

AR-70/1000 V.02 ESP power controller, 70 kV 1A
AR-100/1000 V.01 ESP power controller, 100 kV 1A
High frequency operated DC power source for electrostatic precipitators

Developed by University of Belgrade, Faculty of Electrical Engineering
Development funded by Serbian Government, from MNTR funds for developing science and technology.
Manufactured and distributed by Electrical Engineering Institute, Belgrade
Accepted, installed and verified at EPS-Serbia thermal power plants

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A) Why using high frequency instead of 50Hz SCR power supply

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 a poor energy efficiency, very large size of electrode plates, and it can not 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.

B) AR-70/1000 and AR100/1000 products: Basic functionality and features

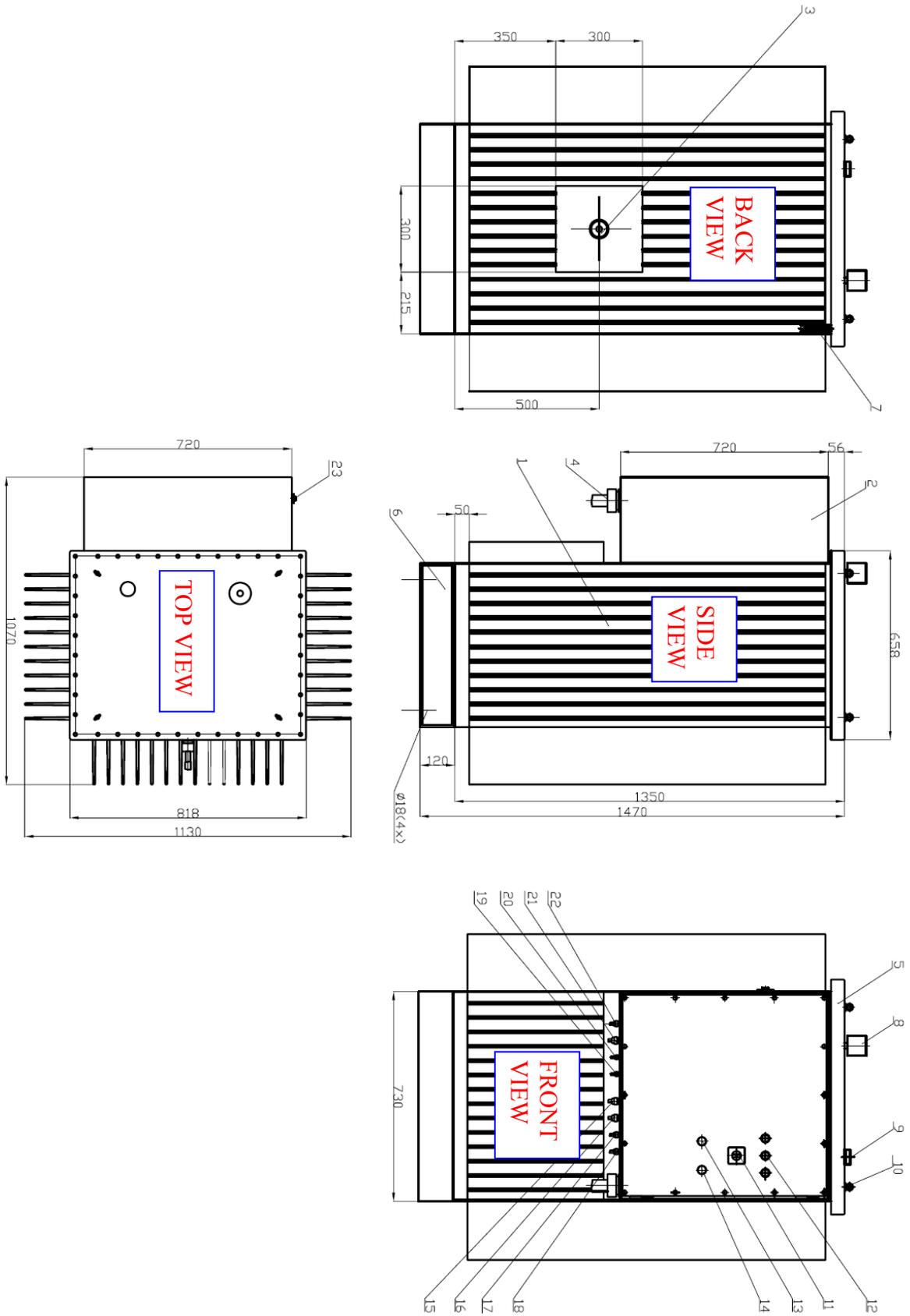
AR-70/1000 unit functions and features comprise:

