of T/R supplied ESP is summarized below:

- Due to a large voltage ripple, the average voltage and the corona current density are lowered;
- It is necessary to have a larger surface of the plates and spend a larger quantity of steel;
- The reactive power, distortion power and losses are relatively high;
- T/R unit represents a single-phase load;
- Spark energy ammounts 130 J – 200 J due to a slow thyristor reaction;
- High spark energy causes a rapid erosion of collecting plates;
- The eroded collecting plates are more difficult to de-dust, so the inner ash layers are permanently retained and fused
- Very long de-ionization intervals (from 40 ms to 100 ms) are necessary due to higher spark energy.

3 Basic Characteristics of The HF Power Supply

The high frequency (HF) power supply of the electrofilter implies the utilization of a power transformer with a high frequency rectifier on the high voltage secondary side, similar to standard thyristor supply. The difference is that instead antiparallel thyristors the HF supply uses an IGBT converter which supplies the primary of transformer with 5 kHz – 20 kHz AC voltage (Fig. 3). The transformer operates at higher frequencies, but it handles the primary and secondary voltage roughly the same as those encountered in a T/R set. Its dimensions and weight are significantly lower than the line frequency transformer, while its core is made of ferrite materials. The HV diode rectifier receives HF high voltage and provides a DC voltage across the plates. Due to a high operating frequency, the voltage ripple is significantly reduced. Therefore, it is possible to achieve much higher average voltages and hence improve the ESP efficiency.

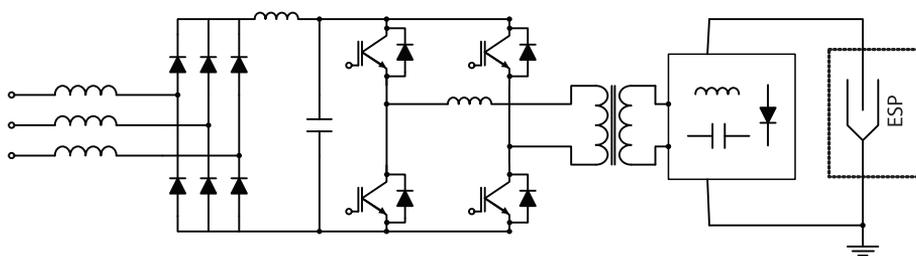


Fig. 3 – The electric scheme of HF HV ESP power supply.

The low voltage IGBT power converter receives the three-phase mains supply and presents a balanced load.. Since the HV supply as a whole is a symmetrical three-phase load, conditions are met for the distortions, power losses, asymmetries, as well as the reactive power to be improved with respect to single-phase thyristor T/R unit. The HF transformer has a significantly lower reactance and a smaller number of turns, as well as a considerably smaller volume. Therefore, the overall system losses are lower, while the energy efficiency is significantly improved. With regard to voltage control, the HF unit provides much faster reaction time, measured in the tens of μs , while a typical T/R unit produces control delays defined by one period of the mains, hence, either 16,7 ms or 20 ms. A quick control reaction in case of arcing reduces the arc energy, hence allowing for a very brief de-ionization intervals and quickly re-applied voltage. The most important characteristic of the HF supply is a higher average voltage and increased current density. For the frequencies ranging between 10 kHz and 25 kHz, the voltage ripple is lower than 3 %, while with thyristor T/R units the ripple amounts 35 % to 45 %. As a consequence,

the HV supply yields up to 20 % higher average voltage, which significantly increases the corona current and the precipitation efficiency.

