Design and Construction of a Laboratory SCADA System

Yulian Rangelov[1], Aleksandar Avramov[2] and Nikolay Nikolaev[3]

Abstract – **During the last decade, the industry has become very "digitalized". Industrial, commercial and domestic electricity consumers are becoming part of the digital revolution. In the near future even the light bulb is expected be able to control and monitor itself. The electric power engineering is also subject to digitalization on a global scale. Every electric power facility is either fully or partly equipped with automated controls, numerical relay protections, multifunctional digital measurement devices and other intelligent electronic devices. The energy industry has been looking for years to find a universal approach to deal with the unification of substation automation and communication devices manufactured by different companies. The standardization institutes in Europe and America have developed the common standard IEC61850, which allows the integration of the communication, the information, the control and all other subsystems.**

This paper is dedicated to the design and development of electronic system for supervision, control and data acquisition (SCADA) of an operational switchgear. It briefly presents basic aspects regarding the development of a SCADA system for a realistic and fully-operational switchgear in the laboratory "Power Plants and Substations" at Technical University – Varna.

Keywords – **Electric Power System, substation, SCADA, standard.**

I. Introduction

Department "Electric Power Engineering" in Technical University of Varna has a unique laboratory named "Electrical Power Plants and Substations", which is built just like real and operational switchgear [1]. The busbar system is single and is divided into three sections (fig. 1), located in two neighboring rooms (area approx. 120 m^2) [2]. Two remotely-controlled synchronous generators are connected to the first section. They can be synchronously connected to the power grid or to each other. On the control panel, there are control buttons, signaling lights and various measurement equipment to supervise the operational variables. The turbines are replaced by variable-speed DC motors, which are powered by another motor-generator aggregate, installed in the same room.

Two-power transformers are connected to the second section and represent a physical implementation of a substation. The substation feeds different consumers – two rotary fans with AC motors, a complex *R-C* load and a complex computer-controlled active power load.

Section 3 is a physical implementation of a classical indoor 10 kV switchgear which practically operates at 0.4 kV. There are three separate cells – laboratory switchgears (LSG) – which are powered by this section. A circuit-breaker with motor-spring mechanism, model SCI4, along with a disconnector are mounted in LSG1. A discrete active power load is fed by a vacuum circuit-breaker (model Tavrida), located in LSG2. LSG3 is a measurement field and has different types of voltage transformers connected to it. All three sections are interconnected by circuit-breakers and disconnectors.

The switchgears of section 1 and 2 are designed to provide operational flexibility, i.e. the generators can be connected directly to the power grid or operate in island mode, while energizing complex loads in the substation.

The laboratory is connected to the external grid by two cable feeder (W1 and W2) which originate from the near-by transformer station of the faculty. There are several digital multifunctional power meters ABB model DMTME, connected to main nodes of the lab's switchgear. There is a total number of 23 remotely-controlled circuit-breakers, 24 disconnectors and 5 power switches.

The following report presents the design and construction of an automation SCADA system, which allows to control and supervise the switching devices and to observe important electrical variables related to the operation of the switchgear (fig. 1). Considering the available resources, the SCADA system should provide graphical user interface (GUI) which allows local or remote control via the web. The control and signaling functions are performed by a local controller based on the Arduino Uno [3] open electronic environment and specifically designed input-output interface circuit boards. The operational data, measured by the ABB DMTME devices is collected via RS485 communication and Modbus protocol, and the converted to LAN interface by an ABB CUS device are sent to the computer station. The input-output data of the local controller can be transmitted over the internet outside the laboratory. The computer interface is developed in Matlab.

