AR100
High frequency switching power supply for 100 kV DC, 100 kW

> Customer:

Thermal power plants

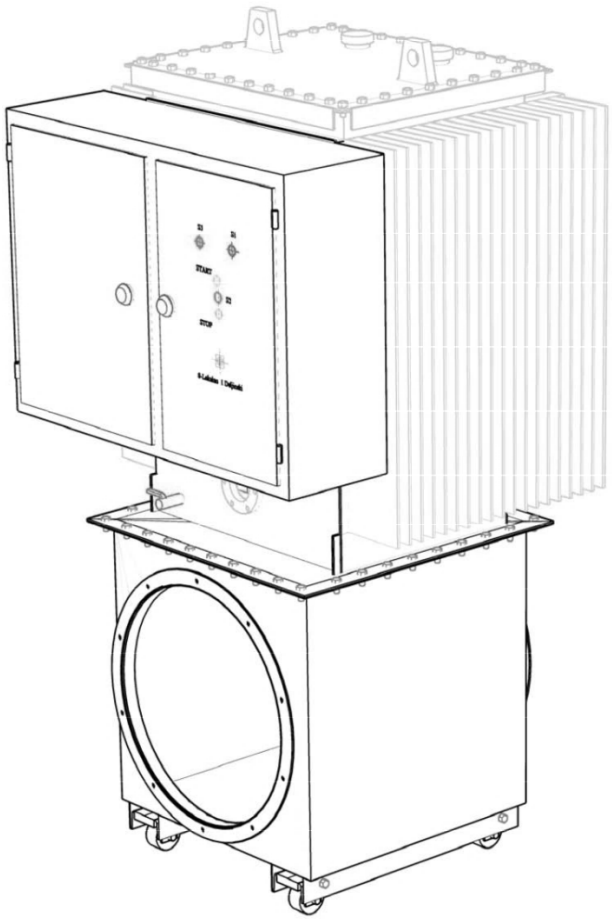
> Product description:

AR100 is high frequency switching mode power supply providing 0-100 kV output and the output power of 100 kW.
AR100 has proprietary converter topology with nonlinear multiresonant secondary circuits providing the grounds for low power losses, reduced size, natural cooling, very low dV/dt insulation stress and prolonged lifetime. It has very low power losses allowing for natural cooling without fans and virtually no maintenance. Basic features are listed below.

> DDC involvement:

Concept, hardware design, safety and EMC norms, DSPcontrol software design and communication software design, preseries production and customer support.

AR100/1000 ESP power controller, up to 70kW (60kV/1200mA or 100kV/700mA)



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A) Project description

Development of HVHF power supply technology and control of electrostatic precipitators (ESP). ESP's usually involves electrostatic filters within coal power plants that process flue gases from steam-boilers and remove fine dust particles.

Reduction of coal dust emission from thermal power plants as and industrial plants is performed by using electrostatic precipitators – the system of electrodes powered with controlled DC voltage that varies from 0V to 150kV during its work. Existing solutions for powering and controlling of filter electrodes follows techno-economical parameters:

- For example, it takes a thermal power plants block of 300 MW power
- Maximum allowed emission is 50mg/m^3 (anon, this restriction will be reduced to 30mg/m^3)
- Electro-filter requires the installation of 1500-2000 tons of steels and occupies volume not less than 2500m^3.
- A cost of this filter varies from 10.000.000 to 15.000.000 EURs.

Over the next few years is expected reduction of the maximum allowed emission of the fine coal particles from 50 to 30mg/m^3. This trend will continue. There are already communities in the EU that are prescribed that the each thermal power plant or industrial plant on their territory must reduce emission of fine particles even to 5 mg/m^3.

Reduction of fine particles emission requires a significant increase in:

- dimensions/volume that occupies electro-filter,
- weight of installed steel,
- cost of installation, maintenance and repair of electrostatic precipitators.

The proposed technology of the HVHF power supplies and controls allows:

- significant (twice) emission reduce at existing electro-filters,
- achieving significant savings in material and money in the installation of new units,
- impairment of space and construction work in the construction of new electro-filters.