In his book entitled “Industrial Electrostatic Precipitation”, Harry White shows the results of the experiment aimed to establish the link between the peak voltage and number of sparks per minute. The equation

$$S = \exp(b(U_{\max} - U_1)) \quad (1)$$

gives the number of sparks per minute in the function of peak voltage U_{\max} , wherein the voltage U_1 is the one leading to precisely one spark per minute. The exponential relation signifies that the probability of spark appearance increases quickly with relatively small rise in the peak operating voltage. Therefore, the fact is that the voltage ripple made by thyristor T/R units is very high, making it a bare necessity to decrease the average voltage in order to minimize the number of sparks to an acceptable range. Considering that the T/R unit voltage ripple is greater than 35 %, while the acceptable number of sparks is only 10 per minute, it may be concluded that the HF supply provides a voltage increase of roughly 20%. It is necessary to mention that the further increase of sparks number is unacceptable, due to every spark event requiring prolonged de-ionization power-down intervals contributing to an increased emission.

Norbert Grass [1, 3, 4], a Siemens engineer, investigated the effects of the HF power supply implementation, and determined that the corona current doubles with HF power supply, compared to the one obtained with 50 Hz T/R units. Therefore, prediction is that emissions can be halved at least with the HF power supply. Moreover, an increased migration velocity of dust particles towards collecting plates contribute that the layers of collected dust are more compact, and this facilitates the rapping process and decreases the probability of the particle retrieval into the gas flow during rapping.

According to measurements performed in the “Morava” thermal power plant, equipped with four HF units, the high frequency ESP power supply provides for a significant increase in both the energy efficiency and the collection efficiency. Considering that the HF supply has a three-phase rectifier, while the T/R unit has a single phase mains supply, the power factor and the line current waveforms of the HF supply more favourable, while the reactive and apparent powers are reduced. According to measurements, the comparison of the two gives the following results:

	50Hz	HF
$\cos \varphi$	< 0.65	> 0.95
$\lambda = P / S$	< 0.5	> 0.75

By measuring the voltage and current waveforms at TE Morava, as well as by logging the gas opacity data from the ESP monitoring system, it is concluded that the HF supply gives the following improvement in relation to 50 Hz T/R supply:

- Spark energy is decreased four to five times. While in the case of a 50 Hz T/R supply the spark energy includes the amount supplied through the thyristors until they cease to conduct, the HF power supply reduces the spark energy down to $W_c = CU^2 / 2$. Namely, the residual spark energy is the one accumulated in the electric field between the electrodes, as the HF source itself has a negligible contribution due to a quick turn-off of IGBT power switches;
- In case of occurrence of an arc or spark, the de-ionization power-down interval is very short, ranging only 2 ms to 10 ms, so that the effects of the power interruption on the dust emission becomes very small;
- According to the evaluation, the necessary surface of electrodes is diminished by 30 %;
- It is possible to enable quick voltage changes in coordination with the rapping, further enhancing the ESP efficiency.

The advantages of the HF supply have made a great number of renowned manufacturers to project and plan the production of ESP HF power supply devices. Siemens has made an effort with the device PIC410F, aimed to operate at frequency of 10 kHz and to provide high output DC voltage. Due to problems [1, 3, 4], they moved on to the experiments with the high voltage transformer which operates at the lower frequencies, that is, at 500 Hz. The British company Genvolt made a transformer operating at frequencies of 20 kHz [2] and with a relatively low power of $P < 50$ kW. The efforts to manufacture a reliable HF power source for the ESP with sufficient power, voltage, and an acceptable life time were made by Alstom, who designed SIR device. Similarly, FL Schmidt designed the HF power supplies operating at frequencies next to 10 kHz. The American company NWL manufactures Power Plus HF power supply for the ESP, widely used in cement mills in the USA, as well as in the factories which include the process of sintering. The NWL devices are somewhat limited in the output voltage, and they cannot reach the voltages above 100 kV, required evermore for the operation of new electrofilters with interelectrode distance in excess to 500mm, recently quite common in thermal power plants. For majority of manufacturers, a wider application of the HF devices is impeded by reliability issues and limited output voltages. In some cases, frequent insulation breakdowns are observed in the field, caused by the simultaneous presence of the high voltage, high frequency, high temperature, high dV/dt and high di/dt values within the device.

