New Laboratory Stand and Teaching Program – Transformer Monitoring System

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Abstract— **High voltage autotransformers are one of the most important and expensive devices in the power system. Hence, it is important to remotely control and monitor their condition. To meet current requirements of power companies it is essential to constantly improve functionality of autotransformer monitoring systems. The main aim in using such systems is to ensure continuity and reliability of the operation of autotransformers, reducing costs and economic losses associated with possible failures.**
This article presents the teaching program of the system which collects data from autotransformers. The system was realized in the Institute of Electric Power Engineering at Warsaw University of Technology and was installed in the Poręba and Bieruń substations.
The new laboratory stand was made to familiarize fifth year students with transformer monitoring system during power system automation classes. Students learn principles of high voltage transformer protections and realization of monitoring system using ADAM5510E/TCP microprocessor controller. There is a possibility to observe operation of electrical and mechanical protections of transformer during simulation of different signals from transformer simulator. Students are familiarized with: WAGO modules, which are used to control transformer cooling subsystem, data acquisition and visualization system based on ADAM5510E/TCP modules which gets data from various devices installed in transformer i.e. from on-load tap changer.

Keywords-educational laboratory stand, transformer monitoring systen; microprocessor controllers (key words)

I. INTRODUCTION

The paper is about the new laboratory stand and teaching program allowing our students (from Electrical Engineering Department) to know the operation principles and features of transformer monitoring system. Laboratory stand consists of three basic elements: simulator of transformer, monitoring system, data acquisition and visualization system. The basic element of the transformer simulator is a PC computer with relevant software for proper use of analog and digital outputs modules. To show operation of important devices installed on high voltage autotransformers, laboratory stand is equipped also with real protection relays, such as: Buchholz relay, pressure relief relay, shutter valve and rapid pressure rise relay. Other measuring equipment like bimetal thermometers, remote thermometer controllers, electrical thermometers, liquid level gauges, direction flow meters, and gas detector relays are made in the transformer simulator PC as binary signals, analog signals or Modbus protocol serial data pockets. Students learn the principles of operation and the aim of applying these devices on real objects. As was mentioned before the monitoring system is based on ADAM 5510E microprocessor controller. It collects data from transformer simulator or from external protective devices which are mounted on 19' rack. The microprocessor controller collects digital signals from protective relays, analog signals concerning temperatures, currents and data from all additional devices, which are connected to microprocessor controller via RS232 and RS485 ports.

Data acquisition system, which communicates with ADAM 5510E using Ethernet, is installed in second PC computer. It downloads data representing analog signals, states of digital inputs and from devices connected via RS485 and RS232 ports. The information is saved to SQL database and is used for reporting and visualization of autotransformer state. The laboratory stand familiarize students with four main applications, which are used in data acquisition system: application which reads data from ADAM5510E in Modbus/TCP protocol and write it to SQL database, application for communication with supervisory SCADA system and application for visualization of data. Additionally, students learn how cooling control system works. One of cooling system elements is based on microprocessor controller WAGO, which performs switching of leading group of radiators according to the program and indicates active radiators group. The last part of teaching program presents the on-load tap changer operation in which additional controllers ADAM5510/TCP and Qualitrol 509-300 are used. Data about measured active and reactive power, the position of LTC in BCD format is recorded in both devices and send to the PC computer for visualization and later analysis. Students learn: the work principles of on-load tap changer, what and how data about on-load tap changer behavior is send to supervisory monitoring system.

II. THE DESCRIPTION OF LABORATORY STAND

The laboratory stand is realized as a supervision system of 160 MVA autotransformer. The system consists of three basic elements:

- autotransformer simulator,
- monitoring system,
- data acquisition and visualization system.

Connections between these three elements are shown in block diagram of the laboratory stand which is presented in Error: Reference source not found.

The actual layout of devices mounted on a laboratory stand is shown in Error: Reference source not found.