B) Why using high frequency instead of 50Hz SCR power

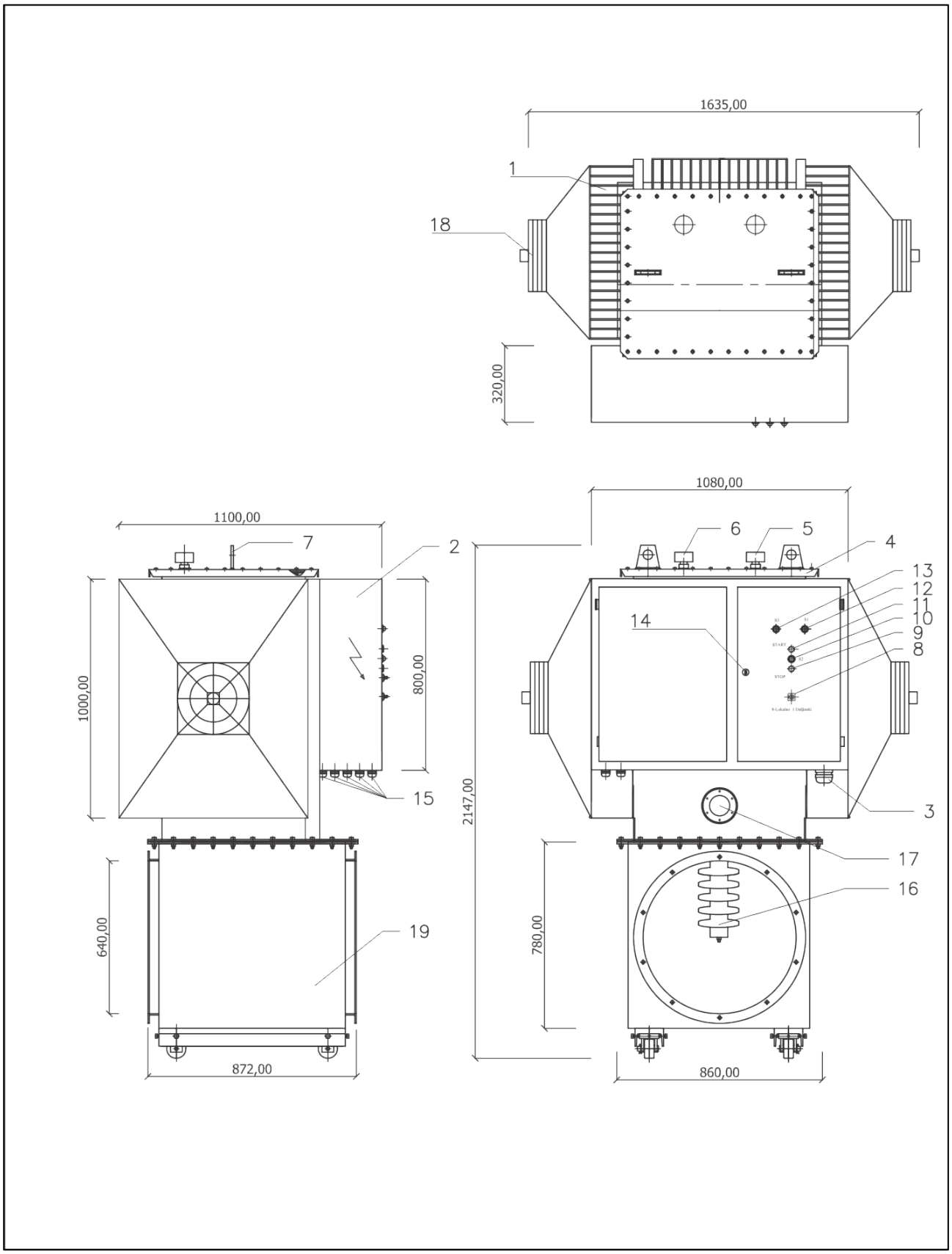
Conventional 50 Hz design had been predominant solution for controlling the particulate emission from large electrostatic precipitators. Although capable to reach removal efficiencies up to 99.8%, 50 Hz design suffers a number of drawbacks, leading to poor energy efficiency, very large size of electrode plates, and it cannot compete with the high frequency power source.

