Hydrogenerator rotor temperature measurement system – application in HPP Vinodol and HPP Dubrava

Goran Orešković
VESKI
Dragutina Golika 63
10000 Zagreb, Croatia

Radivoj Belobrajić
HEP Proizvodnja
Ulica grada Vukovara 37
10000 Zagreb, Croatia

Damir Magić
HEP Proizvodnja
Ulica grada Vukovara 37
10000 Zagreb, Croatia

Mirko Husnjak
Faculty of Mechanical Engineering and Naval Architecture
Ivana Lučića 5
10000 Zagreb, Croatia

Boris Meško
VESKI
Dragutina Golika 63
10000 Zagreb, Croatia

Ozren Orešković
VESKI
Dragutina Golika 63
10000 Zagreb, Croatia

Ozren Husnjak
VESKI
Dragutina Golika 63
10000 Zagreb, Croatia

Summary

This paper decribes the system designed for on-line temperature measurement on hydrogenerator rotor pole windings and on other rotor parts as well. Since signal transfer by wire is not easily applicable in this situation, it was essential to ensure wireless signal transfer from rotor. This was achieved with one radio signal transmitter/receiver mounted on the rotor and the other on the stator. When signals are collected on the stator side, they are sent through the RS232/ENET connection into the PC where they are saved, processed and visualized. The system consists of temperature sensors placed relevant positions on the rotor pole. Temperature resolution is ±0.5°C and the sensor measuring range is up to 125°C. Sensor layout makes possible the analysis of cooling efficiency of particular rotor parts, based on temperature measurements. This information enables hydrogenerator designers (possible) redesign of the cooling system in order to achieve better cooling efficiency on the parts where temperature conditions are not satisfying, according to the measurement result analysis. Furthermore, the thermal map of the pole can be implemented as a part of permanent diagnostic monitoring providing information of current temperature state and of temperature changes due to various exploitation conditions. In addition, the system can be extended by installing sensors on hydrogenerator stator, providing temperature measurements data in order to obtain stator thermal map. Illustration of the system is given by examples from HPP Dubrava and HPP Vinodol. Specifically, in the case of HPP Vinodol, it is evident that parts of the rotor pole are less efficiently cooled. The differences in temperatures on some pole positions are as high as 50°C measured under exploitation condition with ~30 MW active and ~22.5 MVAr reactive power. According to measurement results, pole side closer to exciter is warmer than the opposite one. Also, the side opposite to pole rotation direction is warmer than the other one.

By the time this article was written, temperature measurements on generator 2 in HPP Dubrovnik were performed as well. Efficient cooling of this generator is the reason the temperatures never crossed 70°C and maximal temperature differences are 15°C.

1. Introduction

The basic purpose of on-line temperature measurements on hydrogenerator rotor is to obtain reliable information of its temperature conditions. Based on this data conclusions concerning cooling efficiency can be made. When the hydrogenerator is working in a specific regime (especially when the applied combination of active/reactive power dissipates excessive heat) it is interesting to know thermal map of its rotor elements – for example rotor pole windings.

It is desired for the temperatures to be as low as possible (indicating good cooling efficiency). It is also important that the temperature distribution on pole windings is as uniform as possible in order to avoid temperature asymmetry caused thermally induced stress on pole windings. This stress can result in more or less drastical reduction of life expectancy or, in worst case, insulation failure.

The temperatures can be added to permanent diagnostic monitoring system database and analysed offline as a thermal map at a specific time stamp or in trending diagrams for desired time periods.

2. Technical solution

Since temperature measurements during generator operation is of interest, the basic technical problem to solve was reliable data transfer from rotor to stator. This was achieved using wireless technology (radio link).
One radio receiver/transmitter was placed on rotor and the other on stator side. Temperature sensors pass the signal in digital form to rotor transmitter/receiver after which the rotor transmitter/receiver sends information to receiver/transmitter on stator side (Fig. 1.)
Sensor resolution is ±0.5°C and can measure up to 125°C. Because of their small dimensions – the sensors can be installed on almost any rotor/stator part in layout and number sufficient to obtain data for reliable thermal map calculation. Since the sensors are parallely connected and since each sensor has unique address it is enough to use only one radio transmitter/receiver on rotor thus reducing the overall installation size and complexity.
Due to RS232/ENET (serial/ethernet) converter – as an extra advantage – the temperature data is shared over local area network (LAN) so any authorized user can access it.