- 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.
- Very low power losses allowing for natural cooling without fans and virtually no maintenance
- 3-phase 0.4kV 50/60Hz power supply
- Adjustable 0-70 kV, 0-1000mA DC out
- Coordinated voltage and rapping control
- Optional control of hopper & insulator heaters
- Adaptive intermittent power supply optimized for an improved collection efficiency
- UI spectrum-based spark detection, time-based estimation of dust layer thickness
- UI spectrum-based back corona estimation & remedy
- Adjustable spark-per-minute control
- Adaptive rapping with simultaneous voltage profiling
- Customized voltage and rapping control for the ESP input, middle and output zone
- kWh –meter and mg/Nm³ x h – meter
- Communication: 5kV insulated MODEBUS RTU, RS485 serial link, CANbus 2.0B. Planned: EtherCat

C) Weight, size and connections

Weight of complete AR-70 / AR100 comprising oil and fixtures is $m = 590 \text{ kg} / 650 \text{ kg}$.

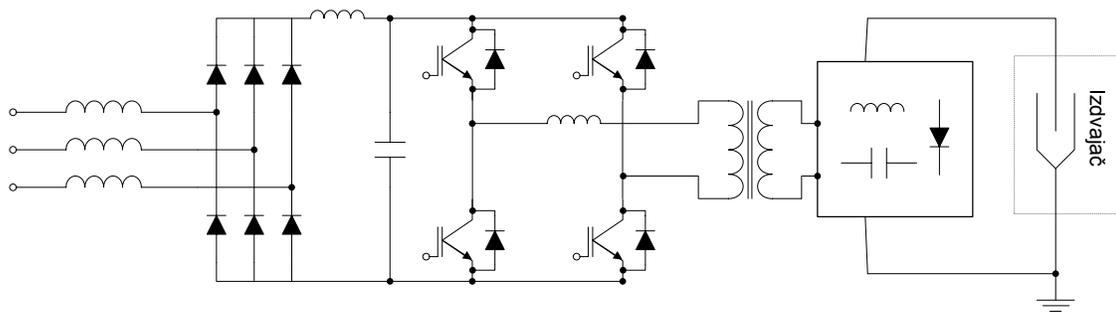
C) Weight, size and connections



C) Weight, size and connections

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	Comprises the power converter components with low power losses and all the remaining low voltage electronic circuits
3	High voltage 100 kV 1A output	Proprietary solution allowing space savings
4	Low voltage power connection	3x0.4kV+PE, 50Hz, 3 x 120mm ² + 95 mm ²
5	Oil filled container upper lid	With pressure valve and oil level indicator
6	The stand	
7	Visual oil level indicator	
8	Oil pressure indicator	
9	Oil refill inlet	
10	Hooks for transportation	
11	Main switch	OFF this switch allows for full disconnection from 0.4 kV
12	Power LED signalization	Reports the status, Standby/Powered/ON/OFF/Fault
13	Taster START	Turns the unit ON in no-fault conditions
14	Taster STOP	Turns the unit OFF, unless „locked“
15	Rapper and AUX signals Control input and output signals IP65 cable inlet M20x1.5 Cable: 12 x 1.5mm ² , Lutze – Silflex N Pur	Rapper OUT 1-4, IN 1-4, Aux 1-2 „Rapper and Auxs“ group of signals is 5kV isolated with respect to ground, power and control and any other group of signals
16	Remote commands and Alarms Control input and output signals IP65 cable inlet M20x1.5 Cable: 12 x 1.5mm ² , Lutze – Silflex N Pur	Alarms 1 – 4 Remote ON, OFF, Power boost, Enable „Commands and Alarms“ group of signals is 5kV isolated with respect to ground, power and control and any other group
17	Analog inputs and outputs IP65 cable inlet M20x1.5 Cable: 12 x 1.5mm ² , Lutze – Silflex N Pur	Analog general purpose inputs 1 and 2 (references, transparency signal, pressure or gas temperature) Analog outputs: U _h vdc, I _h vdc, primary power, oil, transformer and power converter temperatures „Analog inputs and outputs“ group of signals is 5kV isolated with respect to ground, power and control and any other
18	High speed serial link for SCADA connection IP65 cable inlet M20x1.5 Cable: 12 x 1.5mm ² , Lutze – Silflex N Pur	RS485 half duplex multidrop link according to MODEBUS RTU „High speed serial link“ group of signals is 5kV isolated with respect to ground, power and control and any other
19	Man machine hand-held terminal	DB9-water proff, IP65 Ground-reffered outlet for the man-machine interface. A serial –link connected touch-screen type terminal.
20	Monitoring of relevant analog signals	Buffered analog signals normally observed on the scope for starting-up, tuning and debugging
21	AUX & Service	
22	AUX & Service	

