# Performance testing after upgrade of HPP Iron Gate 1

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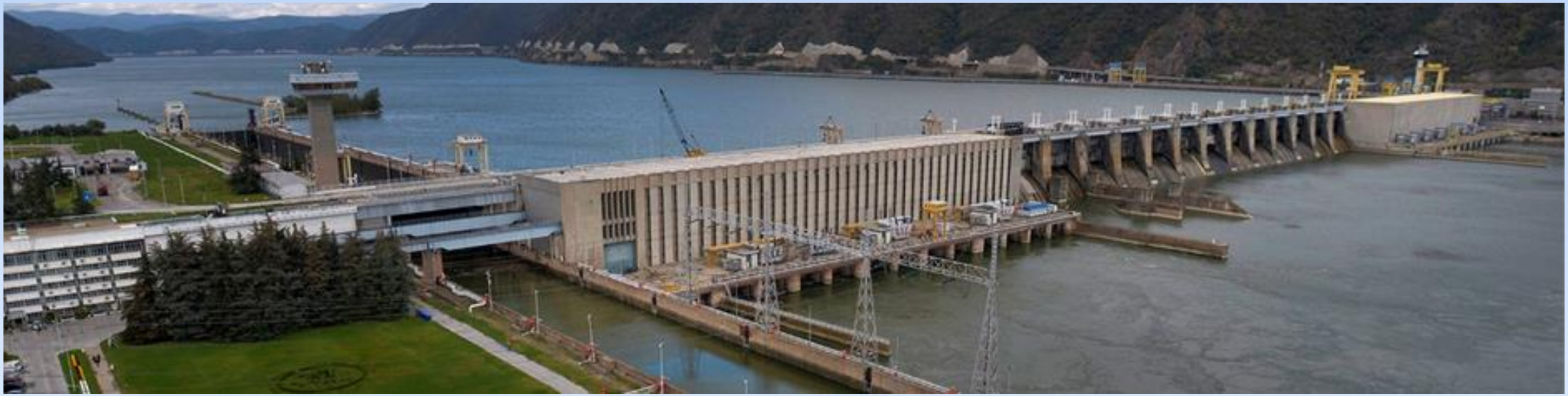
# River Danube

The Europe's 2,nd longest river (2860km), after the river Volga. It flows trough 10 countries: Germany, Austria, Slovakia, Hungary, Croatia, Serbia, Romania, Bulgaria, Moldova and Ukraine.
19 countries share the Danube River Basin, which makes it the world's most international river basin.

# IRON GATE 1

- On the 943 km from the confluence to Black sea,
- Located on the Iron Gate gorge, between Romania and Serbia, in the National park – Djerdap
- Put in operation in 1970,
- Consists of an overflow dam, located in the middle of the river, two hydropower plants at the dam toe in the extension of the dam towards the banks, and two double-step navigation locks located between each power plant and corresponding bank, respectively,
- 6 hydropower units on Serbian side and 6 hydropower units on Romanian side



# National park – Djerdap

National park, the reserve of nature for rare plants, birds and animals that still live in this area.
It is on the national list of proposals for the Network of biosphere reserves (UNESCO- MAB project) and protected natural areas of the world natural heritage under protection of UNESCO (UNESCO World Heritage).

# HPP IRON GATE 1 – property of Public Enterprise EPS (State of Serbia)

- HPP with 6 hydropower units (190 MW per Unit No. 3 and 211,11 MW per Units 1,2,4,5,6) – on Serbian side,
- On the Serbian part of the dam, modernization started in July 2008 (upgrade of last Unit No. 3 is in progress),
- After the reconstruction process, the hydro power plant's capacity has been increased by 10%.
- Spillways are used for protection against flooding of upstream cities in case of high water level of upstream water, caused by snow melting in spring period (this is the most strategic role).

Exactly at the half of the dam is the state border between Serbia and Romania.