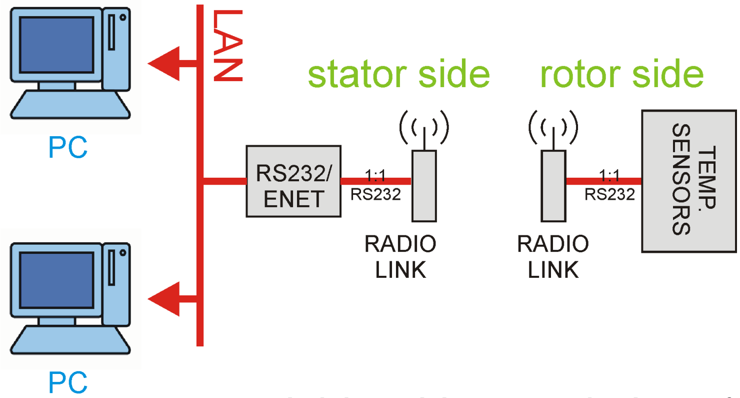

Fig. 1. Schematics of temperature measurement. Radio-link is needed to ensure wireless data transfer from rotor to stator.

2. Measurement results

Measurement results are divided into three sections according to the Hydro Power Plant (HPP) they were measured.

2.1 HPP Dubrava

In HPP Dubrava the temperature sensors are placed on rotor pole windings as shown on Fig. 2.

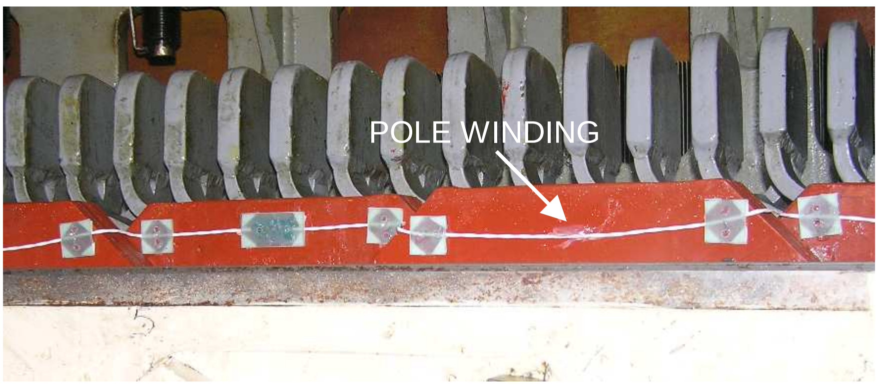

Fig. 2. Temperature sensor layout on rotor pole of generator 1 in HPP Dubrava.

Temperature monitoring system is integrated as a part of permanent diagnostic generator monitoring system because temperature trends are an important indicator of the generator rotor condition. Fig. 3. shows comparison of relevant electrical quantities (excitation current/voltage – diagram D1) and short-time temperature trends on generator 1 in HPP Dubrava.

Fig. 3. Trending of electrical quantities (diagram D1: excitation current/voltage) and temperatures (diagram D2) on generator 1 in HPP Dubrava.

In addition to temperatures, excitation current and excitation voltage, magnetic induction, air-gap (both measured by means of sensor bonded on rotor pole) and resistance of isolation measurements are also a part of the system. Generally, it is possible to collect 8, 16, etc. (depending on the number of integrated modules) analog quantities on rotor and transfer them using wireless technology to stator.

2.2 HPP Vinodol

Cross-section of horizontal generator in HPP Vinodol, where the rotor temperature measurement layout used in following example is installed, is shown in Fig. 4.