4 The Problems of the Existing HF Solutions

The problems encountered in the HF electrofilter supply exploitation are frequently reflected in: (i) the breakdown of semiconductor power switches in the primary circuit, (ii) secondary circuit insulation breakdown, or (iii) the problems of EM noise and control. The first problem emerges due to the circumstance that the IGBT power switches deliver next to 100 kW while commutating at the frequencies from 10 kHz to 25 kHz. Hence, the IGBT power switches operate at the limit of their performance. Therefore, unless zero current switching (ZCS) or the zero voltage switching (ZVS) is ensured, they may suffer serious overheating. The second problem is caused by the rapid insulation degradation and aging in the presence of high dV/dt stress, while the third one is most frequently attributed to an inadequate hardware and software solutions. In particular, low voltage and highly sensitive DSP technology is implemented in a noisy environment of high power converters.

The primary voltages and currents within HF power supply assume values next to 600 V and 300 A. Therefore, the semiconductor power switches to be used are the IGBT devices. In addition to their favourable characteristics, IGBTs also have their commutation losses which limit the maximum switching frequency. The recommended switching frequency for IGBT power switches depends on the rated current, and it is lower as the current rating increases. For transistors of 300A, commutation and conduction losses are equal at the frequencies between 2 kHz and 5 kHz, which represents the technical optimum for their operation. Therefore, it is necessary to utilize resonant topologies in high frequency range, enabling the semiconductor power switches to operate without commutation losses. This enables the elimination or at least a significant decrease in commutation losses.

Up to date literature includes the analysis of a number of power converter topologies [6-18] providing reduction in commutation losses. Attention has been focused mostly to ZVS – zero voltage switching, ZCS – zero current switching as well as to decreasing the dV/dt in the primary circuit of the converter. The HF power supply for the ESP may have high dV/dt values in the secondary circuit, across high voltage diodes, at the ends of secondary inductors and other elements of the secondary circuit. At instances where the secondary voltage switches from -100 kV to $+100$ kV within commutation intervals shorter than $1 \mu\text{s}$, extremely high voltage slopes and extremely quick changes in the electric field may subject the insulating materials under severe stress. As a consequence, the dielectrophoresis occurs as well as the chemical reactions within the dielectric material, caused by the catalytic effect of the high speed electric field changes. The ultimate consequence of the described processes is a rapid degradation of the insulating material. According to the

experience acquired by many electric equipment manufacturers, the insulation breakdown in the secondary circuit takes place after 6-12 months, which is substantially unfavourable for the end-user. This outcome has caused a great number of withdrawals of HF devices from the field. Solution described in this paper eliminates the insulation aging and reliability issues and enables the longevity of the HF power source.

A number of reliability issues is caused by an inadequate application of DSP technology in environment of high power, high voltage, high frequency conversion. Due to high speed voltage changes, as well as high currents at high frequencies, control circuits are submersed by a significant electromagnetic noise which jeopardizes the integrity of analogue and digital signals. Therefore, it is necessary to implement hardware measures in order to protect the integrity of the input signals, output signals, and the elements of electronic circuits. Common measures include the installation of the SMD transistor and the miniature resistors and inductance in places where the electromagnetic disturbance should be prevented and the reinforcement of relevant signals. Besides, during the acquisition of analog signals, the oversampling technique should be used in order to remove the undesirable noise, thus preserving the response speed and the control integrity.

