

INFORMATION TECHNOLOGY IN HIGH VOLTAGE MEASUREMENTS

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ABSTRACT

Remote-distance interactive learning is an important emerging educational trend. The Internet is an ideal medium for remote instruction purposes. This paper describes an innovative real-time remote-access to high voltage laboratory. As an example, an application of remote experiment on measuring and calculating electromagnetic (EM) fields of power frequency 50 Hz inside the high voltage laboratory is described, which can be easily accessed through the Internet. Students can watch the experiments in real time from a remote workstation, hear the sounds in the laboratory, and interact with other laboratory users.

1. INTRODUCTION

As a result of cooperation between Faculty of Electrical Engineering and Computing (University of Zagreb), Faculty of Electrical Engineering (University of Sarajevo) and Sadovic Consultant an innovative real-time remote-access to high voltage laboratory was developed and demonstrated. The remote laboratory was conducted over a high-quality digital video conference system, making it possible for both sides to communicate smoothly with each other and for the remote user to observe close-up details of the laboratory and experiments. Our approach is based on newly developed software packages and commercial measurement equipment. As an example, we describe an application of remote experiment on measuring and calculating electromagnetic (EM) fields of power frequency 50 Hz inside the high voltage laboratory, which can be easily accessed through Internet. Remotely located students are able to learn and watch in real time on the experiments in our laboratory.

2. THE SYSTEM ARCHITECTURE

Two video cameras are used to live broadcast what is happening in the HV laboratory. One camera is located in the laboratory control room and it is used for presentation of measuring equipment and computer calculations while the other is used for presentation of experiment site. Fig.1. shows hardware structure of remote laboratory. The system architecture is conducted totally in digital technology, and is based on the following equipment:

- Internet Protocol Camera, for the equipment display and interaction with the cabin crew;
- Desktop or laptop computer with main software used for camera control, recording and playback of the recorded data.

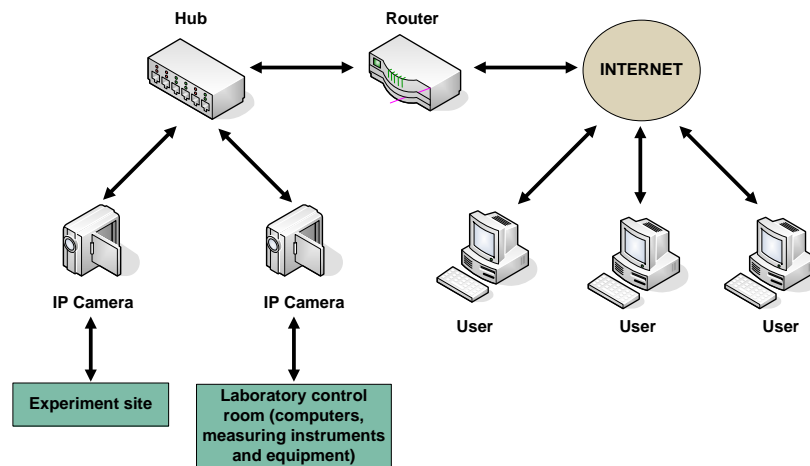


Fig.1. Hardware structure of remote laboratory

Main system features:

- Simultaneous local and remote viewing, control and recording of the cameras by different software users;
- Recorded data stored in digital format is available instantly to anyone over the Intranet/Internet.

2.1 IP Camera

Main IP camera features are:

- IP cameras with Pan, Tilt, Zoom (10x optical);
- Audio In and Out for two-way communication with microphone and speakers;
- Night vision built-in.



Fig.2. IP camera with Pan, Tilt, Zoom

Pan / Tilt feature allows the moving of the camera by 270 degrees horizontally and 135 degrees vertically. This is very useful to cover an area such as a high voltage lab with a small number of cameras. Optical Zoom feature enables a much better display of the equipment without having to install the camera close to it. Higher distance means less risk of failure of the camera due to high voltage testing.

2.2 Communication

Thanks to the IP technology, there is a choice for the equipment communication between:

- Ethernet;
- Fiber optics;
- Wireless WiFi;
- PowerLine Carrier.

Since all of these protocols are compatible, they can be used together. This flexibility allows easier installation of the system with minimal civil work.

2.3 Software

Own developed software is used to operate the system. Main software features are:

- Camera viewing, control and recording;
- Audio communication between different users;
- Playback of the recorded data, export to different video formats such as AVI.