It can be mentioned that additionally data acquisition and visualization system have serial port that can be connected to PC computer with installed SCADA system to show the exchange of data with such supervisory system.

A. *Autotransformer simulator*

The basic element of the autotransformer simulator is a PC computer, with software enabling to use analog and digital outputs cards. To show student real devices and increase possibilities of simulating various signals, the laboratory stand is equipped with protection devices, such as: Buchholz relay, pressure relief device and conservator shutter valve. It enables students to learn operation principles of real transformer protection.

Computer-based autotransformer simulator The main element which enables to simulate different operation states of autotransformer is a PC computer. It is equipped with analog and digital outputs cards. By using appropriate application, students can control these cards and simulate signals from autotransformer. Analog outputs cards, are responsible for such signals as: oil temperature measured in few points, ambient temperature, temperature and humidity of control cabinet and tap changer, currents and voltages on both sides of autotransformer. Using digital outputs, students can simulate states of operation of transformer protections, indicators, differential relay, thermal models etc. The application program controlling the states of binary outputs and levels of analog outputs have form of autotransformer drawing with relevant states and values presented on it, as can be seen in Error: Reference source not found in Error: Reference source not found.

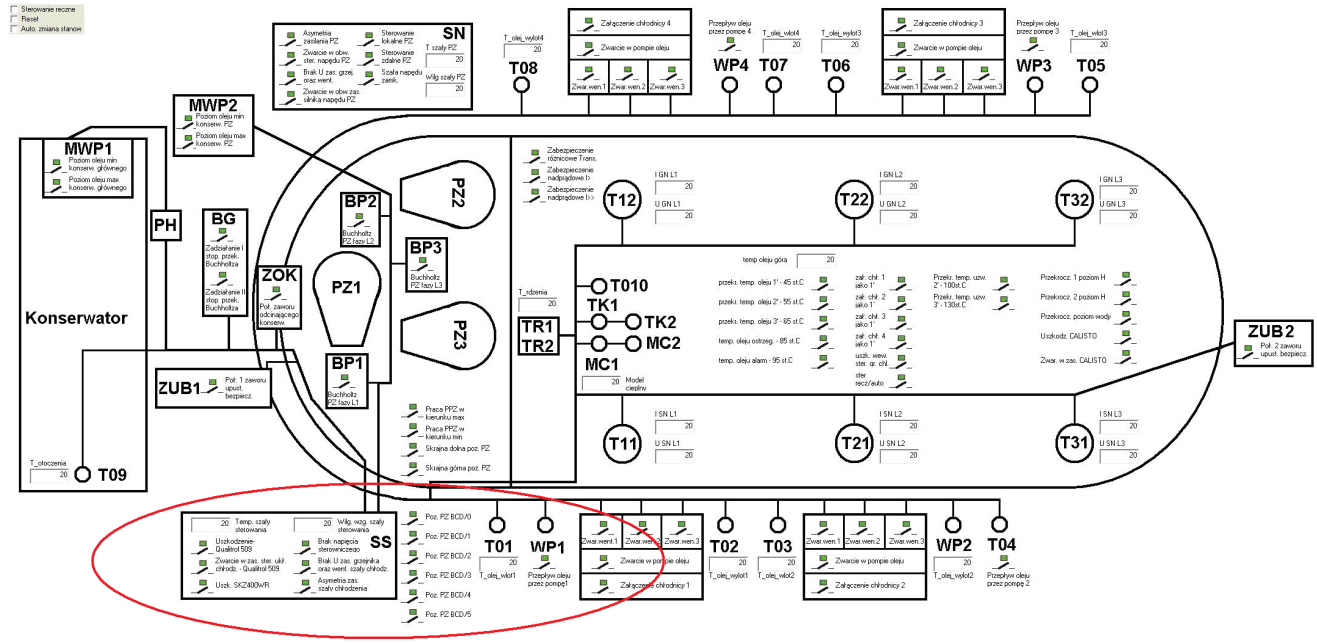

Figure 1. Arrangement of protection devices, sensors, indicators and wiring in the autotransformer simulating program