5 The Basic Characteristics of the AR70-1000

At the School of Electrical Engineering, the University of Belgrade, a group of researchers worked on the development of the HF power supply for the ESP over the past four years. The project was funded by the Ministry of science and technology of The Republic of Serbia. As the result, the first specimens of the HF power supply have been manufactured in Serbia. Two years ago, “Morava” power plant was equipped with HF power supplies AR70 which are constantly in operation ever since. During these two years, a series of tests was performed in order to investigate the impact of HF power supplies on the ESP operation. The basic characteristics of HF power source AR70-1000:

- Distributed multiresonant topology in the secondary circuit enables decreasing in commutation losses and reduces the insulation stress, hence suppressing the catalytic effects of the electric field high speed changes and preventing chemical reactions leading to accelerated dielectric aging;
- Precipitator control and diagnostics are based on the spectral analysis of corona current and plate voltages, providing a cheap and reliable way for early detection of sparking, an efficient detection of the back corona, and a reliable estimation of the thickness of the ash layer accumulated on the collecting plates.

- Converter topology enables ZCS commutation of IGBT power switches, significantly lowering the overall converter losses;
- Voltage and current control includes the possibility controlling the number of sparks per minute;
- From the accelerated aging, the MTBF of the device can be estimated to 20 years.

The total mass of the active material in AR70-1000 transformer with rated power of 100 kW and operating frequency of 10 kHz amounts only 50 kg. Distributed multiresonant secondary circuit is made of conventional reactive components having a relatively low weight, and it uses standard HV diodes (Figs. 4-6). Within the secondary HV rectifier, high speed diodes are not required as the converter topology enables the rectifier operation in ZVS mode. Besides, it is the ZVS mode that reduces the dV/dt in the secondary circuit and ensures the longevity of the insulation materials.

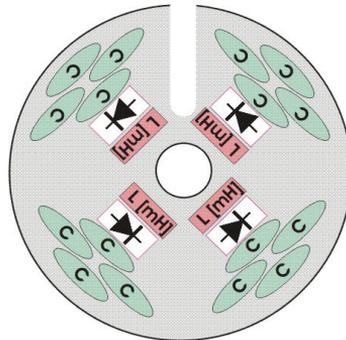


Fig. 4 – One element of the multiresonant circuit within the secondary of the AR70-1000.

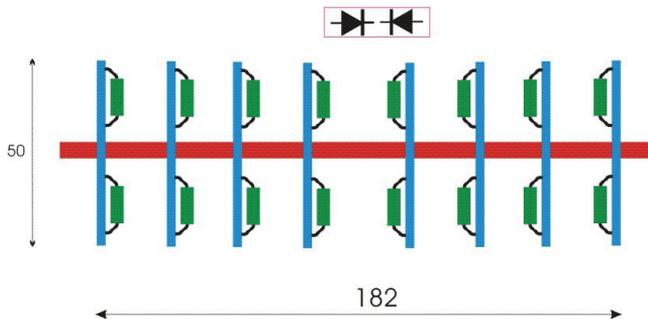


Fig. 5 – A group of multiresonant circuits.

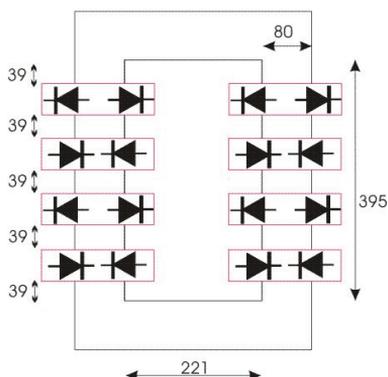


Fig. 6 – Connecting multiresonant circuits in groups.

In comparison to standard 50 Hz sources including the thyristor cabinet and the T/R group, the HF power supply AR70/1000 is five times smaller in volume, about 5 times lighter and up to 30 % cheaper. It should be noticed that the HF source features explained above provide a significant increase in precipitation efficiency, contribute to a more favourable shape of the line current, ensure much lower reactive power and reduces significantly the erosion of the plates due to a significant decrease in the spark energy. Due to the original multiresonant topology, DSP unit for control and supervision as well as the original solution of thermal handling, and mechanical protection, the AR70/1000 meets the following standards and regulations,

- Low Voltage Directive (73/23/EEC);
- EMC directive (89/336/EEC);
- CEI EN 60204-1, par. 6.2.3, 20.3, 20.4;
- IP Code, EN60529;
- CEI EN60800-3;
- EN60800-3/A11.