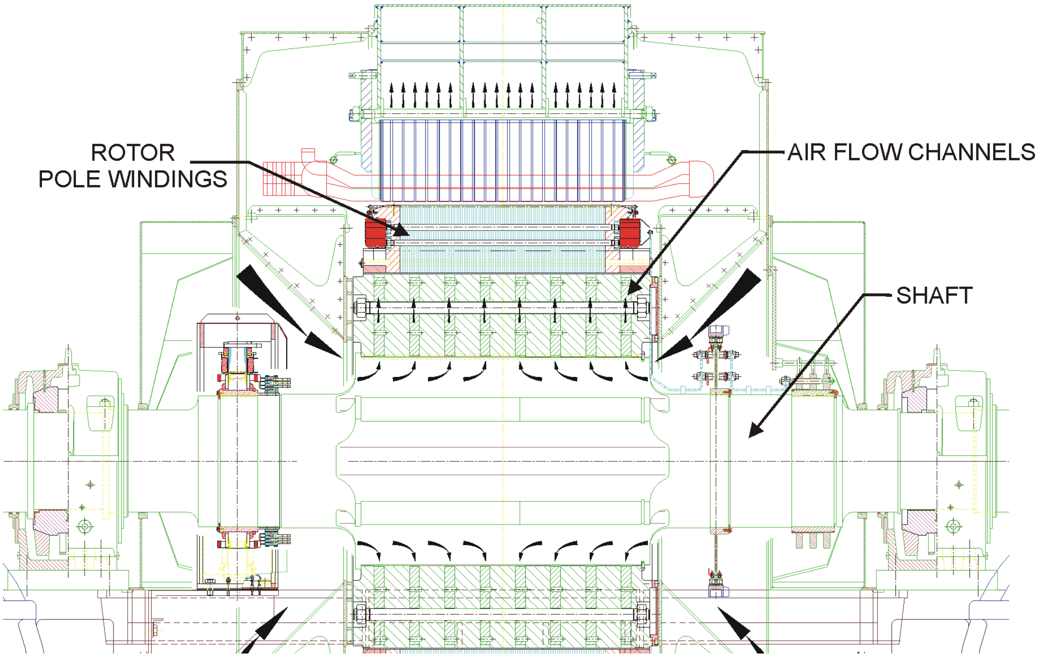

Fig. 4. Cross-section of generator in HPP Vinodol. The arrows show the direction of air flow. Important generator parts are labelled.

Important elements have been labeled. Air inflow is axial and outflow radial as indicated by arrows.
Detailed temperature measurements (thermal map) on rotor pole windings were implemented under different exploitation conditions. Temperature sensors (total number 112) were installed as shown in Fig. 5.

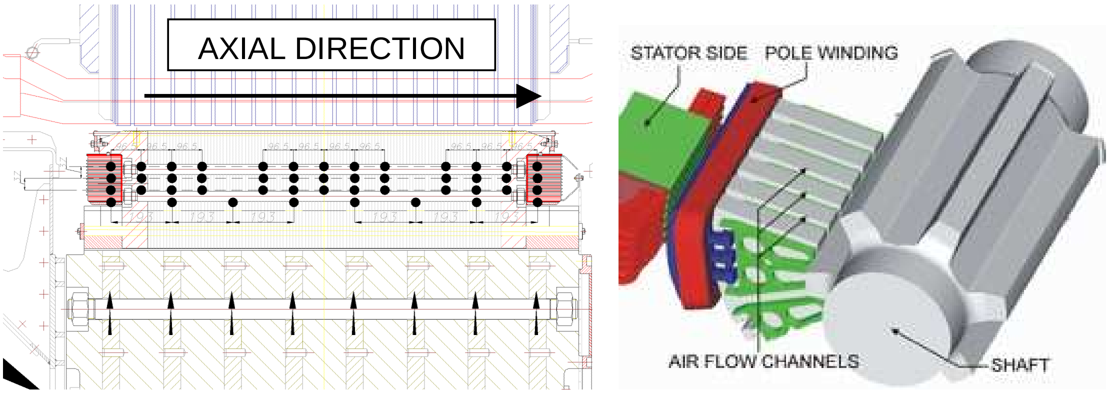

Fig. 5. LEFT: Rotor cross-section. The air flows in arrow direction. Black dots mark the places where temperature sensors are installed. RIGHT:Partial cross section of the rotor. Important elements are labeled.

Sensor layout is determined by the design of pole cooling channels. The poles are cooled by air – flowing radially through air-flow channels. Leaving the channels the air flows into inter-winding area where it takes over the heat dissipated by pole windings. After that, the air flows into the stator air channels.
The first topic of these measurements was to check whether the temperature of air flowing into the air channels was the same for all channels. The sensors were also installed in-between air channels on the same distance from the shaft to obtain axial temperature distribution throughout the entire pole length. The sensors were also installed on different distance from the shaft (radially).
Temperature sensor layout is shown on Fig. 5.
Due to symmetrical design of generator (Fig. 4.) close to uniform distribution of temperatures was expected. There is no particular reason for asymmetrical temperature distribution on pole winding, respectively, different sides of winding (axial direction) should have similar temperature distribution. But, as described later in text, the measurements show unexpectedly large temperature differences on various measuring positions.
Photo of pole winding in HPP Vinodol is shown in Fig. 6. The photo was taken during the process of sensor installation.