# Scope of Upgrade Works

includes replacement of the following equipment :

- generators,
- excitation system,
- turbines runner blades,
- turbine governors,
- step-up transformers,
- units and step-up transformers cooling water equipment,
- units and step-up transformers control and protection equipment,
- generator voltage equipment (armored busbars, switchgear, measuring transformers),
- auxiliary power supply distribution boards,
- equipment for fire detection inside generators and step up transformers.

# Generators` parameters:

- Rated power 211.11MVA,
- Rated voltage 15.75kV,
- Rotating speed 71.43 r/min,
- Stator diameter 8.5m,
- Rotor diameter 8.194m.

Turbine shaft: 10 m long, diameter 1, 6 m  and 90 tons weight, connects the runner blades and generator rotor.


Positioning of rotor into a stator frame with mutual distance of 19mm

# 400t portal crane's moving vital parts of generator

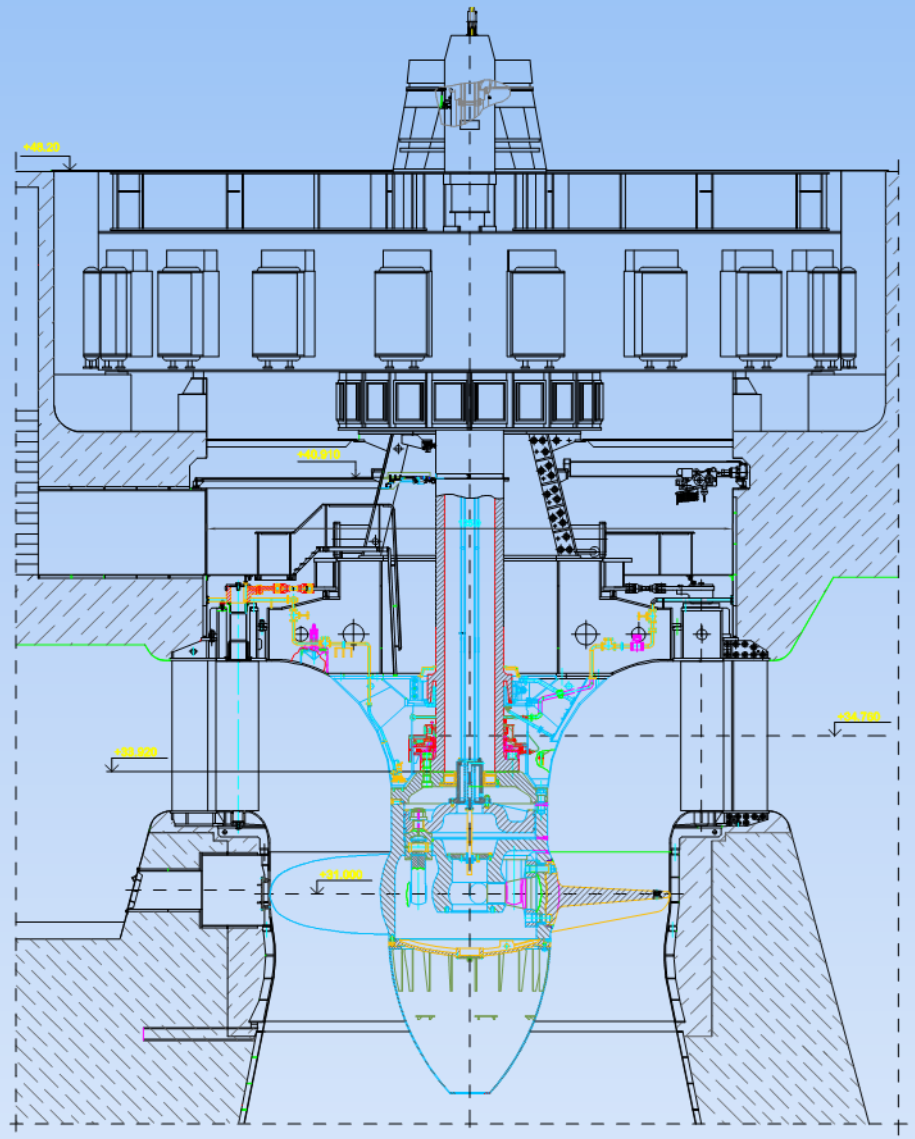
Complete stator replacement (stator housing, stator core and windings), rotor windings, air coolers, guide and thrust bearings, bearing oil coolers. Equipment and assemblies are defined for increased Units power.