D) Proprietary power converter topology

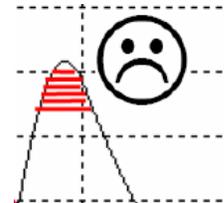


- AR70 and AR100 comprise proprietary power converter topology. It has nonlinear multiresonant tanks on the secondary side. Topology insures low power losses, reduced size, natural cooling, very low dV/dt insulation stress and prolonged lifetime.
- High current primary side comprises the ZCS IGBT bridge 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
 - Accelerated aging of insulating materials due to high dV/dt rates,
 - Failures of power components
 - Issues with forced cooling system

Therefore, AR70 and AR100 units 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

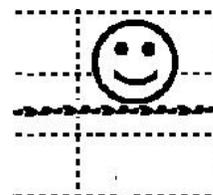
- Conventional 50Hz SCR ESP control has reaction time of 10ms/20ms. Therefore, it is slow in adjusting the output voltage and quitting spark and arcing.
- Rectified output with 100Hz ripple stays close to the peak and generates corona only 3-5ms out of 10ms half periods. Therefore, ESP must have an increased overall surface of electrodes and an increased weight.
- SRC 50 Hz 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 mains supply. Main ESP-group 6kV/0.4kV transformer is exposed to harmonics, low frequency pulsations, mechanical stress and audible noise.
- Reactive and apparent power are very large, with $\cos(\varphi) < 0.65$, whilst power factor $\lambda=P/S < 0.5$. On the other hand, the HFESP high frequency supply has diode rectifier in input stage with $\cos(\varphi)$ above 0.95 and power factor above 0.75.



Benefites of high frequency power supply

Rectified high frequency voltage gives a flat, ripple free voltage

- ESP operates 100% of the time in the region of massive corona generation
- 30% saving in electrode surface and weight for interelectrode distances $d > 500\text{mm}$
- 18% saving in electrode surface and weight for interelectrode distances $d < 300\text{mm}$
- Arc energy reduced from 200J (50Hz SCR) down to 30J. Therefore, lesser electrode wear.



Reliability issues of high frequency power supply

- At high frequencies and high voltages, dV/dt is very high
- dV/dt triggers processes similar to dielectrophoresis and causes wear and aging of insulation
- Insulation lifetime is reduced up to 10 times. Rectified high frequency voltage gives a flat, ripple free voltage
- Some high frequency ESP have an increased number of early failures in the field.

What about AR-70/1000 reliability: Warranty

- AR-70/1000 has main and auxiliary resonant tank on the primary side, smoothing the waveforms and reducing the

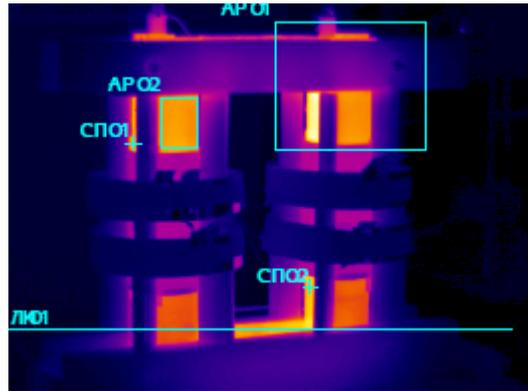
- commutation losses in IGBT, providing for quasi zero current switching.
- Secondary side with high frequency rectifier has distributed multi-resonance elements, smoothing the voltage waveform between any two points.
- Parasitic capacitances and inductances of the transformer are integrated within LC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

Therefore, the warranty for AR70 and AR100 units in appropriate use extends to 5 years for air filled container and 10 years for the oil filled container.

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.

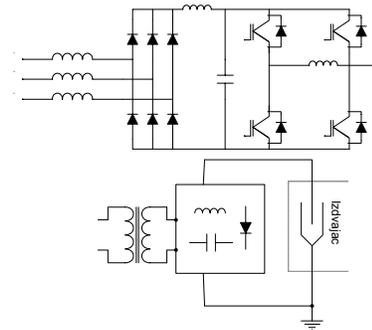
Each core is IR-TV scanned under the thermal stress to insure homogenous temperature distribution, and, therefore, reliability of the core.