High frequency ESP power supply and control require a lower size and weight of electrodes, offers significant energy savings, prevents back corona, brings up a very fast reaction to flashover, results in a much higher high power factor, and has a transformer/rectifier set several times smaller and lighter compared to traditional 50Hz design.

C) AR100/1000 unit: Basic functionality and features

- 3-phase 0.4kV 50/60Hz power supply.
- Up to 70kW output power.
- Adjustable 0-100kV, 0-1200mA DC output.
- Proprietary converter topology with nonlinear multi-resonant secondary circuits providing the grounds for low power losses reduced size, natural cooling, very low dV/dt insulation stress and prolonged lifetime.
- Very low power losses allowing for natural cooling without fans and virtually no maintenance.
- Coordinated voltage and rapping control.
- Optional control of hopper & insulator heaters.
- Adaptive intermittent power supply optimized for improved collection efficiency.
- UI spectrum - based spark detection, time- based estimation of dust layer thickness.
- UI spectrum - based back corona estimation & remedy.
- Adaptive rapping with simultaneous voltage profiling.
- Customized voltage and rapping control for the ESP input, middle and output zone.
- Communication: 5kV insulated MODEBUS RTU, RS485 serial link.

D) Dimensions and elements configuration



ELEMENTS OF AR100/1000 UNIT		
Item	**Description**	**Comment**
1	Oil filled container walls	Comprises the transformer, nonlinear multiresonant secondary circuits and all the power converter components with power losses
2	Air filled container housing the electronic and electrical circuits (power box)	Comprises the power converter components with low power losses and all the remaining low voltage electronic circuits
3	Low voltage power connection	3x0.4kV+PE, 50Hz, 3 x 120mm2 + 95 mm2
4	Oil filled container upper lid	With pressure and inspection valve and with transportations hooks
5	Oil pressure indicator	For regulation of pressure inside the oil tank
6	Inspection opening	Visual inspection
7	Hooks	For transportation
8	Key hole	Local or Remote control
9	Power LED signalization, S2	Reports the status, Standby/Powered/ON/OFF/Fault
12	Power LED signalization, S1	
13	Power LED signalization, S3	
10	Taster START	Turns the unit ON in no-fault conditions
11	Taster STOP	Turns the unit OFF
14	Key hole of electrical enclosed	Opens the electric cabinet
15	Cable glands, IP65 cable inlet M20x1.5mm^2	For: - Communication with SCADA (high speed serial link according to MODBAS RTU), - AUX signals - Remote signals commands - Rapper signals - External fan power supply All group of these signals are 5kV isolated with respect to ground.
16	High Voltage Insulator	Output of the AR100/1000
17	Inspection opening	Offers the possibility of visual inspection of interior of the oil tank, even when the AR100/1000 is ON.
18^i	External Fan	For forced cooling of oil tank walls, optional.
19^i	High Voltage Chamber	An integral part of the high voltage tube. Dimension can be changed on request.

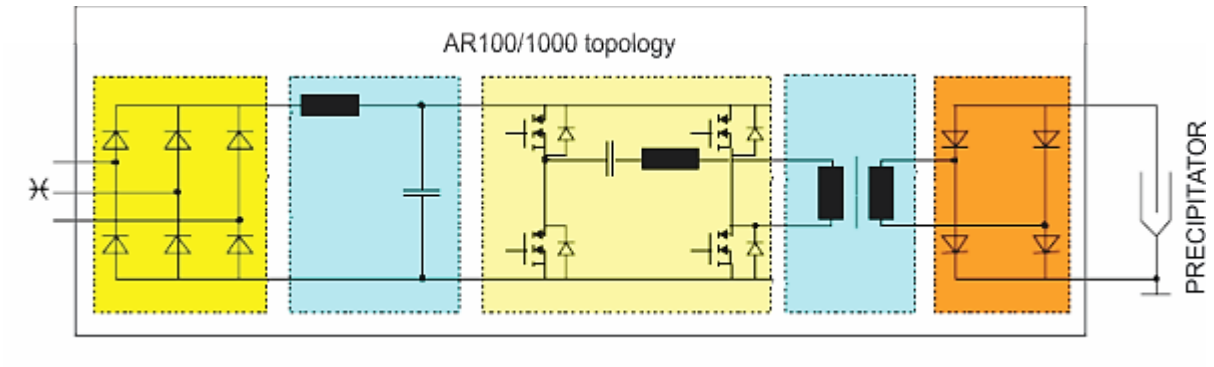
18^i - If the ambient temperature rising above 35^{0}C, than external fans are strongly recommended.