Positioning of stator (G=610t)

Positioning of rotor

# Generators` after upgrade of works:

| | |
|---|---|
| • generator type | vertical with the thrust bearing below the rotor and the guide bearing above the rotor (according to IEC 60034-7 type 8310) |
| • manufacturer | Elektrosila-Russia |
| • rated apparent power | 211.1 MVA |
| • rated speed | 71.43 rpm |
| • frequency | 50 Hz |
| • maximum constant load | 216 MVA |
| • voltage on units outlet | 15.75 kV ± 5% |
| • rated current | 7739 A |
| • nominal power factor | 0.9 |



Unit cross-section

# Auxiliary generators` parameters :

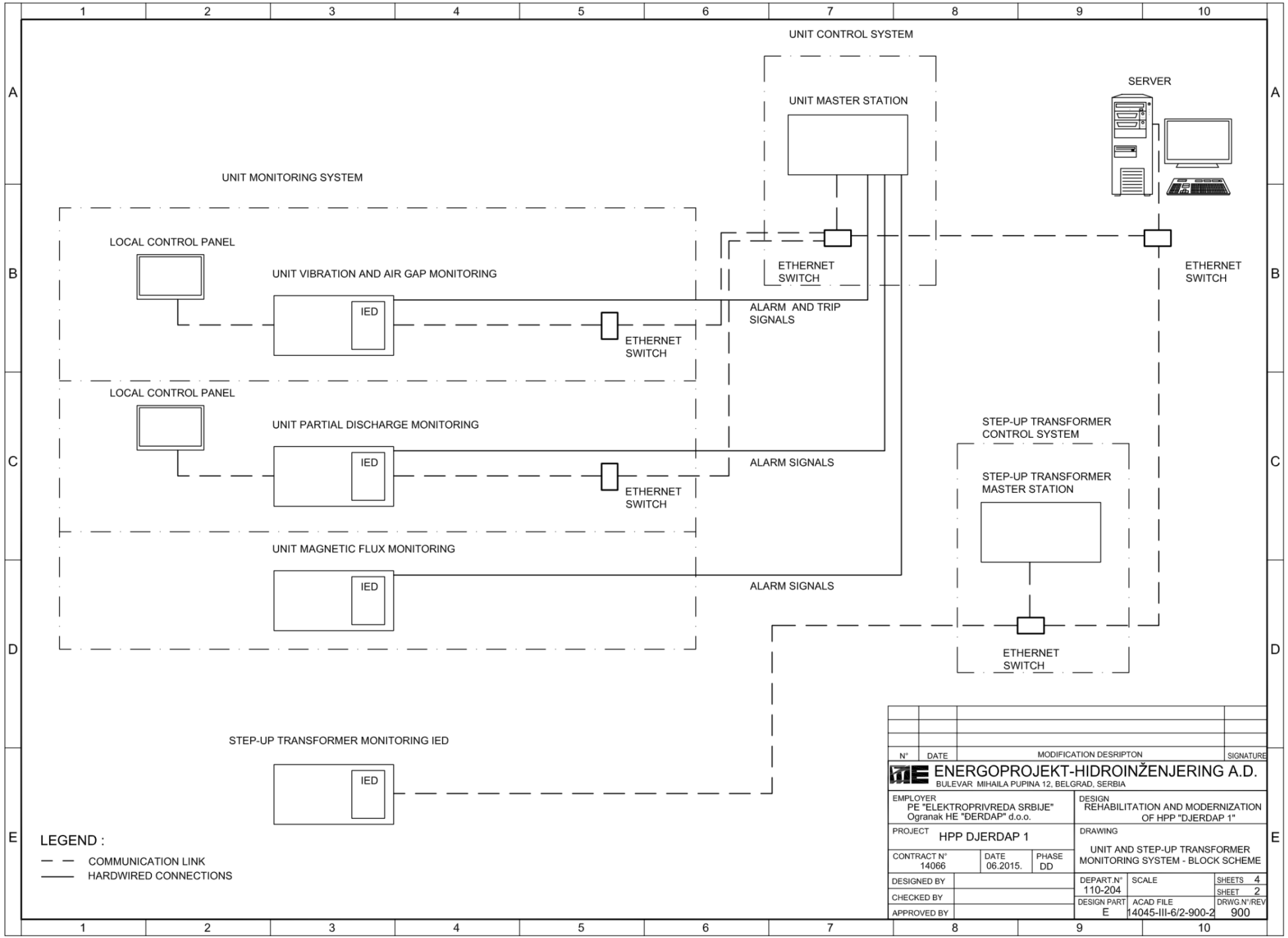
| | |
|---|---|
| • generator role | Exciter for main generator |
| • manufacturer | Elektrosila-Russia |
| • rated apparent power | 2.222 MVA |
| • rated speed | 71.43 rpm |
| • frequency | 50 Hz |
| • rated voltage | 720 V |
| • rated current | 1782 A |