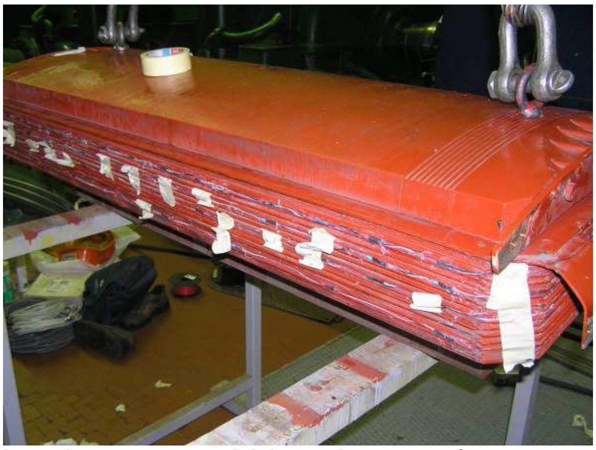

Fig 6. Photo of pole winding in HPP Vinodol during the process of temperature sensor installation.

At ~16h on 14. 3. 2007. the generator regime was ~30 MW, ~20 MVAr (excitation current ~900 A). The generator was working in this regime for a couple of hours (until ~19h). By comparing two measuring positions on the windings with largest temperature differences, maximal difference value of about 50°C (at 19h) was recorded – Fig. 7 (positions of sensors with these temperatures are marked on Fig. 8.).

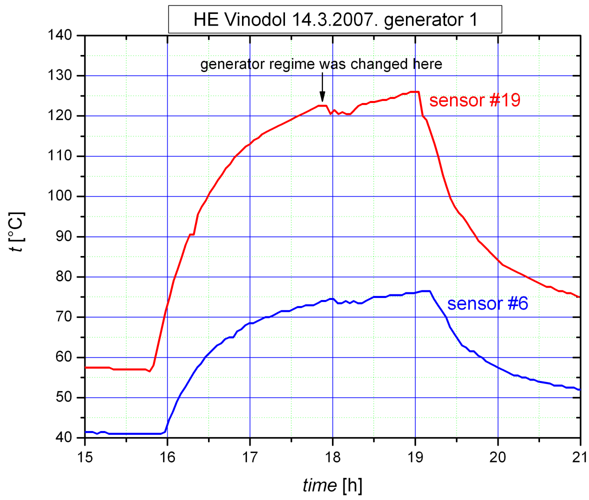

Fig 7. Temperature as a function of time on two selected sensors on pole winding. At ~16 h the generator started working in the regime ~30 MW, ~20 MVAr (excitation current was ~900 A). After a few hours the generator stopped working in this regime (at ~19 h).

Due to power consumption requirements in the distribution system during the measurement, the temperature stationary state couldn't be reached. Presumably the rotor would continue to heat up if the regime remained. Rough estimate shows that the sensor 19 (red – Fig. 7.) would heat up to 140°C. Sensor 6 (blue – Fig. 7.) is expected to heat up to 90°C.

A clearer picture of temperature distribution is accomplished by thermal map (Fig. 8.) where pole winding is represented in 2D and it clearly shows that the temperature distribution isn't uniform thus indicating that the cooling isn't uniform as well. The side closer to the exciter (right side of Fig. 8.) is less efficiently cooled than the opposite side (left side of Fig. 8.)