19^i - Dependently of customers' demands, dimension are optional.

E) Specifications of AR100/1000 unit

ELECTRICAL SPECIFICATION AR100/1000	
Input line voltage	3x400VAC +/-10%, 50/60Hz
Input line current	(0 - 150)A
Rated output voltage	(0 - 100)kVDC
Rated output current	(0 - 1200)mA
Nominal output power	70kW (e.g. 100kV/700mA or 60kV/1200mA)
Power factor	> 0,94
Losses	< 5%
Output voltage ripple (p-p)	≤ 5 kVDC
Output switching frequency	(6 - 12) kHz
Arc switching time reaction	< 5μs
Communication protocol	Modbus RTU
PHISICAL SPECIFICATION AR100/1000	
Dimension (Width, Height, Depth)	(1635x2147x1100)mm
Weight	1200 kg
Insulating fluid	500 liter
Type of insulating fluid	Mineral oil
OPERATING CONDITION AR100/1000	
Range of humidity interior of power box	(0-85)%
Nominal temperature of electrolytic capacitors	55^0C
Absolute maximum temperature of electrolytic capacitors	85^0C
Temperature of insulating fluid	<55^0C
Operating ambient temperature range	(-20^0C) - ($+40^0$C)

F) Power converter topology

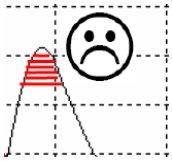


- AR100/1000 comprises proprietary power converter topology. It has nonlinear multiresonant tanks on the secondary side. Topology insures low power losses, reduced size, natural cooling, very low dV/dt insulation stress and prolonged lifetime.
- High current primary side comprises the ZCS IGBT bridge and only one reactive component, a small power choke.
- This topology resolves the reliability issues encountered with high frequency ESP power supplies, such as the:
  - (i) Accelerated aging of insulating materials due to high dV/dt rates,
  - (ii) Failures of power components
  - (iii) Issues with forced cooling system

Therefore, AR100/1000 unit meet the longevity of the conventional, line commutated SCR systems. The reasons why the high frequency power supplies are superior over the conventional SCR systems are as follow:

Drawbacks of 50Hz SCR design

- Control of Conventional 50Hz SCR ESP power supplies has reaction time of 10ms – 20ms, therefore it is slow in adjusting the output voltage and quitting spark and arcing.
- Rectified output with 100Hz ripple generates corona only 3-5ms out of 10ms half periods, therefore ESP must have an increased overall surface of electrodes and an increased weight.
- Conventional design provides discontinuous, pulsating output, depending on the thyristor firing angle. The input line current is therefore distorted, with a high harmonic distortion in the main supply. Main 6kV/0.4kV transformer is exposed to harmonics, low frequency pulsation, mechanical stress and audible noise.
- Reactive and apparent power are very large, with cos(ϕ)<0.65 (figure 1).
- Very poor power factor λ=P/S < 0.5 and unfavorable waveform of electrics currents and voltages.
- The short circuit reactance of single phase high voltage transformer (HVT) is relatively small and insufficient for the proper limitation of the short circuit current.
- Fast erosion of electrodes system because of the slow reaction time.



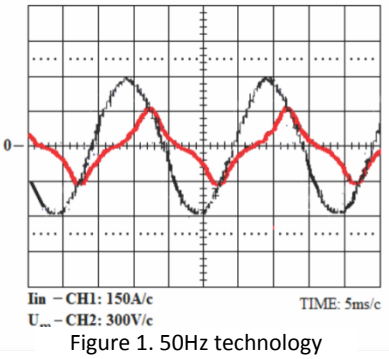
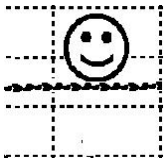


Figure 1. 50Hz technology
Red - Power network current
Black - Power network voltage