Auxiliary generator erection works

# Installed Monitoring Systems

Equipment installed on the generators used for continuous measurement and monitoring of:

- Temperature,
- Partial discharge,
- Vibration and air gap and
- Magnetic flux.


UNIT CONTROL SYSTEM
UNIT MASTER STATION
SERVER
UNIT MONITORING SYSTEM
LOCAL CONTROL PANEL
UNIT VIBRATION AND AIR GAP MONITORING
IED
ETHERNET SWITCH
ALARM AND TRIP SIGNALS
ETHERNET SWITCH
ETHERNET SWITCH
LOCAL CONTROL PANEL
UNIT PARTIAL DISCHARGE MONITORING
IED
ETHERNET SWITCH
ALARM SIGNALS
STEP-UP TRANSFORMER CONTROL SYSTEM
STEP-UP TRANSFORMER MASTER STATION
UNIT MAGNETIC FLUX MONITORING
IED
ALARM SIGNALS
ETHERNET SWITCH
STEP-UP TRANSFORMER MONITORING IED
IED
LEGEND :
COMMUNICATION LINK
HARDWIRED CONNECTIONS
N°
DATE
MODIFICATION DESRIPTON
SIGNATURE
ENERGOPROJEKT-HIDROINŽENJERING A.D.
BULEVAR MIHAILA PUPINA 12, BELGRAD, SERBIA
EMPLOYER
PE "ELEKTROPRIVREDA SRBIJE"
Ogranak HE "ĐERDAP" d.o.o.
DESIGN
REHABILITATION AND MODERNIZATION OF HPP "DJERDAP 1"
PROJECT
HPP DJERDAP 1
DRAWING
UNIT AND STEP-UP TRANSFORMER MONITORING SYSTEM - BLOCK SCHEME
CONTRACT N°
14066
DATE
06.2015.
PHASE
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APPROVED BY
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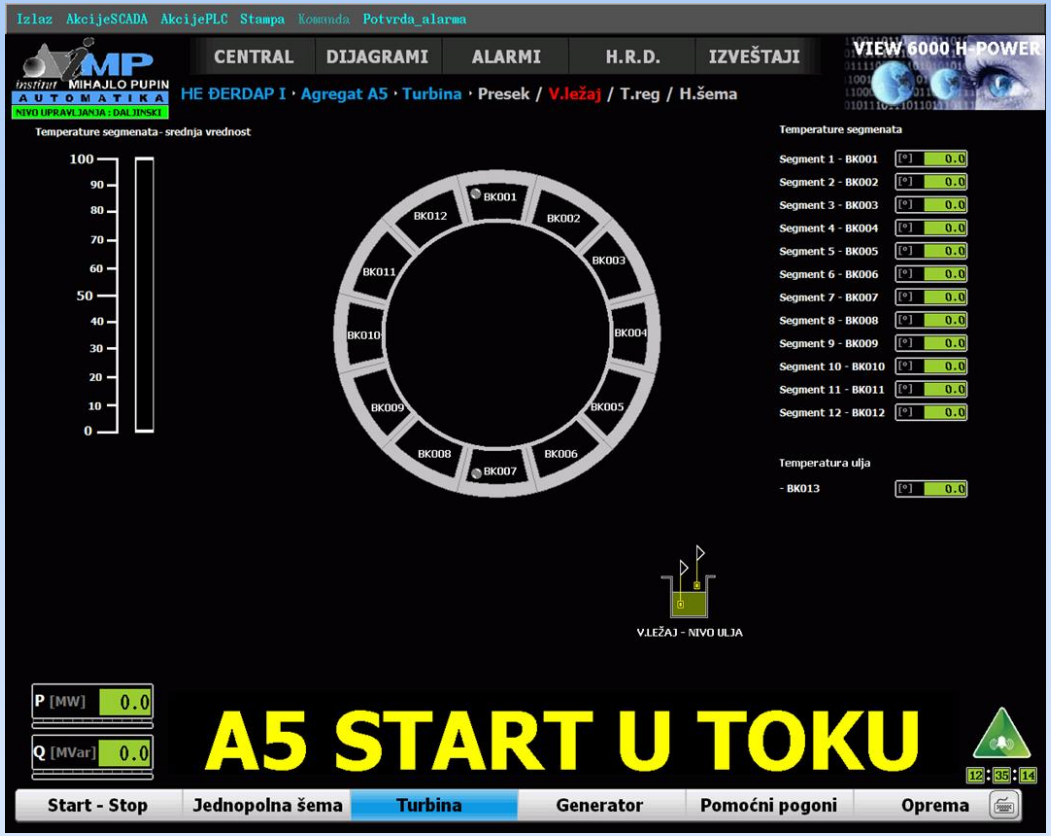
# Temperature monitoring (within Unit Control System)