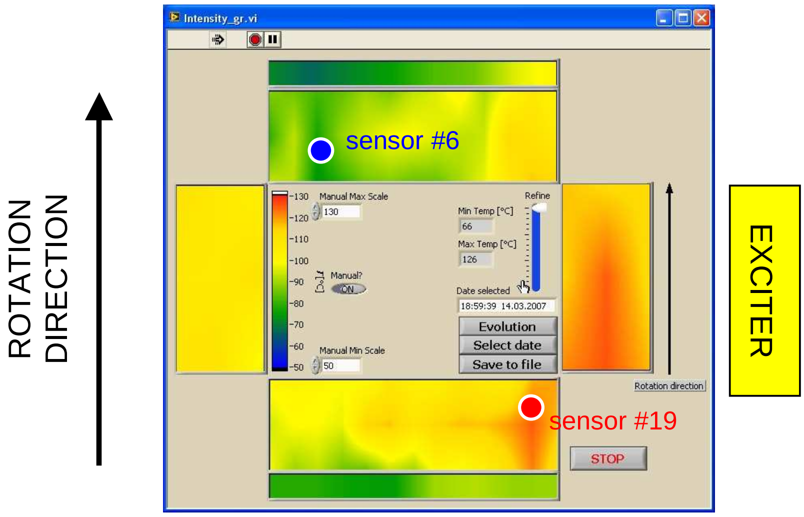

Fig 8. Thermal map of rotor pole winding in HPP Vinodol at ~19h. The pole is represented in 2D and rotation direction is marked. Temperature asymmetry is clearly seen. The blue and red dots mark the place where sensors #6/sensor #19 are mounted.

2.3 HPP Dubrovnik

Temperature measurements were performed on pole winding of generator 2 in HPP Dubrovnik during its operation. Total number of 45 sensors were mounted as seen on Fig. 9. and Fig. 10.

Fig. 9. Temperature sensors glued to rotor pole winding in HPP Dubrovnik. All sensors are mutually connected in parallel and end up with one transmitter/receiver.

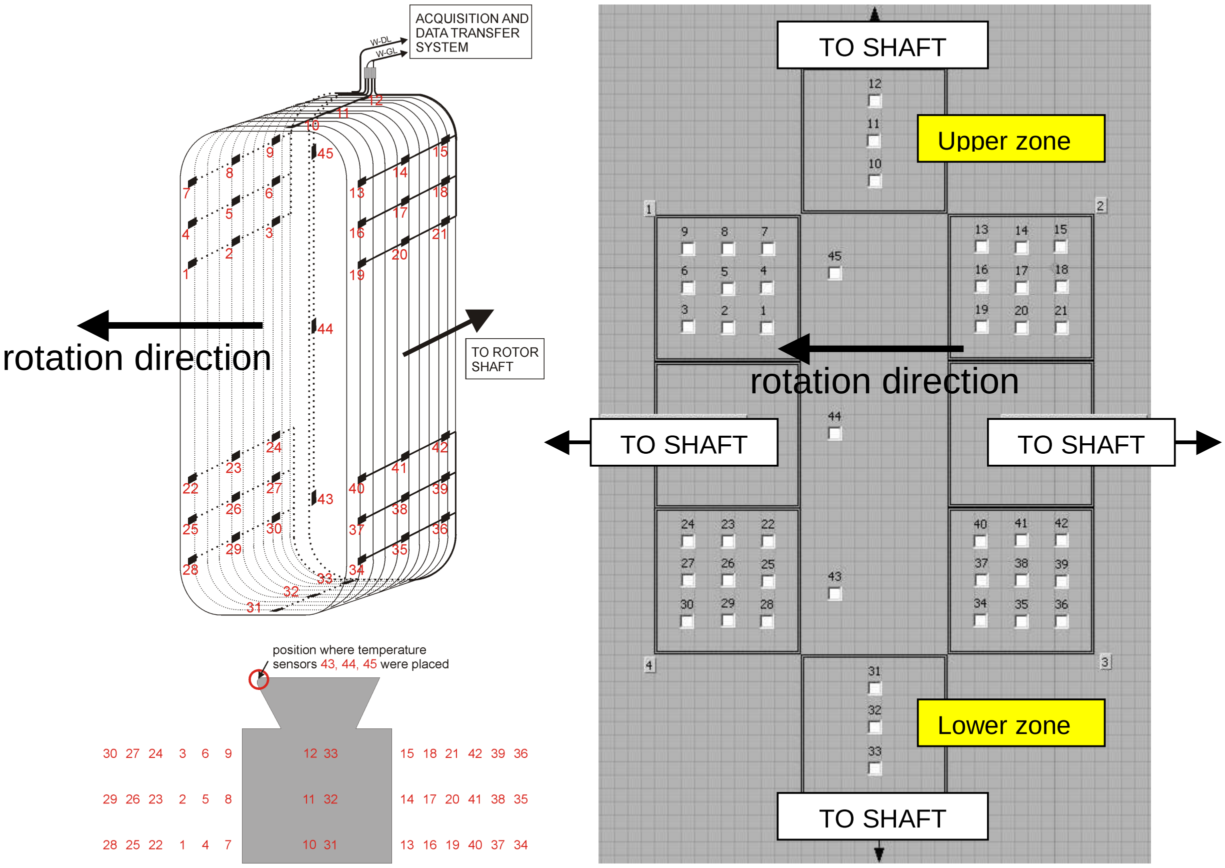

Fig 10. LEFT: 3D isometric view of pole winding in HPP Dubrovnik with sensor positions. RIGHT: Two-dimensional representation of pole winding with temperature sensor positions.