Benefits of HVHF power supply

- ESP could operate 100% of the time in the region of massive corona generation.
- Rectified high frequency voltage gives a flat, ripple free voltage (figure 3).
- Operating at high frequencies and high voltage provides high dV/dt.
- Controlled high frequency gives small ripple at output
- Arc energy reduced up to 10 times
- Fast reaction at flashover
- Adaptive controlled intermittent regime
- Prevents back corona generation
- Time duration of deionization is 2ms-10ms
- Weight of filter electrodes is 30% less
- Much better power factor, due to the low reactive power (figure 2).
- High cleaning efficiency
- Offer significant energy saving
- For the maximum efficiency of particle collection, the ESP needs to operate as close to the breakdown potential as possible. With the highest voltage feasible and the maximum electric field, the collection efficiency improves. The collection efficiency is proportional to the square of the applied voltage.



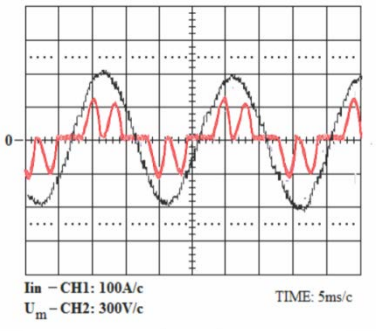


Figure 2. HF technology
Red - Power network current
Black - Power network voltage

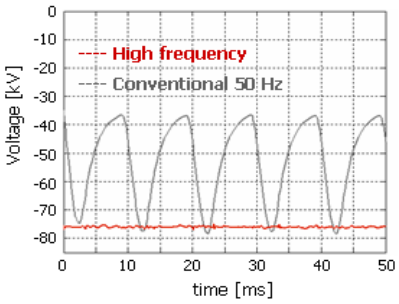


Figure 3.
Red – Flat output voltage (HF)
Black – Riple output voltage (50Hz)

G) AR100/1000 reliability: Warranty

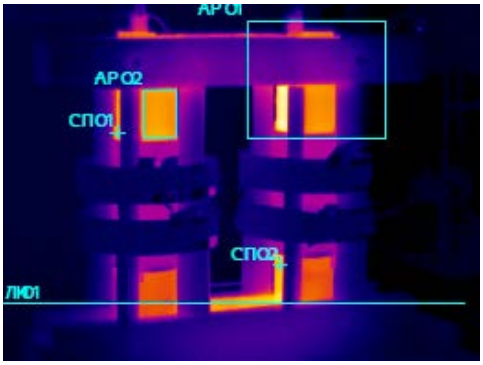
- AR100/1000 has main and auxiliary resonant tank on the primary side, smoothing the waveforms and reducing the commutation losses in IGBT, providing for quasi zero current switching.
- Secondary side with high frequency rectifier has distributed multi-resonance elements, smoothing the voltage waveform between any two points.
- Parasitic capacitances and inductances of the transformer are integrated within LC resonant tanks.
- Insulation lifetime comparable with 50Hz design.

Therefore, the warranty AR100/1000 unit in appropriate use extends to 5 years for air filled container and 10 years for the oil filled container.

H) Thermal test

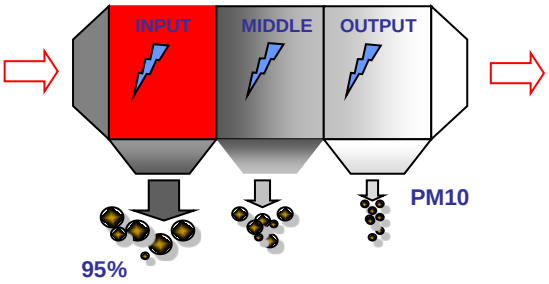
Ferrite cores for high frequency power transformers are prone to thermal runaway. Proprietary design of AR-70/1000 magnetic circuits insures uniform power loss distribution and proper cooling.

Each core is IR-TV scanned under the thermal stress to insure homogenous temperature distribution, and, therefore, reliability of the core.



I) ESP zones control

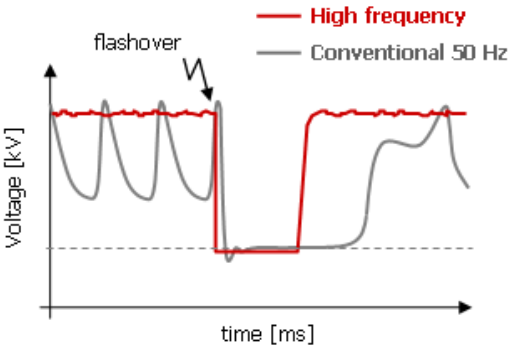
Power conversion and controls of AR100/1000 unit are programmed to fit the needs of the input, middle and the output sections of the ESP.