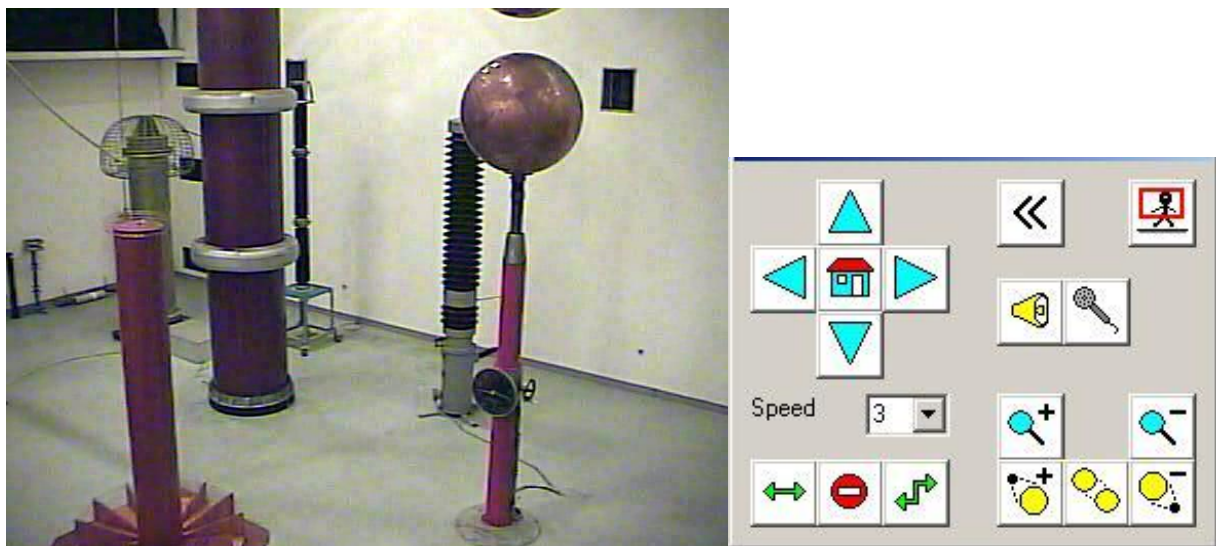


Fig.3. Camera control interface

Different users can use the software with various administrative privileges. This defines for example if a user has the right or not to control one of the cameras.

2.4 Application of the system to the High Voltage lab for teaching purpose

Two cameras are installed and connected to the Faculty Intranet, with access to the Internet. One is in the laboratory control room and the second one is on the experiment site. Three users have access to the system by using the software “Fig. 4.”:

- User A with all the privileges. He operates the system locally from the laboratory control room by moving the cameras.
- User B with the viewing rights (cannot control the cameras). This is typically an Intranet user inside the Faculty network, such as a classroom, which is following the high voltage experiment without having to be inside the lab.
- User C with the same privileges as User B. This is a remote user that is following the same experiment over the Internet, such as a classroom of another faculty.