An interesting regime was obtained on 7. 7. 2007. when the generator was working with ~90 MW, ~65 MVAr thus dissipating a lot of heat. By looking at Fig. 11. it can be seen that the time for system to reach stationary state is ~4-5 hours (at ~14h active and reactive powers are nearly constant and the system reaches its constant temperature at ~18-19h, that is, 4-5 hours later). Although, because this interesting regime was achieved exactly at the time of measurement system installation, some points are missing (between ~9:30h and ~11:30h), it can be said (without making a big mistake) that the temperature wouldn't exceed 70°C in the lower zone and 65°C in the upper.

As it is logical the lower zone is warmer (because of the construction – the air is more confined in the lower area). Also, the zone opposite to rotation direction is warmer.

Maximum temperature differences in viewed zones are ~10°C and maximum absolute difference is ~15°C. So, there are no large temperature differences that could lead to insulation failure.

The temperature measurements on iron (sensors 43, 44 and 45) are also interesting. It can be seen that during the first three hours the iron temperature was dropping and then – at ~8:30h the heating started. Clearly – the cooling of iron is a consequence of establishing water flow through turbine so the heat was conducted from iron to turbine. At the same time the iron is heated by conduction from dissipated heat on pole winding and (possible) eddy currents in iron. But the iron is never heated above 40°C.

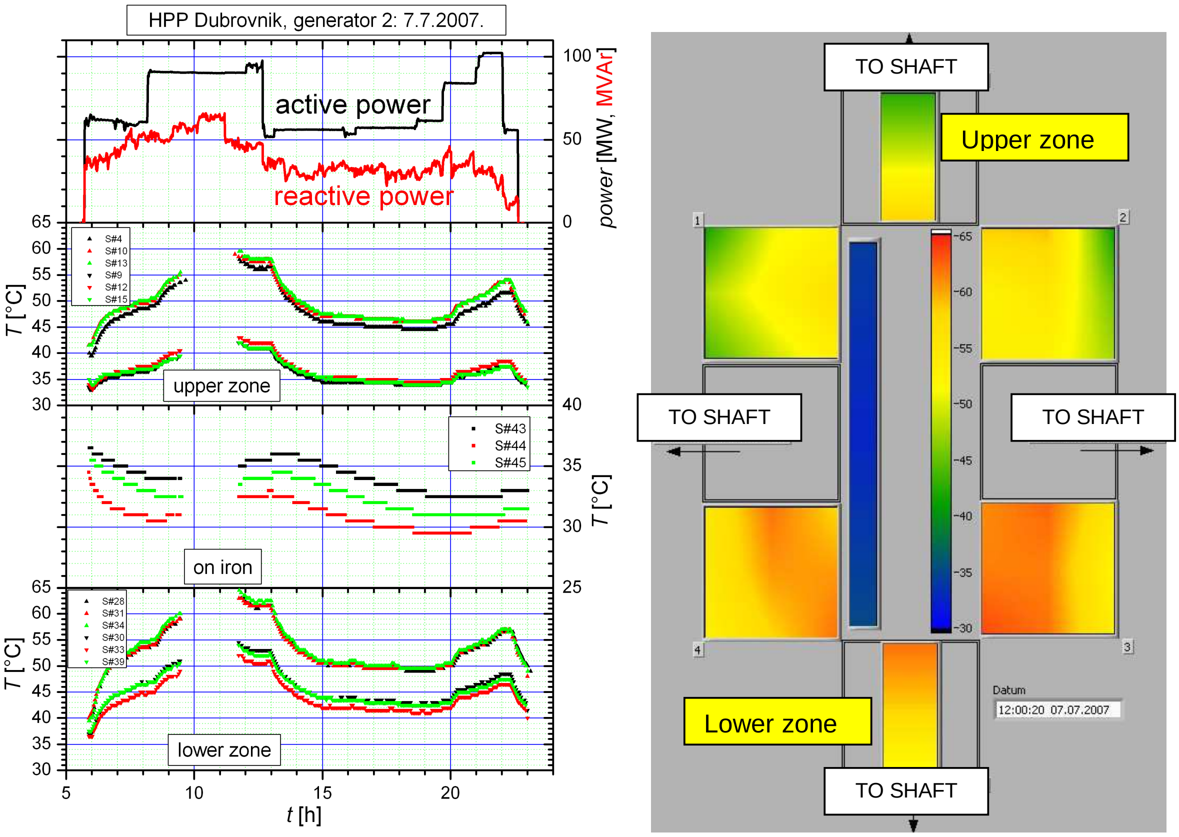

Fig. 11. LEFT: Comparison of highest/lowest temperatures in viewed zone according to sensor number. RIGHT: Two-dimensional thermal map at ~12 h on 7. July 2007.