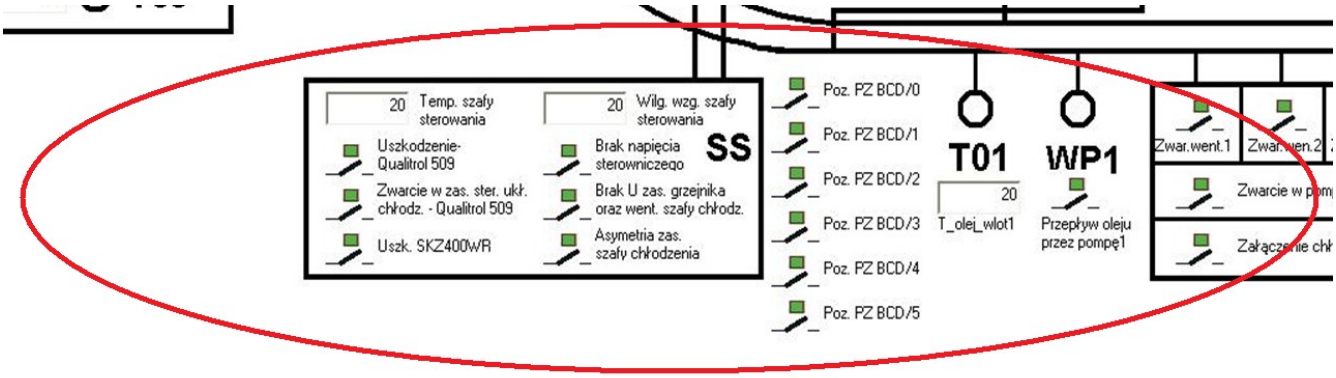

Figure 2. Fragment of simulating program screen with green check boxes to change the state of digital signals and text boxes allowing making changes to values of analog signals

Real power transformer protections

In addition to the method of simulating transformer signals, using simulator program, there is also a possibility to simulate digital signals from real transformer protections mounted on the laboratory stand, such as: Buchholz relay, pressure relief relay, shutter valve and rapid pressure rise relay.

The actual layout of devices mounted on a laboratory stand is shown in Error: Reference source not found.