Continuous measurement (Pt100 probes) of the following generator elements:

- Stator windings and core for main and auxiliry generators,
- At the end packages of the stator core sheets,
- In the segments of the guide and thrust bearings,
- In the zones of hot and cold air,
- At the inlet and outlet of the water from the air coolers of the generator, the thrust and guide bearings oil coolers,
- On the inlet and outlet collectors of water for cooling system of the generator.

Signalling the exceeding of the limit values for temperatures, by installed capillary pressure gauges:

- In the thrust and guide bearings segments,
- In the hot air zone,
- On the inlet and outlet collector of cooling water.




Measuring of stator segments temperature

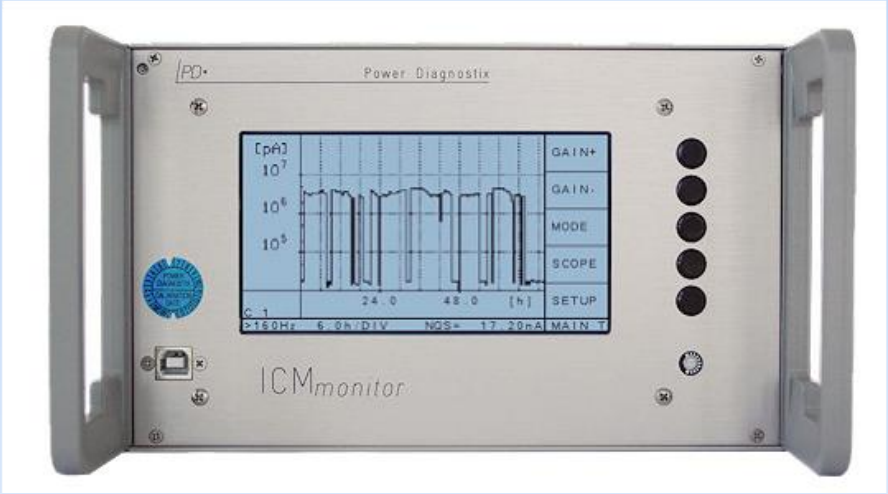
# Monitoring of partial discharges

- Continuous monitoring of important parameters of the state of the insulation of the generator stator windings, as well as monitoring their dependence on the dynamics and changes in conditions during the operation of the generator.
- Goals:
  - ➢Increasing the operational safety of the hydrogenerator,
  - ➢Assessment of the current, pre-overhaul and post-overhaul condition of the insulation.
- This system fulfil the following requirements:
  - ✓Inspection of the state of insulation during the operation of the generator under operating conditions, when electric, magnetic, thermal and mechanical stresses are present in the generator;
  - ✓Performing of tests that do not require a change in the operating mode of the generator;
  - ✓Do not endanger or interfere with the operation of the generator.

The system for measuring partial discharges on the unit consists of the following elements:

- Partial discharge signal transmitters, type CC20B (145 pF, 21kV)
- Data acquisition system (signal conditioning, multiplexer, preamplifiers and I/O modules, partial discharge analyser, data storage, etc.)

The generator windings: three-phase, with three parallel branches per phase( measurement on each parallel branch).



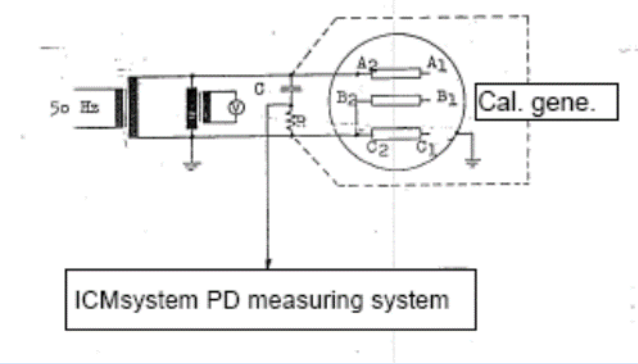

The equipment is manufactured by Power Diagnostix

# Verification of the Unit parameters after completing the assembly of the new generator

- Measurements of mechanical and electrical parameters in several stages:
  - Before filling the flow tract with water,
  - After filling the flow tract,
  - Starting the unit by manual control of the turbine governor,
  - No-load tests without and with excitation,
  - Automatic Unit start-up and synchronization,
  - On-load operation testing,
  - Load rejection tests.
- Generator testing procedures are fully in accordance with the requirements of the technical standard for testing rotating machines GOST 10169-77 and the international standard IEC 60034-4.
- Measurements of generator partial discharges and generator vibrations were processed as part of the tests.

# Measurements of Partial Discharges

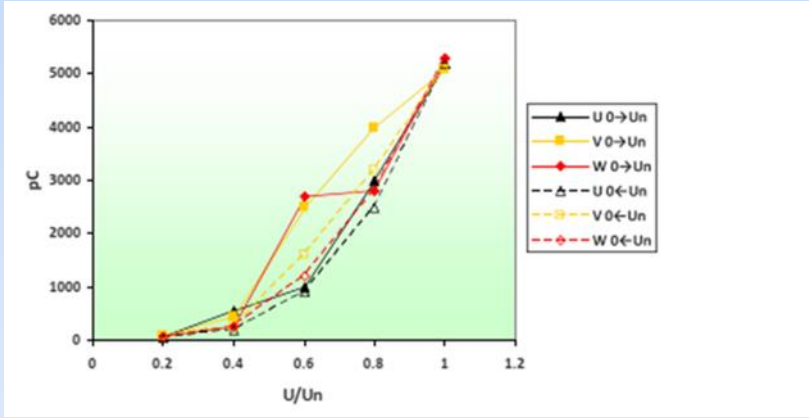
- The measurement is based on the collection-acquisition of PD pulses and intensity measurement, as well as determination of other parameters - place of occurrence depending on the phase of the test voltage, polarity, number, etc.
- The intensity of partial discharges is measured with the same power supply schemes as for measuring the dielectric loss factor and capacitance, i.e. voltage is applied to the winding under test, while the other two phase windings are grounded.