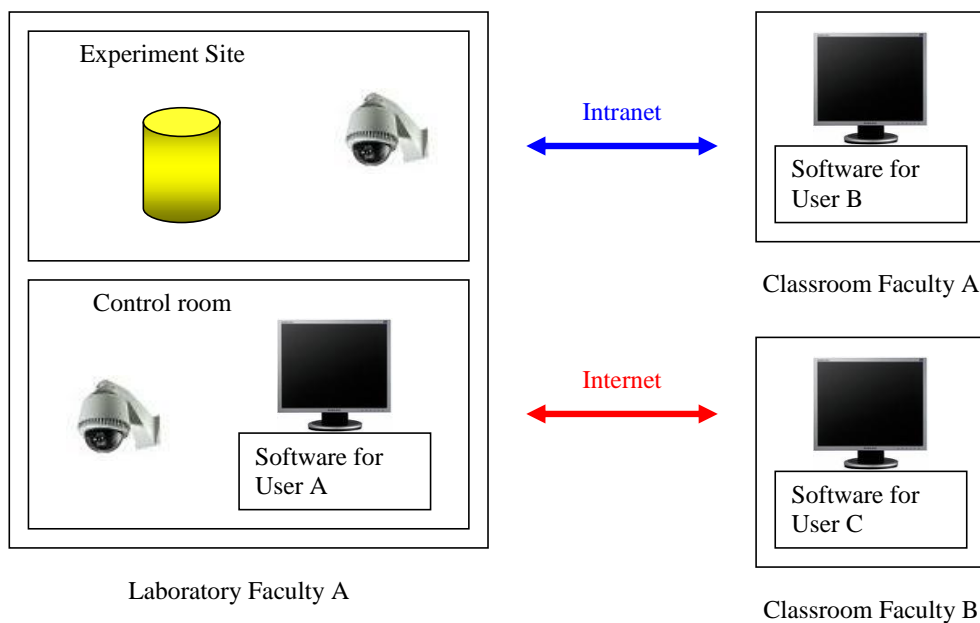


Fig.4. System interaction

2.5 Mode of operation

Operators in the laboratory control room prepare the experiment. A document with detailed description about experiment is available by Internet to all users. Operators are in charge of controlling the cameras by displaying all the useful information of the equipment, measuring instruments and test object. They can communicate with other users in order to explain what they are doing or answer any question. Once the experiment is finished they have all the recorded data stored on their computers.

Local and remote classroom users see through the software on a projection screen everything the laboratory control room wants to show to them. They can communicate with the cabin crew in case they have a question (two-way communication). Once the experiment is finished they also have all the recorded data stored on the classroom computer ready to be shared.

3. ELECTRIC AND MAGNETIC FIELDS IN HV LABORATORY

The values allowed by the *Regulations* [1] for area of professional exposure are: 5 kV/m for electric and 100 μ T for magnetic field of 50 Hz. With the help of the modern computer programs it is possible to predict values of EM fields in the vicinity of electric power objects. The accuracy of the calculation is connected with the detailed representation of conductors and the knowledge of the operation state (currents), what is special important in the case of magnetic fields. Some of them are characterized with statistical variability that is very difficult to predict. The value of magnetic field depends, before all, on current (amplitude, phase angle, degree of asymmetry) and conductor geometry. The calculations of magnetic field are very often conducted on the basis of the worst expected case (maximal current).

3.1 Theoretical background of calculations

Calculations of EM fields in HV laboratory are conducted using EFC-400 software, which enables EM field calculations in 3D. The field can be illustrated by field lines, which form concentric circles around the conductor. The magnetic induction of conductors is calculated with the Biot-Savart equation as a superposition of the subfields of individual conductor segments. To apply the equation a point in space has to be defined at which the magnetic field has to be computed. Holding that point fixed, the integration over the current(s) path is conducted to find the total magnetic field at that point.

The electric field can be represented by the negative gradient of the scalar potential $\Phi(x,y,z)$. The application of the mirror-charge procedure [2] is applied.

In case of n conductor segments this yields a system of equations with n unknown variables:

$$U_i = PK_{ij}Q_j \quad (1)$$

PK_{ij} is described as the matrix of the potential coefficients. Inverting PK_{ij} yields the distribution of the line charges. EFC-400 is able to solve this set of linear equations for a PK_{ij} matrix with 16000 x 16000 elements. Predefined conductor geometry can be approximated by 16000 segments. The computation time for electric fields is 2-3 longer than for magnetic fields, due to the inversion of PK_{ij} matrix.

“Fig. 5 a)” shows plan view of HV laboratory and “Fig. 5 b)” model of HV testing transformer for magnetic induction calculation.