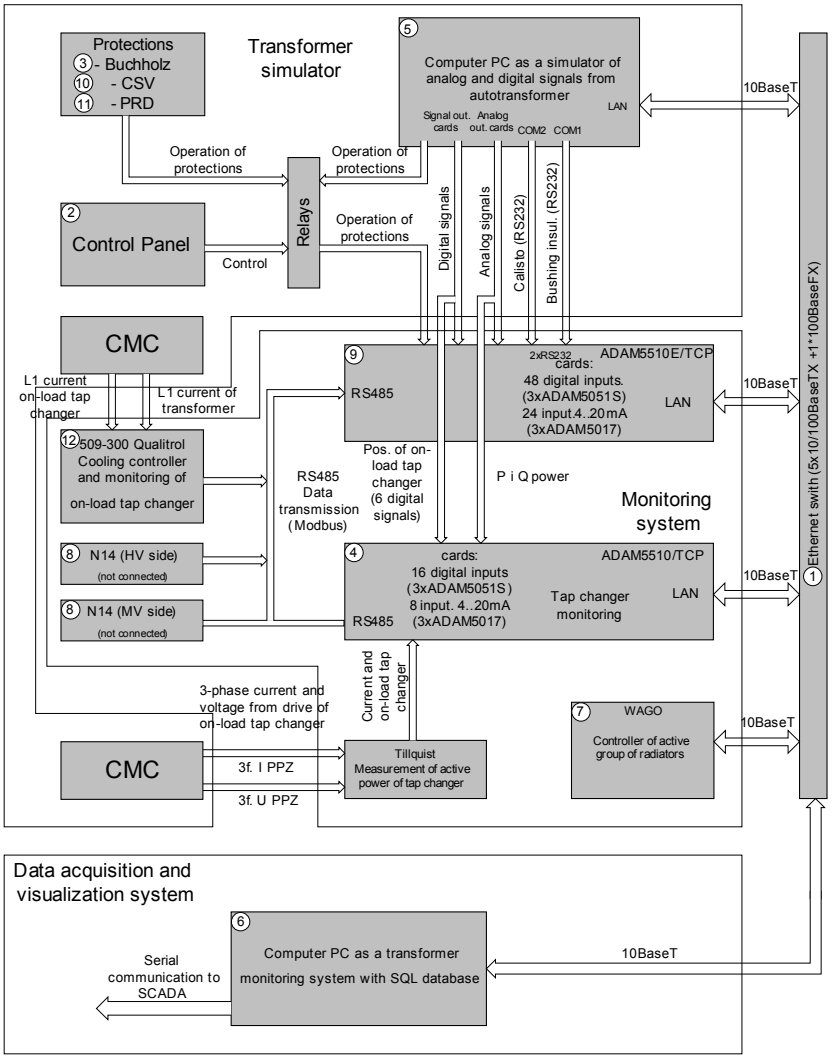

Figure 3. Block diagram of autotransformer simulator and monitoring system (numbers in circles correspond to numbers of devices presented in figure 3)

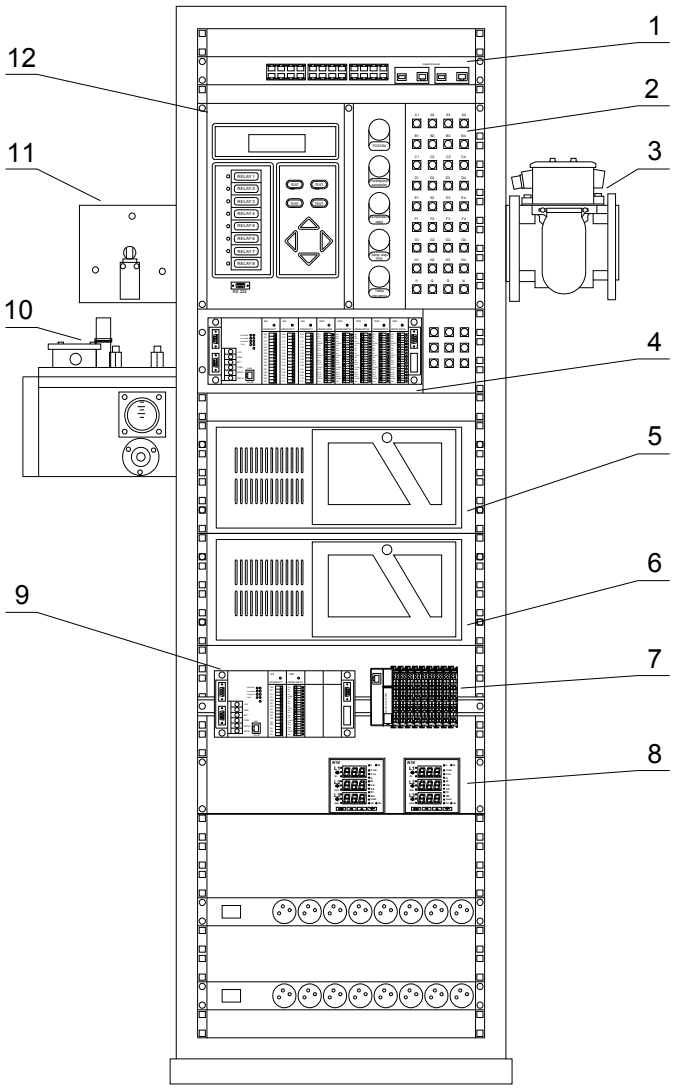

Figure 4. The front view of laboratory stand, 1 – Ethernet switch, 2 – control panel, 3 – Buchholz relay, 4 – ADAM5510E/TCP controller (monitoring), 5 – PC computer, autotransformer simulator, 6 – PC computer with SQL database, 7 –WAGO controller of active group of radiators, 8 – N14 (measurement of currents, voltages and power of autotransformer), 9 –ADAM5510/TCP controller of tap changer, 10 – conservator shutter valve, 11 – pressure relief device, 12 – Qualitrol 509 controller of radiators