Connection diagram during testing

- The intensity of the partial discharges of the individual windings is satisfactory and uniform across phases.

| | Phase | $U_{isp}/U_n$ | 0,2 | 0,4 | 0,6 | 0,8 | 1,0 |
|---|---|---|---|---|---|---|---|
| | | $U_{isp}$ [kV] | 3,15 | 6,30 | 9,45 | 12,60 | 15,75 |
| PD (pC) | U | $0 \rightarrow U_n$ | 60 | 550 | 1000 | 3000 | 5200 |
| | | $0 \leftarrow U_n$ | 50 | 200 | 900 | 2500 | 5200 |
| | V | $0 \rightarrow U_n$ | 70 | 450 | 2500 | 4000 | 5100 |
| | | $0 \leftarrow U_n$ | 80 | 250 | 1600 | 3200 | 5100 |
| | W | $0 \rightarrow U_n$ | 60 | 250 | 2700 | 2800 | 5300 |
| | | $0 \leftarrow U_n$ | 60 | 250 | 1200 | 2800 | 5300 |



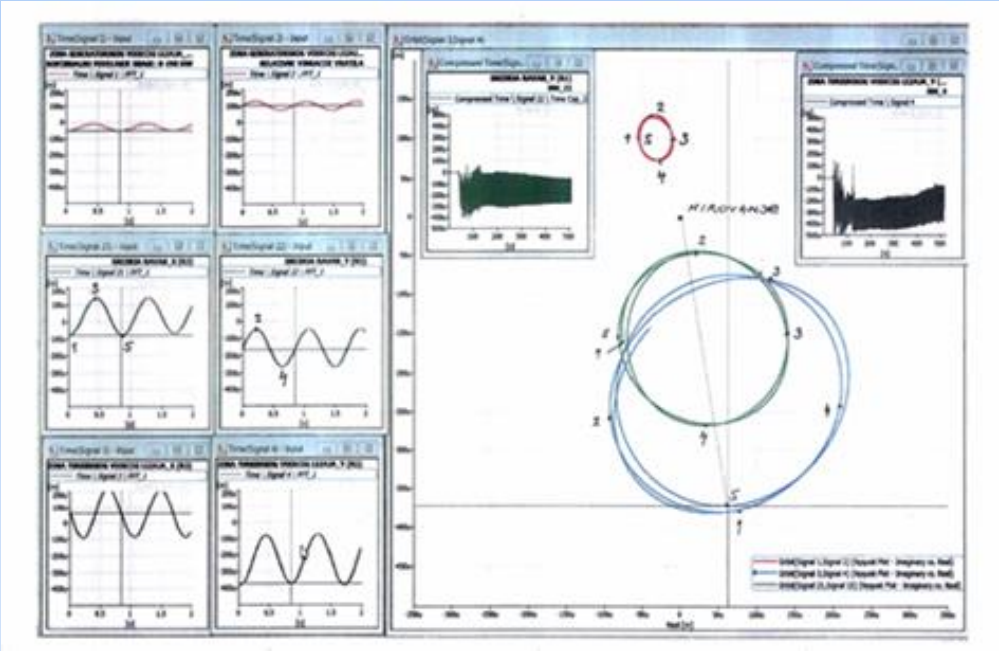

Measured PD intensity in all three phases, in relation to applied voltage

# Vibration measurement

- The tests were carried out in different modes of stable operation of the unloaded and loaded aggregate.
- Tests were also performed in different modes of unstable operation:
  - Starting the aggregate
  - Stopping the aggregate with mechanical braking of the generator
  - Stopping the aggregate with electrical braking of the generator
  - Continuous power increase 0-190 MW
  - Increasing the number of revolutions - runaway: mechanical and electrical
  - Power rejection_100 MW
  - Power rejection _148 MW
  - Power rejection _204 MW
  - Power rejection _98 MW with emergency shut-down
  - Power rejection _194 MW with emergency shut-down
  - Quick shut-down_190 MW

# Vibration measurement results:

- The highest values of relative vibration amplitudes - in no-load modes.
- Dominant components correspond to the basic frequency by the number of revolutions (1.19Hz) and its third harmonic (3.6Hz).