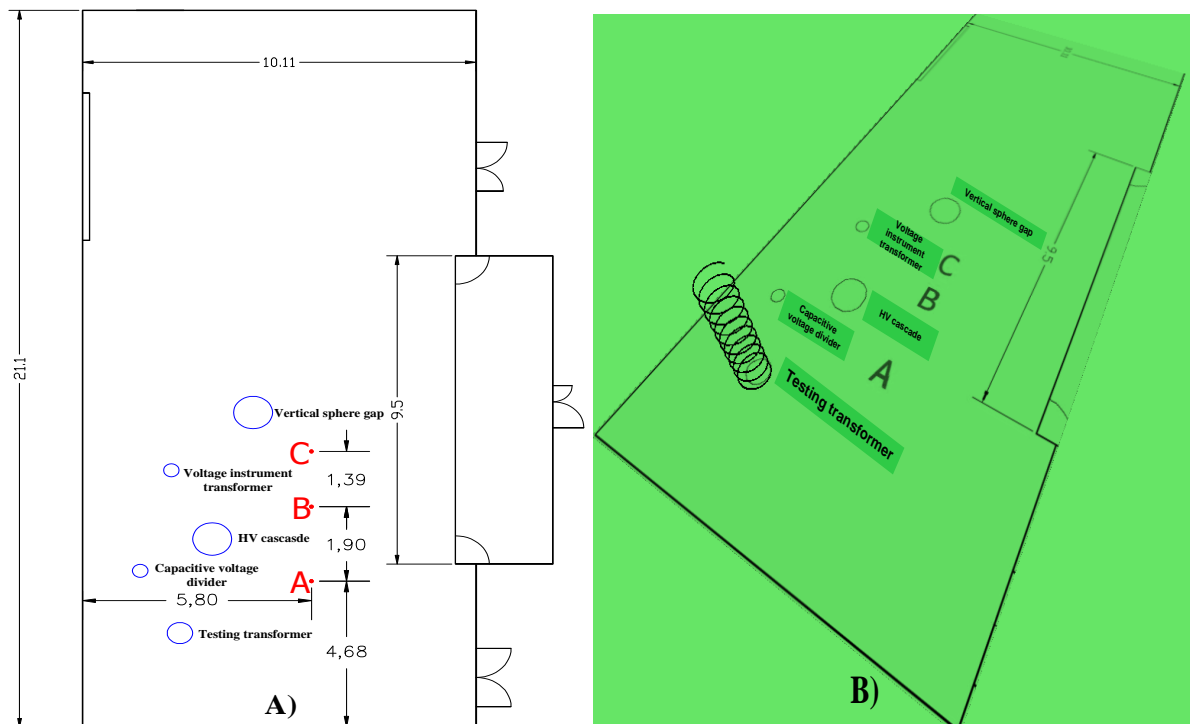


Fig. 5. a) Plan view of HV laboratory with placement of points for calculation (A, B and C),
b) HV testing transformer model in HV laboratory

Testing transformer is the main source of magnetic flux density. Calculations of the RMS-value of magnetic induction are conducted for 1 m height above ground. Current value of 780 A was used in simulation (current is recalculated for 10 turns). Calculation results are shown in “Fig. 6.” which shows that magnetic induction values are higher than allowed value of 100 μT (for area of professional exposure) only in vicinity of HV testing transformer, which can’t be avoided due to transformer construction. In other areas of laboratory magnetic induction is lower than allowed value of 100 μT . “Fig. 7.” shows model of HV bus for electric field calculation. That way the main source of electric field is modelled. For voltage a value of 73,6 kV in measuring moment was used in simulation.

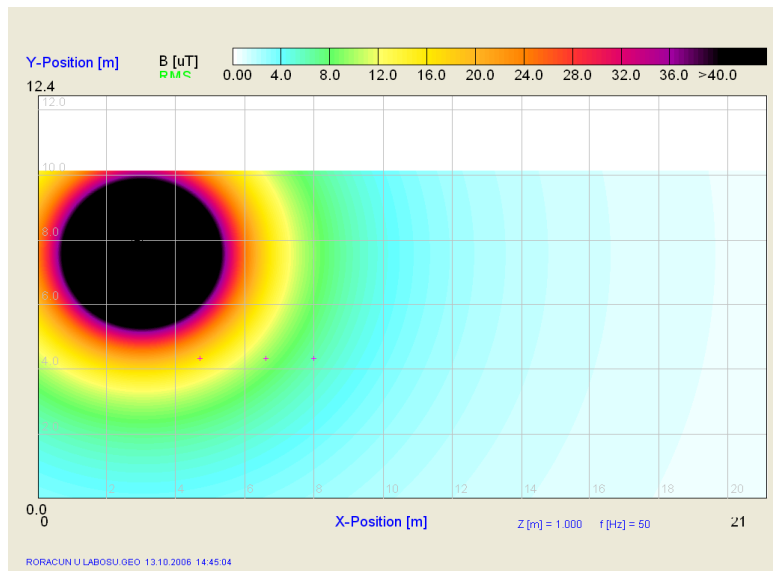


Fig. 6. Magnetic induction in HV laboratory on 1 m height (in black colour area magnetic induction is higher than $40 \mu\text{T}$) $B_A=16,35 \mu\text{T}$, $B_B=9,50 \mu\text{T}$, $B_C=6,27 \mu\text{T}$