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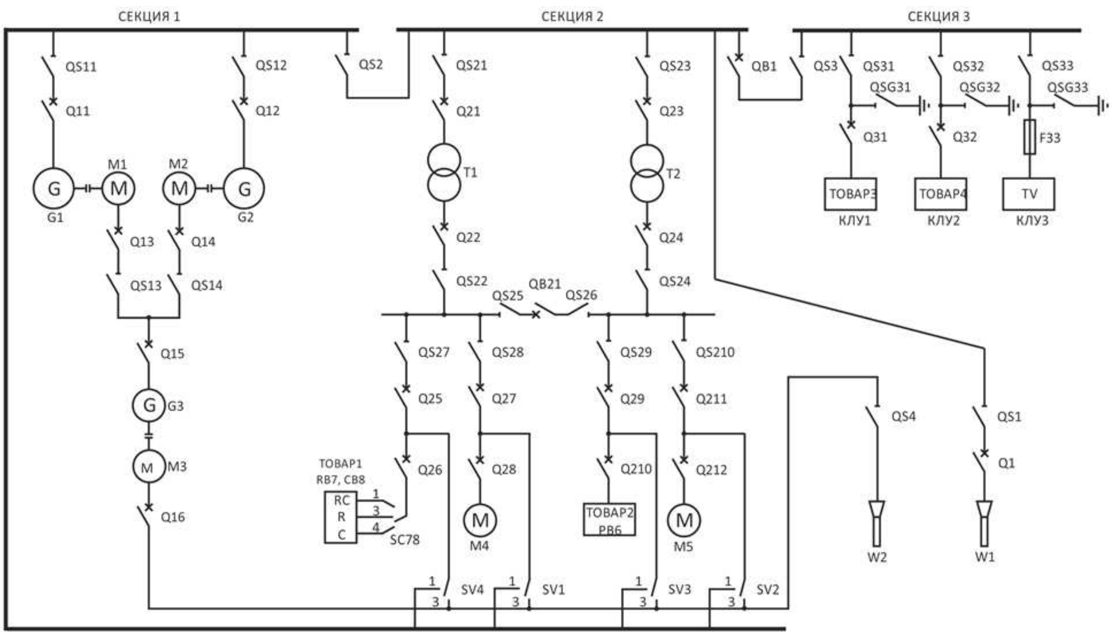

Fig. 1. Single-line diagram of laboratory "Electrical Power Plants and Substations

II. Design of an Automated System for Control and Supervision of laboratory "Electrical Power Plants and Substations"

A. General Concepts

The approach to build an automated control system of the laboratory is based on the Bulgarian regulations and standards [4, 5]. What is built is the so-called informational control complex with a computer system for real-time telecontrol, telesignalling and telemeasurement. This is basically a system for data acquisition, supervision, data processing and control of switching devices – SCADA [4].

A telecontrol system is developed for switching devices which are technically available for remote control. The switch-on and –off commands are released via individual general-purpose relays for each individual switching device.

The telesignalling provides information about the state of the switching devices and thus gives valuable information about the system's topology. The device state is observed be means of its own auxiliary contact. If there is no available auxiliary contact, additional relay is connected to provide more contacts.

The telemeasurement system transmits information about the important electrical quantities.

The project documentation complies with the standards and regulations regarding the symbolic and numerical designations [6].

To provide for clear presentation of the paper's ideas, it is necessary to depict all electrical diagrams for control and signaling of every switchgear component. However, these diagrams are too many and cannot be presented due to the restricted length of this report.

The local controller is based on Arduino Uno board, extended with an Ethernet shield, four custom-designed boards with 16-inputs and four boards with 16-outputs, main board that controls the I/O of the other boards. All measurement units are connected in a RS485 network, which is accessed from the computer via TCP/IP gateway ABB CUS. All the boards are located in a dedicated SCADA panel.

The Arduino board and the I/O boards have independent 5 V power supplies. The TCP/IP gateway is powered with 220 V via a miniature circuit-breaker.

In the SCADA panel there is additional 24 V source which supplies the general purpose relays.

Fig. 2 depicts the main structure diagram and the connections between the local controller and the other boards.