- The orbital trajectory of the path of the shaft axis in the area of the turbine guide bearing (blue color), in the area of the top of the turbine shaft (green color) and in the area of the generator guide bearing (red color), at the nominal load of the aggregate 190MW.

  The trajectory in the turbine guide bearing zone several times higher than the trajectory in the top of the turbine shaft zone, and several times higher than the one in the generator guide bearing zone.

  This indicates the fact that there is a certain breakage of the axis of the shaft and that the shaft rotates at a certain inclination, facing the Y direction.

- With increasing power, the trajectory in the top zone of the turbine shaft decreases, while that in the turbine guide bearing zone increases, which confirms the conclusion of shaft axis breakage.

The aggregate state assessment was carried out according to the relevant standards and by the contract defined limit values of relative and absolute vibrations in stable regimes.

| | Measured values | Limits defined by standards or Contract |
|---|---|---|
| **Relative vibrations:** | | |
| **Shaft run-out (amplitude - $A_{o\text{-}peak(\Sigma)}$)** | 68 µm | **≤ 170 µm as per A/B* boundary zone in accordance with ISO 20816-5** |
| **Absolute vibrations:** | | |
| **Bearings (housing) (double vibration amplitude - $2A_{o\text{-}peak(\Sigma)}$)** | 34 µm | **≤ 180 µm as per A/B* boundary zone in accordance with ISO 20816-5** |
| **Magnetic stator core, component of 100 Hz (double vibration amplitude - $2A_{o\text{-}peak(100\ Hz)}$)** | 2.5 µm | **≤ 30 µm as per IEC 60034-33** |
| **Stator frame and magnetic stator core, component of 1.19 Hz / 4.545 Hz (double vibration amplitude - $2A_{o\text{-}peak(1.19Hz\ /\ 4.545\ Hz)}$)** | 10.4 µm | **≤ 30 µm as per Contract** |
| **Lateral connections of stator winding (end-winding) with jumpers and ring connections, component of 100 Hz (double vibration amplitude - $2A_{o\text{-}peak(100\ Hz)}$)** | 32 µm | **≤ 100 µm as per GOST 5616-89** |
| **Upper generator bracket, component of 1.19 Hz / 3.6 Hz (double vibration amplitude - $2A_{o\text{-}peak(1.19\ Hz\ /\ 3.6\ Hz)}$)** | **16 µm** | **≤ 180 µm as per Contract** |

In order to compare the measurement results, the measured values on the aggregate before its replacement are shown below.

Shaft runout measurement (shown sizes are in 1/100mm)

As can be seen from the measurements of the shaft displacement on the old unit, the unit could be in operation without any restrictions in operation.

| Redni broj | REŽIM RADA AGREGATA | GENERATORSKI LEŽAJ | | TURBINSKI LEŽAJ | |
|---|---|---|---|---|---|
| | | Y | X | Y | X |
| 1 | Prazan hod 80% (n) na ručnom | – | – | – | – |
| 2 | Prazan hod 100% (n) na ručnom | – | – | – | – |
| 3 | Agregat opterećen sa 90 (MW) | – | – | – | – |
| 4 | Agregat opterećen sa 130 (MW) | 8 | 10 | 10 | 10 |
| 5 | Agregat opterećen sa 180 (MW) | 15 | 13 | 12 | 14 |
| 6 | Kota gornje vode (m) | 68.44(m) | | | |
| 7 | Pod u C.K. (m) | 27.77(m) | | | |

# Thank you!

ENERGOPROJEKT
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