J) Fast flashover detection and clearance response time

With the AR-70/1000, reaction time is below 100µs. Conventional 50Hz supply has the reaction time of 10ms or more. Result is a significant improvement of precipitator performances in terms of energy saving and improving the collection efficiency.

Conventional 50Hz SCR system has flashover energies of 200J, while AR100/1000 makes less than 30J of flashover energy. Therefore, wear of electrodes surface is decreased significantly.



K) Power factor and efficiency

	50Hz system	HFESP system
Cos(φ)	< 0.65	> 0.94
λ=P/S	< 0.5	> 0.95

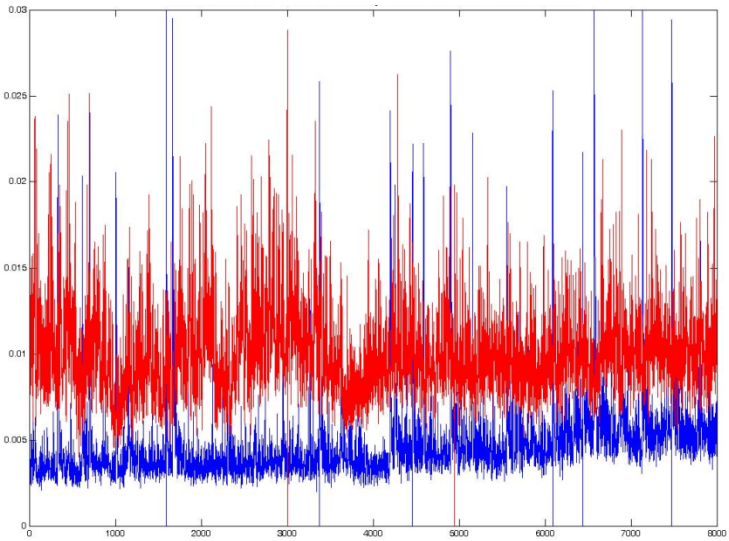
L) The result of the previous research

HVHF technology and control of electro-filters is designed in time period 2007-2008. Experimental HVHF unit is built in electro-filter Thermal Power Plant Morava, where during four years of serves was determined that implementation of HVHF technology results in twice lower emissions compared to existing solution. Towards, system of electrodes in Morava remained unchanged. It is in progress installation and commissioning of the HVHF technology at one branch of electrostatic filters block A1 in Thermal Power Plant Nikola Tesla near Belgrade, where system of filter electrodes also remaining unchanged.

Installed HVHF AR100/1000 units at the roof of electrostatic filter block A1 in Thermal Power Plant Nikola Tesla

Characteristics of existing HVHF systems as and the results of previous studies of exploitation tests can be found at www.esp.etf.rs.

50Hz solution | AR100/1000



RED – emission with 50Hz
BLUE – emission with AR100/1000

M) Goals of further research and development

- Compliment range of product (until now AR70 for 70kV and AR100 for 100kV) with HVHF units for operating voltages up to 150kV. Increased distance between the electrodes leads to better filtration effects in the given volume of the filter, and the substantially improved removal of dust particles that are particularly harmful.
- Developing of technology and equipment for the use of compact HV coaxial cables for high DC voltage in order to increase system reliability of HVHF installation, decrease parasitic ozone generation and achieve savings.
- Should adopt the modular principle of the realization of system, in order to facilitate expansion of the system, changes in the configuration, as well as eventual replacements.

- Solve the problem of accelerated aging of insulation due electrophorese in the presence of high DC voltage, in order that the interval MTBF (mean time between failures) reach 10 years and that the mean expected time of the equipment exploitation reach 20 years.
- In terms of control and supervision, should upgrade equipment so that in addition to the existing industrial protocols, HVHF technology support and Ether Cat and Real-Time Ethernet.

N) Norms

- 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

O) Who we are?

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  - INDUSTRIAL ROBOTS
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