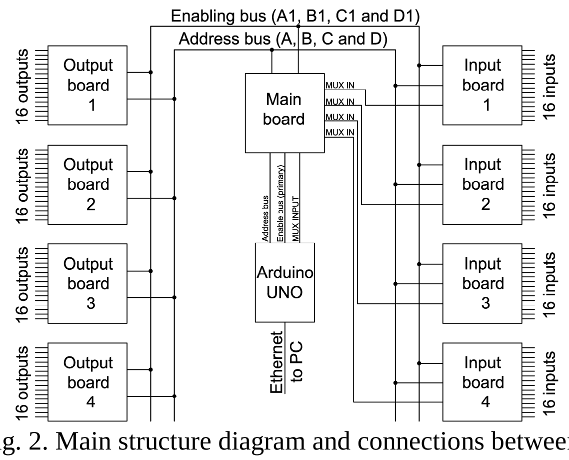

Fig. 2. Main structure diagram and connections between the boards

B. Main Board Design

Several of the Arduino outputs form an address bus (A, B, C and D), an enable bus (A1, B1, C1 and D2) and an input bus (MUX IN) which transmits the state of the switching devices to the Arduino board. The address bus sets a binary code to choose among the inputs or outputs of the demultiplexors (DEMUX) or multiplexors (MUX), chosen by the enable bus.

C. Input Boards Design

Every input circuit-board has a TTL DEMUX chip SN74150J and an EL817 optocoupler. The DEMUX collects the binary signals from the optocoupler. The optocouplers have independent power supply in order to avoid the penetration of high potentials in the electronic part of the SCADA system.

D. Output Boards Design

Each output boar consists of one SN74154N MUX chip, three SN7404N inverter chips, 16 relays HM4100F and two ULN2803A relay drivers. Via the address and enable bus, the Arduino board chooses which MUX output it will activate and the respective relay will either switch ON or OFF the device. The activation command holds for 0.5 seconds to make sure that the tripping or closing action will be successful.

A dedicated software is written for the Arduino platform. The Arduino itself is a bridge between the I/O boards and the Matlab computer software. The diagram of the Arduino's algorithm is depicted in fig. 3. The code starts with initialization of the Arduino's inputs, outputs and the TCP/IP communication with Matlab. Then the program checks whether Matlab is connected. If yes it reads the variable *matlabMessage* and if it is equal to 255 then the Arduino reads all the inputs and sends information about the state of the switching devices to Matlab. If the message is less than 255, then, depending on the number code, the Arduino decides which output relay it activates for 0.5 seconds.

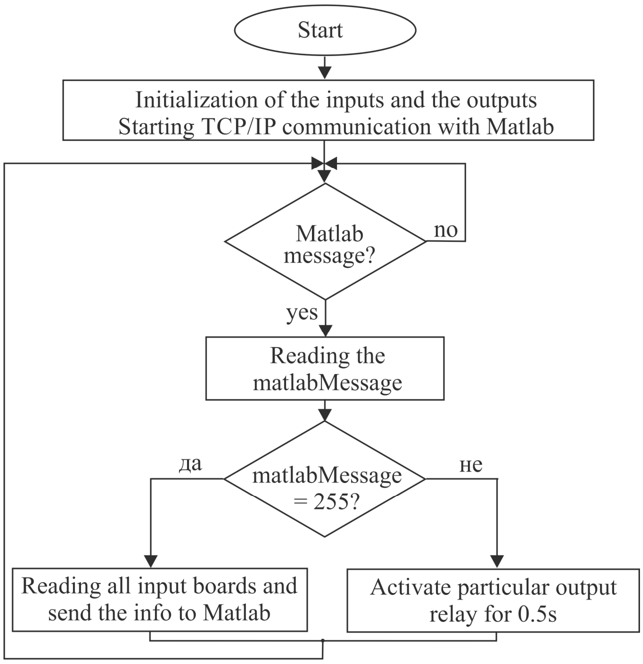

Fig. 3. Algorithm diagram of the Arduino board

Fig. 4 depicts the algorithm diagram of the Matlab program. It starts by loading the graphical user interface. At the same time the configuration file is loaded and the objects from classes *DMTME* and *SWITCH* are created. Then follows the setup of the communication with the Arduino board and the measurement devices. If there is a command to stop the SCADA software, the TCP/IP ports are closed and the connection is terminated. Next, the program checks if the user wants to switch a device. If *yes*, then a number code less than 255 is sent to the Arduino. After that, code 255 is sent to tell the Arduino to read all input boards and to return information about the status of the switching devices and the GUI is refreshed. Finally, the DMTME measurement devices are read and the GUI refreshed again.