The appearance of the AR70/100 device is given in Fig. 7.

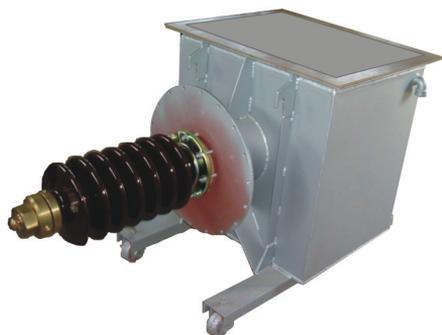


Fig. 7 – The appearance of AR70/1000 device.

One of the problems encountered by other manufacturers is the ferrite core protection. Namely, in cases of overheating, larger ferrite elements used for assembling the magnetic core of the HF transformer may crack, hence disabling further operation due to an increased equivalent air gap and magnetic resistance. This happens due to positive power loss coefficient of the ferrite, and due to difficulties in cooling the innermost ferrite blocks. Such an outcome is prevented in AR70 unit by using the original cooling design and a custom shape of the core. Fig. 8 illustrates the temperature distribution of the ferrite core obtained by using the thermal imaging. This figure shows that the heat distribution is uniform. The external dimensions of the AR70 device are given in Fig. 9.



Fig. 8 – The temperature distribution in ferrite core.

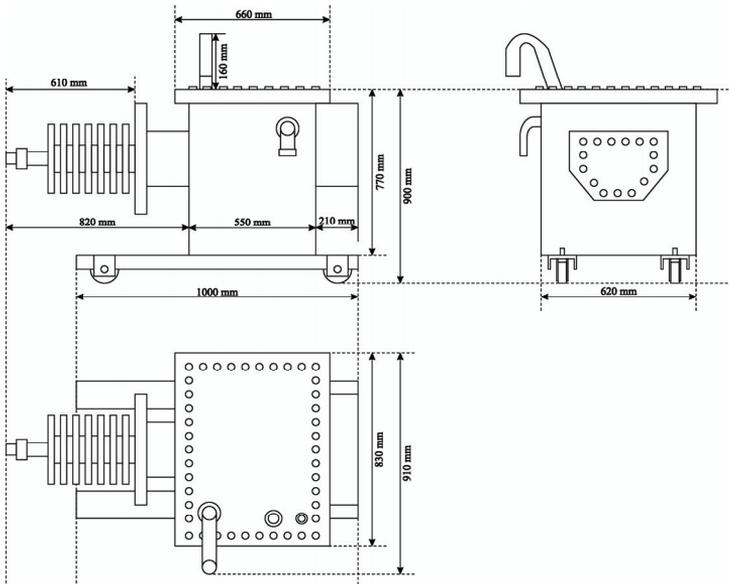


Fig. 9 – External dimension of AR70/1000 device.

6 The Field Experience

Since June 13th 2008 until July 21st 2010, the testing took place at “Morava” thermal power plant in Svilajnac, equipped with AR70/1000 units. The measurements were organized in order to determine the effects of the HF power supply on the precipitation efficiency and to establish the expected reduction in dust emission. The following equipment was installed at the Morava PP:

- Four HF power sources for the ESP, two of them being AR70/1000 and the other two NWL Power Plus devices.
- HV splitter with selector switches which enables the ESP supply either from conventional 50 Hz T/R units or from the HF power sources;
- The P/Q/S/Energy measurement group for logging of the the active, reactive, apparent, and distortion power, as well as active and reactive energy;
- One triboelectric dust sensor, mounted in the back feeding channel of the right ESP branch.