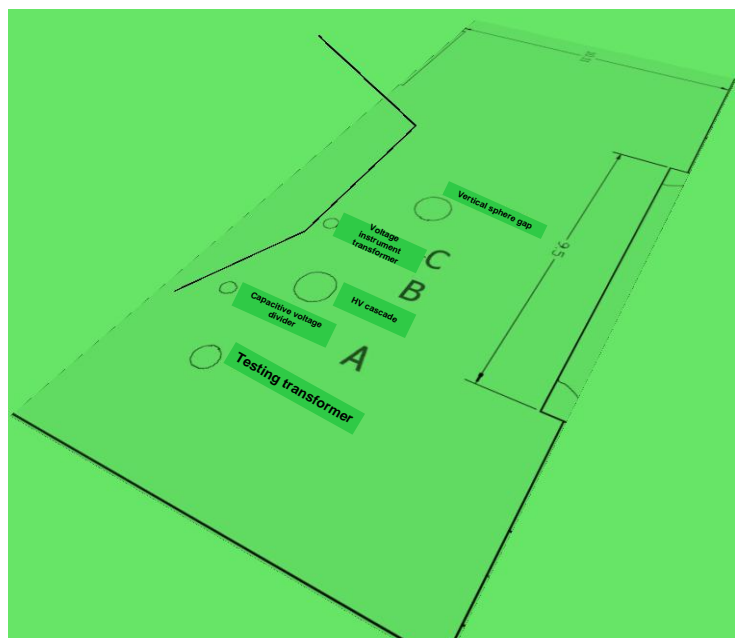


Fig. 7. HV bus model in laboratory

“Fig. 8.” shows that electric field strength values on 1 m height are lower than allowed value of 5 kV/m (for area of professional exposure). In area below bus electric field is higher than 2 kV/m. Measurement results can easily be presented over Internet (camera in control room recording results from monitor or projection). Owing to audio and video communication, results and calculation procedures can be explained to students watching the experiment.

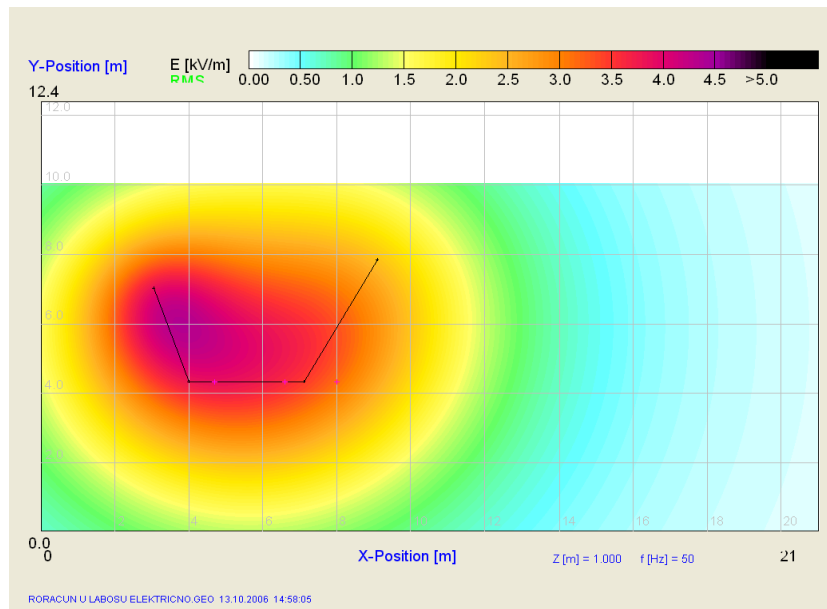


Fig. 8. Electric field in HV laboratory on 1 m height (5 kV/m), $E_A = 3,87$ kV/m, $E_B = 3,61$ kV/m, $E_C = 3,14$ kV/m

Calculation results are shown in Table I.

Table I: Calculation results (calculation points in area of professional exposure)

Measuring points	Rated voltage [kV]	El. field E_z [kV/ m]	Mag. induction B [μ T]	Limitary values satisfied
A	73,6	3,87	16,35	YES
B	73,6	3,61	9,50	YES
C	73,6	3,14	6,27	YES

3.3. Measurement of EM fields in HV laboratory

Voltage on the HV bus during measurements was 73,6 kV. The main source of magnetic induction in HV laboratory is testing transformer with open magnetic core and the main sources of electric field is bus, upper sphere of vertical sphere gap, HV resistor and metallic cap on top of testing transformer (“Fig. 9.”). Measurements are conducted in accordance with standard IEC 61786:2001. Electric field is measured on 1 m height above ground. RMS-value of electric field is measured in z axis. The human body can influence electric field measurements so measuring instrument was placed inside control room and connected with optical fiber cable to electric field probe and recorded by video camera. Magnetic induction is measured on 1 m height above ground.