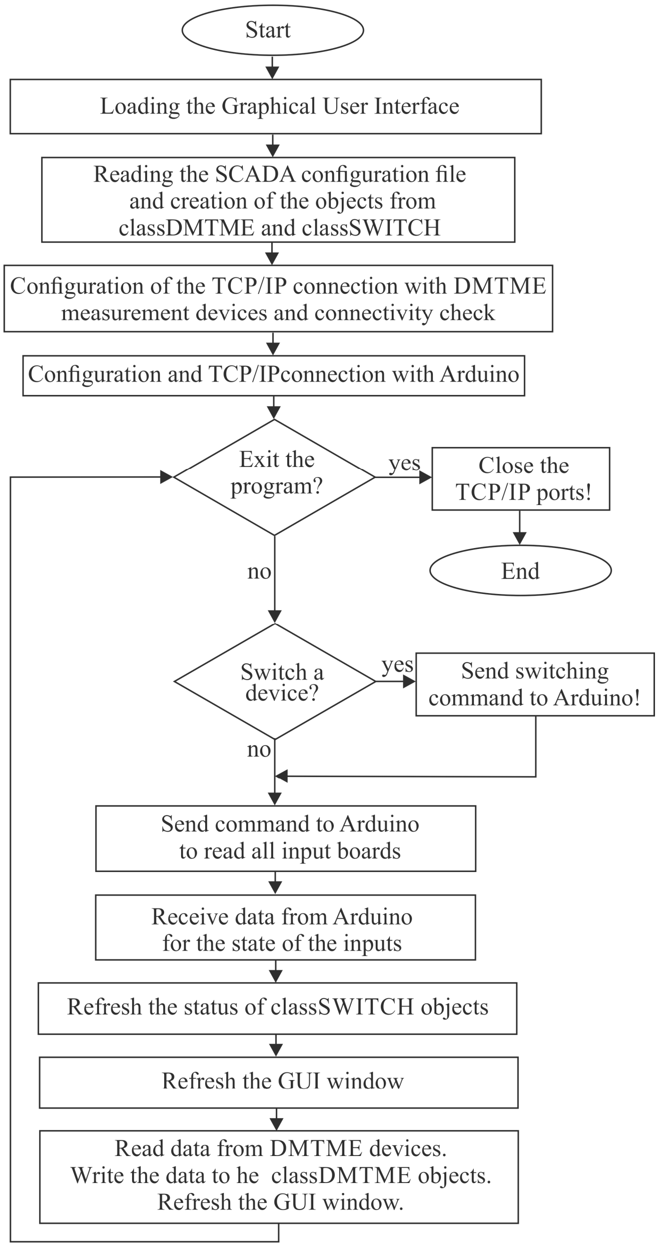

Fig. 4. Algorithm diagram of the Matlab computer program

Fig. 5 depicts the local controller and the final look of the SCADA panel.