3. Conclusion

The conclusions being made are sorted according to generators in HPP where temperatures on rotor elements were measured.

3.1 HPP Dubrava

The main purpose of temperature measurements on rotor pole winding was to monitor and obtain temperature trends which are a good indicator of the generator rotor state changes. This data is easily integrated into the monitoring system already supplied for this power plant.

3.1 HPP Vinodol

Very detailed temperature measurements on rotor pole winding were performed with the total number of 112 sensors. In a active/reactive power combination regime dissipating excessive heat the pole would heat up to almost 140°C! It was also determined that the pole cooling isn't uniform. On different pole positions – temperature differences up to 50°C were measured. This is, obviously, not satisfactory because of induced thermal stress which can result in insulation damage eventually leading to failure. The life span of the generator is also drastically reduced.

3.1 HPP Dubrovnik

Rotor pole winding temperature measurements on generator 2 in HPP Dubrovnik have shown the following:

- pole winding will never heat above 70°C

- the temperatures are the highest in the lower zone (because the air is more confined in this area) and opposite to rotation direction but absolute temperature difference is never greater than 15°C
- temperature measurements on iron show that it never heats above 40°C indicating that the losses in iron are not large

References

1. **Ž. Dujmović, B. Meško, G. Orešković, R. Belobrajić, D. Magić**, "Sustav za beskontaktni monitoring procesnih veličina na rotoru hidrogeneratora – primjena u HE Vinodol i HE Dubrava", *7. savjetovanje HO CIGRÉ*, Cavtat, Hrvatska, studeni 2005.
2. **A. Sharma, J. Al A'Ali, N-I. Landgren**, "Thermal evaluation of air cooled generators to investigate the generator rotor overheating – a prerewind evaluation case study", 40. zasjedanje CIGRÉ, Pariz, Francuska, kolovoz-rujan 2004.

The Authors

Goran Orešković graduated in Faculty of Mechanical Engineering and Naval Architecture and also at Department of Mathematic at University of Zagreb. He has worked in Končar where he was involved in vibration diagnostic and analysis. After that he (along with two colleagues) founded his own company *VESKI* where he has been working for the last seventeen years. He has been involved in numerous in-field vibration problem solving, but his main area of interest is development of flexible (according to customer needs), modular and highly reliable monitoring systems.

Radivoj Belobrajić graduated in Faculty of Electrical Engineering at University of Zagreb. For the last 25 years he is head of HPP Vinodol, and in the last 10 years manager of the power plant.

Damir Magić graduated in Faculty of Electrical Engineering at University of Zagreb. For the last 28 years he is head of HPP Dubrava, and in the last 15 years manager of the power plant.

Mirko Husnjak graduated in Faculty of Mechanical Engineering and Naval Architecture at University of Zagreb. After graduation he became an assistant at the same faculty where he succesfully defended his doctor thesis and became a teaching professor. He is the head of Department of Experimental Mechanics. He was involved in solving numerous problems in fracture mechanics, vibrations etc. experimentally, but also by modelling

Boris Meško graduated in Faculty of Mechanical Engineering and Naval Architecture at University of Zagreb. He has worked in Končar where he was involved in vibration diagnostic and analysis. He is one of the founders of *VESKI* where his main area of expertise is vibration analysis and development and programming of monitoring systems.

Ozren Orešković graduated in Faculty of Mechanical Engineering and Naval Architecture at University of Zagreb. He is employed in *VESKI* for the last three years. His area of expertise is vibration diagnostics and programming.

Ozren Husnjak graduated in Department of Physics, Faculty of Science at University of Zagreb. After graduation he was employed as an assistant at Department of Physics where he was involved in experimental laboratory research. Four years later he received his Master of Physics degree and after that became an employee of *VESKI* where he has worked since (for the last six months). His area of expertise is programming.