Fig. 10 shows the block diagram with the specified equipment mounted in “Morava” power plant. The HV splitter system enables hot-swap selecting either the conventional T/R units or the HF power supplies in the course of the ESP operation. Hence, comparison of the two was possible in almost identical conditions. In HF mode, one of the ESP branches is supplied from the NWL units, while the other feeds from AR70/1000 sources. All the devices may be selected in the course of operation, so it is possible to compare T/R units with AR70/1000 units, T/R units to NWL units, or NWL units to AR70/100 units. In this way it is possible to determine the best solution with regard to precipitation efficiency. The location where the HF units were mounted are shown in Fig. 11.

The triboelectric sensor is shown in Fig. 12 and mounted in the back feeding channel of the right ESP branch. The mounting location is shown in Fig. 13. It has been selected so that the gas flow is laminary so as to insure stability and accuracy. Alternative solutions, i.e. eventual mounting within the post-confusor channel has been abandoned, since it was not possible to identify location that would be far enough from the channel curves or the fan, so as to ensure a laminary flow. As it is well known, mouning of the opacity meters in zones with pronounced turbulence contributes to significant errors.

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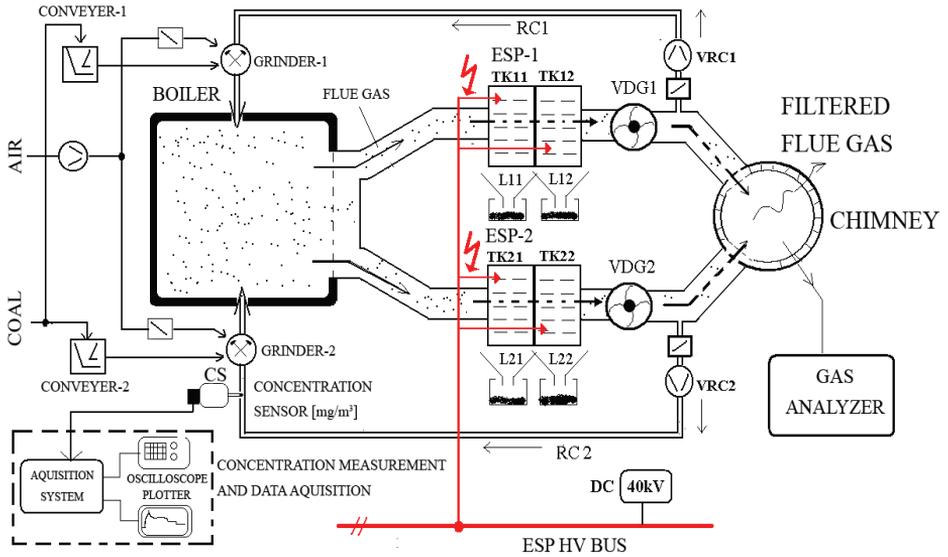


Fig. 10 – The equipment installed at Morava PP.



Fig. 11 – HF power supplies.



Fig. 12 – Triboelectric sensor.



Fig. 13 – Mounting location.

7 Preliminary Measurements

After mounting the first two HF units in the Morava PP, the series of measuring was carried out in order to perform the comparison of the precipitation efficiency of ESP which are supplied from T/R units and ESP which is supplied from the HF source. Two configurations were tested on that occasion:

- The supply of all sections from T/R units (the total of 4 T/R units);
- The supply of 2 sections from the HF source and two sections from T/R units.

The amount of ash which is separated in the exit section funnel was measure indirectly, on the basis of the measured temperature of the funnel wall. On the basis of the known ash temperature which is collected in the funnel, the known specific ash temperature, as well as the known conditions of heating and cooling of funnel, the relative quantity ash change was noticed, which is separated after the HF supply implementation. It was noticed that the ash quantity in the exit section funnel was increased by 80 % by application of HF supply. This finding was confirmed by the fact that after the HF supply implementation, it was necessary to empty the funnel twice often (The exit section funnel is emptied manually in the Morava PP).