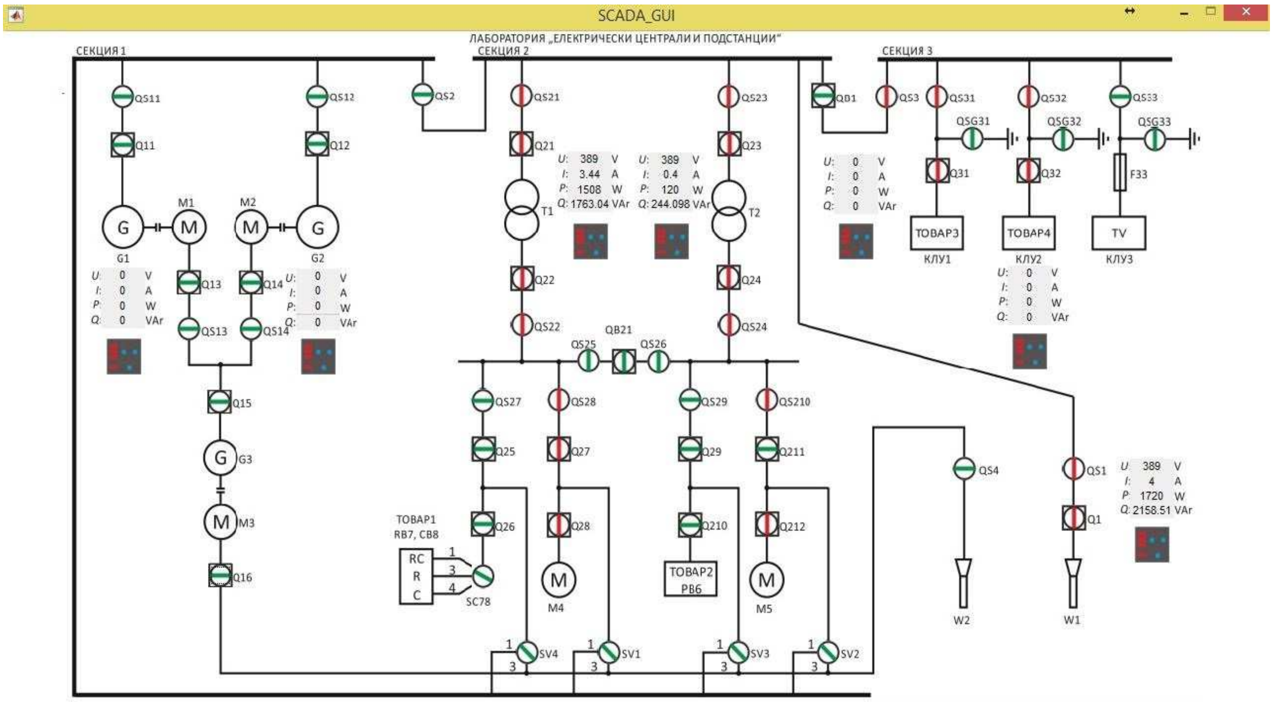

Fig. 5. Graphical User Interface of the SCADA

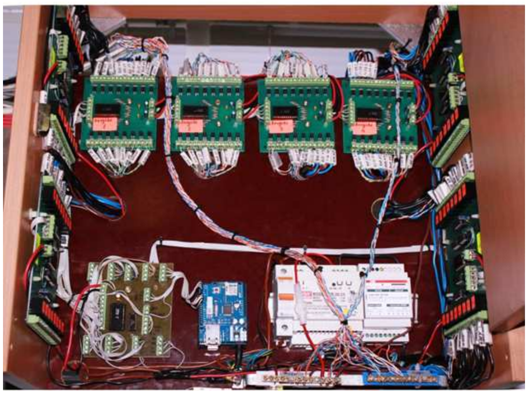

Fig. 6. Local controller in the SCADA panel

The GUI of the SCADA system is presented in fig. 6. As a first step, it is developed just enough to test all control, signaling and measurement functions. The object-oriented programming approach is used to make the software easily maintainable and extendable. The device symbol turn red when it's ON and green when it is OFF to make the visualization perceivable. The entire single-line drawing is depicted in single GUI window. Display panels are placed at the measurement points to allow the user to keep track of the voltage, the current and the power.

III. Conclusions

Here we draw the main conclusions of the paper:

1. Based on thorough study on existing internet reports, national regulations and standards an intelligent electronic platform is created, which we call a local controller. It implements all the inputs and output to interface the switching and measurement devices which are part of existing switchgear and makes connection to the operator's computer station.
2.
3. Approximately 1000 meters of cables are used to connect every component of the switchgear (83 devices) to the local controller in laboratory "Electrical Power Plants and Substations".
4. A human-machine interface is created to observe and control the operation of the laboratory switchgear.
5. The paper shows that it is possible to build a low-cost fully-functional SCADA system with existing open-source microcontrollers, such as Arduino. The required devices and equipment is worth approximately 500 euro.

Acknowledgement

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