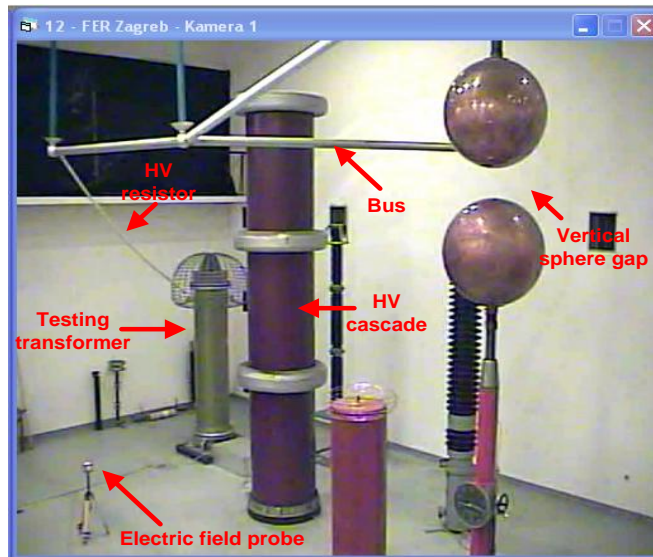


Fig. 9. View on HV laboratory from camera

RMS -value of magnetic induction is measured in x, y, z axis. Measurement results are shown in Table II. Calculation and measurement results show good coincidence.

Table II: Measurement results (measuring points in area of professional exposure)

Measuring points	Rated voltage [kV]	El. field E_z [kV/ m]	Measuring uncertainty [kV/ m]	Mag. induction B [μ T]	Measuring uncertainty [μ T]	Limitary values satisfied
A	73,6	3,6	$\pm 0,25$	18,02	$\pm 0,370$	Yes
B	73,6	3,2	$\pm 0,25$	8,38	$\pm 0,178$	Yes
C	73,6	2,8	$\pm 0,25$	5,53	$\pm 0,121$	Yes

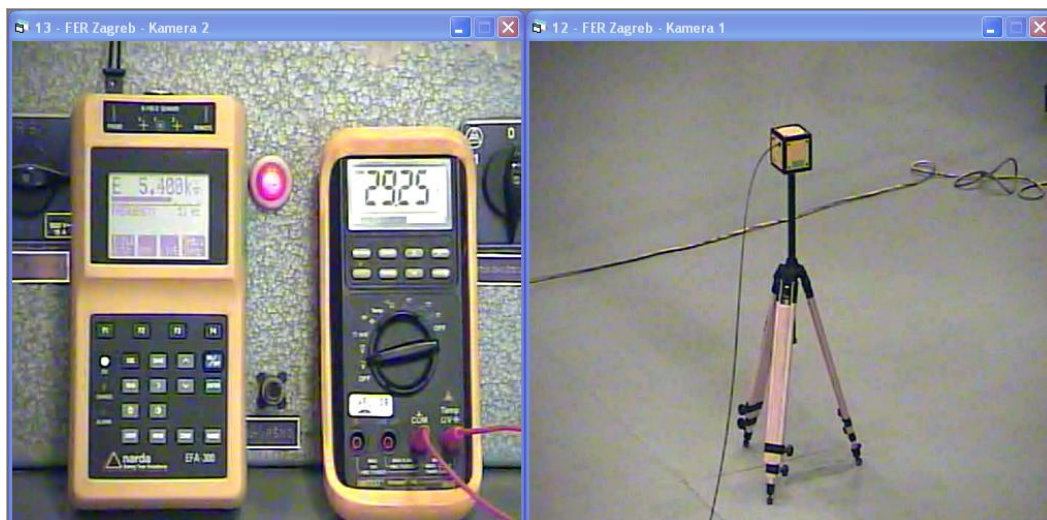


Fig. 10. Measuring instruments in control room and electric field probe in laboratory

Pictures from cameras “Fig 10.” show instruments in control room for measurement of electric field strength and voltage (left) and electric field probe in the laboratory (right).

4. CONCLUSIONS

Remote laboratory experiment can be used in following fields: share expensive laboratory equipment and experiments with other university or laboratory; distance learning for part time and remote students without time and distance limitation; enable students to use expensive laboratory experiments which they actually have no access; pre-experiment for undergraduates before they go to the actual laboratory. Although we concentrated on one experiment, the use of information technology can be applied to a wide range of experiments. Audio and video communications are valuable and give the remote user the feeling of being in the laboratory.

5. REFERENCES

- [1] Regulations for protection of electromagnetic fields. National Journal of Republic Croatia No. 204/03.
- [2] Narda: EFC-400 Magnetic and Electric Field Calculation, User's Manual, Berlin 2004.

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