Fig. 14 – The left part of the figure illustrates the smoke appearance in configuration of $4 \times 50\text{Hz}$. The right part of the figure illustrates the smoke appearance in configuration of $2 \times 50\text{Hz} + 2 \times \text{HF}$.

During measuring it has not been disposed of transducer for tracking changes of the flue gas dusting. The HF supply effects for the total emission can be evaluated on the basis of the smoke appearance from the chimney, which is illustrated in Fig. 14. The left part of the Figure shows the smoke appearance in the configuration of 4×50 Hz devices. The right part of the Figure shows the smoke appearance in the configuration of 2×50 Hz + 2×HF devices.

8 Measurements from the Opacity Transducer

Fig. 15 shows the voltage waveform between the electrofilter plates. The CH1 trace shows the voltage waveform in case of supply from T/R units of 50 Hz system. The CH2 trace shows the case when the ESP is supplied from HF units. It can be noticed that HF supply contributes to the significant decreasing of voltage ripple. As a consequence, it is possible to achieve the significantly higher mean voltage value between the electrodes. Fig. 15 shows also system reaction time for voltage control. It is possible to notice that the HF system enables substantially faster voltage changes.

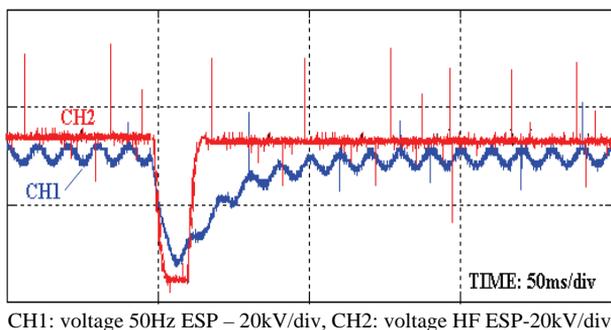


Fig. 15 – *The comparison of the waveform voltage between the plates in case of 50 Hz supply and HF supply.*

After mounting the triboelectric transducer, the possibility is opened to measure relative changes in the emission of dust during the filter operation. Fig. 16 shows the obtained results. The left part of the figure shows the emission difference in case of using the HF supply, that is, if the right filter branch is supplied by two HF units. The transition from HF system to 50 Hz system was made in the middle. Considering the fact that the HV dividers are commuted in the non-voltage state, electrodes are left without supply for a short time interval, so that the reading from transducer becomes saturated due to very high particle emission. After switching the HV divider into the location for 50 Hz supply, the voltage is re-established between the electrodes. The right part of the figure shows the emission change from 50 Hz T/R units. In the observed figure it is noticed that the HF supply diminishes the emission from

650 mg/m³, which is obtained for the supply from 50 Hz T/R units, to only 150 mg/m³.

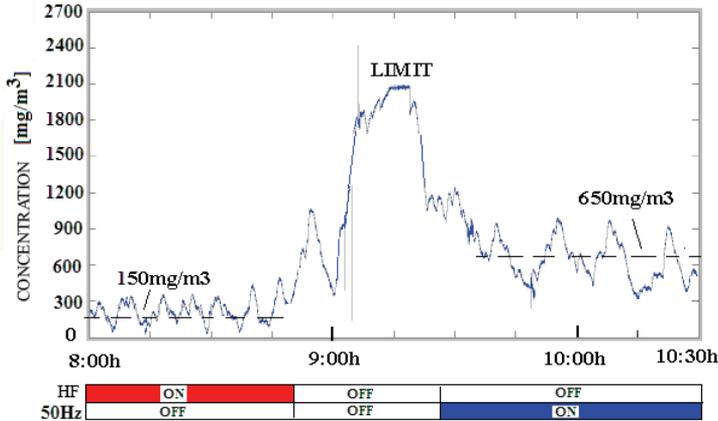


Fig. 16 – The emission of flue ash depending on the way of electrode system supply.