AR-70/1000 subassemblies

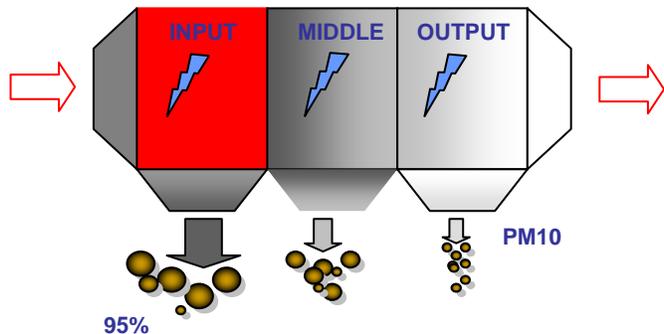
Power conversion and controls of AR-70/1000 unit comprise:

- 3-phase 0.4kV mains front-end converter
- IGBT inverter bridge
- Multiresonant tanks
- Proprietary ferrite transformer
- High voltage diode rectifier
- Distributed multi-resonant circuits.
- DSP-based 300 MFLOPS controller
- Digital Voltage, rapping and heating controller
- Integrated PLC functions



ESP zones control

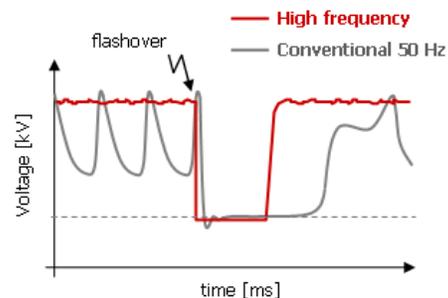
Power conversion and controls of AR-70/1000 unit are programmed to fit the needs of the input, middle and the output sections of the ESP.



::: Fast flashover detection and clearance response time

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

Conventional 50Hz SCR system has flashover energies of 200 J, while AR-70/1000 makes less than 30 J of flashover energy. Therefore, wear of electrodes surface is decreased significantly.



Power factor

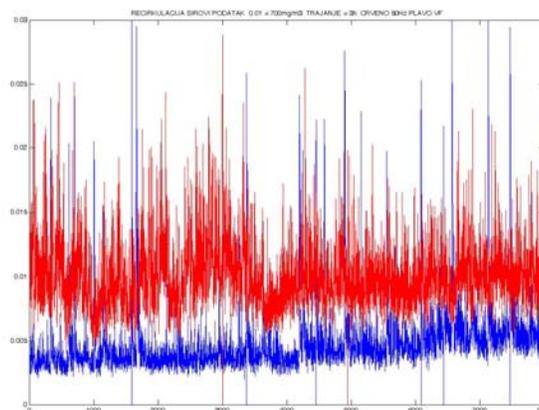
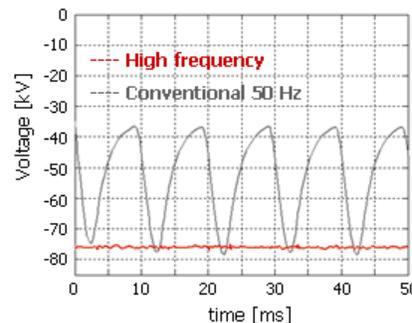
	50Hz system	HFESP system
Cos(φ)	< 0.65	> 0.95
λ=P/S	< 0.5	> 0.75

Sample installation and performance verification

High frequency units are installed on a 100MW block of a coal thermal power plant in Serbia. AR-70/1000 units were tested during 18 month period. They provided an increase in the average voltage by 15%, and halved the emission.

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.

High frequency power supply has a negligible ripple, below 1%, and the mean value of voltage can achieve 98.5% of Umax. The two images below reflect the change introduced by replacing 50Hz supplies by AR-70/1000



RED - emission with 50 Hz
 BLUE - emission with AR70

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

::: Advantages of high frequency power supply:

- **High collection efficiency**
- **Significant energy savings**
- **High power factor**
- **Lower size and weight of electrodes**
- **Reduced wear of the electrodes due to much lower arc energies**
- **Increased average voltage and corona current**
- **Fast reaction to flashover**
- **Overall cost reduction up to 30% compared to SCR 50 Hz systems**

::: Advantages of AR70 and AR100 units:

- **Proprietary converter topology offers superior efficiency and low losses**
- **Natural cooling systems reduces maintenance and provides very long MTBF**
- **Nonlinear multiresonance secondary reduces dV/dt**
- **Reduced dV/dt stress keeps the insulation healthy and extends the lifetime of the HF transformer. Oil refreshing and filtering required every 10 years**
- **State of the art ESP controls comprising spectrum based ash-layer-thickness estimation, back corona suppression and voltage reduction during rapping**
- **Proprietary HV outlet eliminates the need for protruding HV insulators, reduces the size of the unit and contributes to an increased safety**

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