B. Monitoring system

The monitoring system, which collects data from autotransformer simulator or from external transformer protections (which are mounted on the laboratory stand), is based on ADAM 5510E/TCP controller. The controller collects digital signals from protection devices, analog signals (temperature, current etc.), and also signals from additional devices, which are connected via RS232 and RS485 ports, such as:

- 509-300 Qualitrol – radiators and tap changer controller,
- N14 – monitoring of current, voltage and power on both sides of autotransformer,
- Calisto – monitoring of water and dissolved hydrogen in oil,
- devices for measurement of tgδ and capacity C which are installed in bushing insulators,
- monitoring system of tap changer.

ADAM 5510E/TCP controller

The controller consists of three analog inputs card (ADAM-5017), which collects data about: oil temperature in upper layer of transformer, temperature at inlet and outlet of each of the four radiators, ambient temperature, temperature and humidity of control cabinet and tap changer, currents and voltages on both sides of the autotransformer.

Five digital inputs cards (ADAM5051S) are installed to collect data about operation of protection devices, excess of temperatures, asymmetry or loss of power supply of each controllers etc. All information is available by MODBUS IP protocol using Ethernet connection. Data is send via Ethernet to the SQL database. The view of controller is presented in Error: Reference source not found.

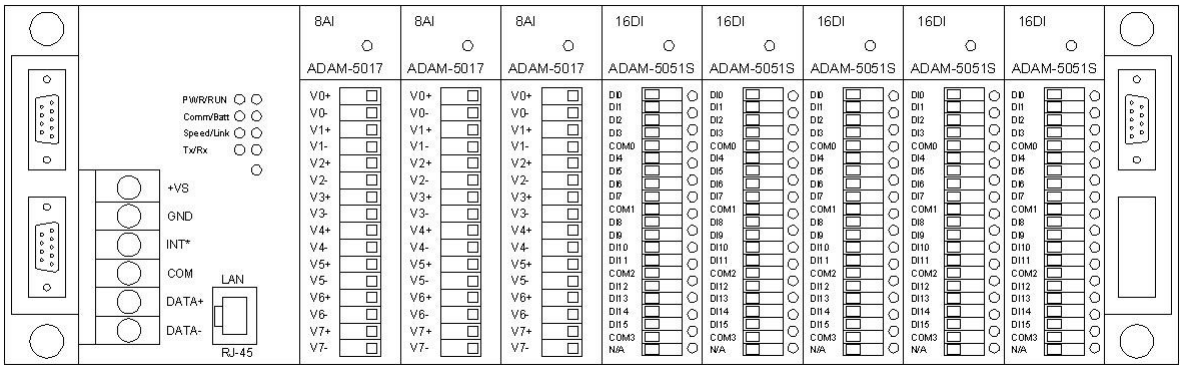

Figure 5. ADAM5510E controller

ADAM 5510/TCP - controller of tap changer

This is an additional controller, which has one analog inputs card and one digital inputs card. The microcontroller is working in the system as recorder that collects data from a tap changer, which can be simulated by application of the autotransformer simulator or a CMC (Omicron) tester.

Values of active and reactive power which are sent to analog inputs and digital signals represent actual position of a tap changer and its operation, are simulated by simulator application. The application automatically starts a process of simulating of active and reactive power on analog outputs (as currents of 4..20mA range), after change is made in position of a tap changer. Then the process of recording simulated signals in ADAM5510/TCP controller begins. After couple of seconds (set as parameter in controller during the setup process) controller download recorded values in a form of two Comtrade files to the ftp server installed in data acquisition system PC (which will be described later).