The left part of the Fig. 16 shows the emission in case of using HF supply. The transition from HF to 50Hz system was made in the middle. The right part of the figure shows the emission in case of 50 Hz T/R units.

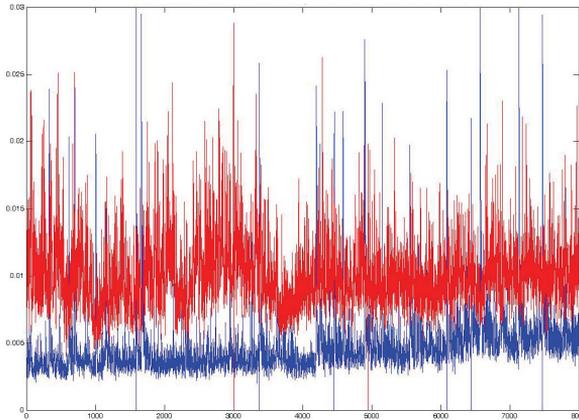


Fig. 17 – The comparison of emission for HF supply and 50 Hz supply in the time interval of three hours. The measuring was performed during 2010.

The blue colour (lower) in Fig. 17 denotes the emission for 4xHF supply, that is, in case when the ESP is completely supplied by the HF unit. The red colour (upper) denotes the emission for configuration 4x50 Hz, that is, when the total ESP is supplied by 50 Hz T/R units.

It is necessary to mention that the particle emission is significantly changed depending on the coal content, kettle regime, as well as the other process parameters. So, in order to validly compare two systems of supply, it is necessary to perform measuring in somewhat longer time interval. Fig. 17 shows the emission comparison of the HF supply and 50 Hz supply in time interval of three hours. The measuring was performed during 2010. The blue colour denotes the emission in case of supply $4 \times \text{HF}$, that is, in case when the ESP is completely supplied by HF units. The red colour denotes the emission in configuration $4 \times 50 \text{ Hz}$, that is, when the total ESP is supplied by 50 Hz T/R units. Mean emission value determination in the interval of three hours shows that for conventional 50 Hz supply with T/R units, mean emission value amounts to 700 mg/m^3 , while for the HF supply the mean emission value totals 350 mg/m^3 . So, by implementation of the HF supply, the particle emission is halved on the same electrode system.

9 Price comparison of HF Equipment and 50 Hz Equipment

The wider implementation of the HF supply in thermal power plants depends on the price of equipment also. Thus, this section compares prices of equipment needed for supply of one filter section which has parameters of 70 kV and 1000 mA.

A T/R unit and thyristor converter for 50 Hz supply

T/R units of European manufacturers have prices in the range of 19 000 € (FLSmith Airtech). Alongside the T/R unit, it is necessary to have also a pair of antiparallely connected thyristors with the controller and the appropriate equipment. Cabinet including controller, thyristors, and the appropriate equipment costs 11 000 € (Castelet, Kraft).

So, in order to provide the supply of 70 kV and current of 1000 mA, it is necessary to purchase equipment which costs around 30 000 €

B HF Supply

The HF supply unit is very frequently applied so that the high frequency power transformer and low voltage converter are located in the same housing and have a single heat removal system. The fabrication cost of the HF voltage supply unit of 70 kV and current of 1000 mA will total 24 000 €

It may be concluded from the above that, besides other significant advantages, the HF power supply also has a lower price, compared to conventional T/R units.

10 Conclusion

- The particle emission is diminished twice by implementation of the HF ESP power supply.
- The HF equipment is five times lighter than conventional T/R 50 Hz units;
- The HF supply equipment has lower price than the equivalent thyristor-controlled T/R units;
- The necessary surface of the electrodes and the quantity of steel built into a new ESP can be lowered by using HF units;
- There is a consolidated Serbian-manufactured solution for the HF supply based on the original multiresonant HF HV technology and intermittent control. The solution has the potential of involving local industries in ESP building and reconstruction.

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