Alternatively the laboratory stand is equipped with Tillquist transducer. This is a transducer of active and reactive power, which is consumed by drive of tap changer. The transducer is mounted on a DIN bus on a rear side of the laboratory stand and there is a possibility to connect the transducer with CMC tester, which simulates currents and voltage during operation of tap changer. Is such configuration real 3 phase currents and voltages are converted in transducer to instantaneous values of active and reactive power scaled in a form of 4-20 mA standard. This configuration allow ADAM5510/TCP controller to record and send to ftp server power curves generated by Tillquist transducer reflects 3 phase signals simulated in CMC tester.

Data acquisition system

The data acquisition system is installed on the second PC computer, which communicates with ADAM5510E/TCP controller via Ethernet. PC computer collects data about analog and digital outputs and other devices which are connected via RS485 and RS232 ports. The data is stored in SQL database, which is also a source of information for reports and visualizations. The whole data acquisition system is mainly realized by four applications, which are discussed in following chapters.

SQL database

SQL database is a basic application that runs automatically at system booting process. The database enables to store the whole history associated with operation of digital and analog outputs, data from Calisto or from bushing insulators. The database stores information about datasheets of autotransformers, passwords and access permissions of users.

Reading data from ADAM5510E/TCP

This is the next application which is used for monitoring system support. The program is running “in the background”, and is used for communication with ADAM5510E/TCP controller in Modbus/TCP protocol. It uses Ethernet to download all information from the controller, after change of one of state or after a certain period of time. Information is automatically saved to the SQL database.

Monitoring

The monitoring program is used to visualize data stored in SQL database. The view of the main window of *Monitoring* application is shown in Error: Reference source not found. This figure presents information about actual load of autotransformer, which is calculated using values from CTs. Error: Reference source not found also presents information about oil temperature, ambient temperature, state of tap changer and bushing insulators. Messages about operation of protection devices and other devices mounted on the transformer, are presented on the bottom of the figure 6.

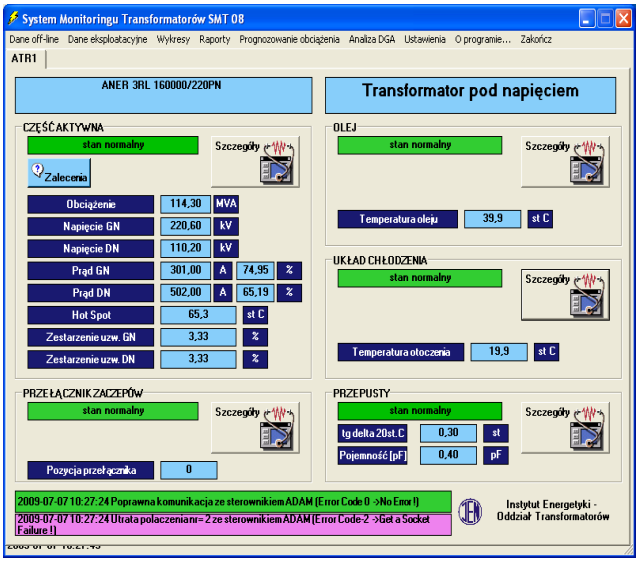

Figure 6. View of the application *Monitoring*

III. PROCEEDING OF THE EXCERCISES

Exercises which are realized by students during classes are presented below. The classes are divided into three parts.

- monitoring system,
- operation of protection devices,
- operation of the system which controls operation of radiators.

A. *Monitoring system*

This part aims to familiarize students with monitoring system.

Autotransformer simulator

- run simulator program,
- open two windows with simulator of Calisto device (used for measurement of dissolved hydrogen and water in oil) and with simulator of tgδ and capacity C of bushing insulators measurement,
- by clicking on proper icons near protection devices and indicators, students can simulate their operation, which is indicated by change of color from green to red,
- analog values are entered in the appropriate windows,
- operation of particular digital inputs are shown on ADAM5510E module in lighting of Green LEDs.

Monitoring system

- run CPU, where software with monitoring system and SQL database is installed,
- run three programs, which enables to support data acquisition and visualization system,
- in the task manager, make sure that the program works correctly, and reads data into an SQL database,
- simulate operation of few protection devices or indicators in the simulator program and observe the result in monitoring program. The same, students have to do with analog signals associated with i.e. temperature or currents.

Operation of protection devices

The exercise aims to familiarize students with the architecture and principles of operation of protection devices, which are used in high voltage transformers. In the laboratory stand there are installed such protections like Buchholz relay, pressure relief device and conservator shutter valve. All these protection devices can be started manually to operate and their operation can be observed in monitoring program.

Preparation of the laboratory stand

- run the autotransformer simulator and monitoring system,
- in the moment of simulating signals from protection devices there will be a message in the monitoring system about pickup of Buchholz relay and conservator shutter valve. This is a proper operation of these devices, because they are in abnormal state all time, due to lack of oil.

Operation of Buchholz relay and conservator shutter valve

- students have to check the Buchholz relay and conservator shutter valve construction and principle of work,
- they should change the state of Buchholz relay to the normal – inactive state and then force the relay to operate due to lack of oil,
- in order to cause these protection devices to dropout, students have to move floats of protection devices,
- students have to observe results in the monitoring system.

Operation of the system which controls radiators

The exercise aims to familiarize students with capabilities of the digital system which controls operation of radiators. WAGO controller is used in the exercise and its operation is indicated by diodes on control panel.

Controlling of radiators using a simulator

- run autotransformer simulation program,
- in simulator program students have to change oil temperature in upper layer by
- entering value from -30 to 170˚C,

- in simulator program, the following levels of oil temperature (45, 55 i 65˚C) should become active,
- students have to observe operation of WAGO device, activation of cooling levels and switching on radiators with different time delay.

Control of radiators operation using Qualitrol 509

- using potentiometer marked as „oil temperature" on control panel, students have to change oil temperature (potentiometer replaces PT100 sensor), which is indicated by Qualitrol 509,
- the device will switch on next levels of oil temperature based on excess of measured temperature. The information is send to WAGO device,
- students have to observe operation of WAGO device, this means switching on following cooling levels and starting operation of radiators with different time delay.

D. *Operation of the system which controls operation of radiators*

The exercise aims to familiarize students with principles of operation of the data acquisition system which collects information about on-load tap changer. Data from ADAM5510/TCP controller, are send to the virtual server for later analysis.

Measurement system using ADAM 5510/TCP – controller of tap changer

- run the simulator and monitoring program ,
- set any position of on-load tap changer, in BCD code, in the simulator program,
- generate voltage and current consumed by tap changer during its work using CMC tester,
- recording of active power using ADAM5510E (controller of tap changer) begins after simulation of position change of a tap-changer in the simulator program,
- ADAM5510E controller will automatically send a file to the server with recorded values of active and reactive power and position of a tap changer.

Measurement system using Qualitrol 509

- students have to generate current in single phase of the tap changer and in single phase of the transformer using CMC tester,
- using potentiometers which are placed on a control panel students have to set a tap-changer position,
- students have to observe data from Qualitrol 509 on its LCD panel and in its dedicated program.

IV. CONCLUSIONS

The laboratory stand enables to familiarize students with monitoring system of high voltage monitoring system.

Microprocessor controllers like ADAM5510E/TCP and other devices i.e.: Calisto, Qualitrol 509, Tillquist give opportunity to familiarize students with modern transformer monitoring system. Simultaneously discussing the theoretical issues combined with the use of real devices allows for a better understanding of the theory and practice relating to monitoring of transformers.

The laboratory stand will be developed further with the development of new methods of transformer monitoring. It is also planned to adapt existing solutions to the IEC 61850 communication, as well as realizing of the entire monitoring system using WAGO controllers.

REFERENCES

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