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# Application of Electrical Substation, Ring Topology versus Star Topology

Cosmin-Ionuț Toma, Mihaela Popescu, Mihăiță Daniel Constatinescu, Popa Ion Cristian
University of Craiova, Faculty of Electrical Engineering, Craiova, Romania,
ctoma@em.ucv.ro, mpopescu@em.ucv.ro, mconstatinescu@em.ucv.ro, cristip77@yahoo.com

***Abstract* – In order to solve the problem of analyzing network performance of SCADA (Supervisory Control And Data Acquisition) system communication of power grid in effective and practical way, this paper proposes to change the star topology with ring topology, specifically method rapid spanning tree protocol (RSTP), in an electrical substation. The paper discusses about SCADA architecture, main equipment like remote terminal unit, intelligent electronic device, server, server network time protocol, HMI (human machine interface), router and their role in the electrical substation. Also, the levels of the command hierarchy in the SCADA system are discussed. Each level has certain tasks set for the optimization and reliability of the electrical substation. The data flow describes the types of information that are transmitted between hierarchical levels. In the last part the paper the topologies of the system are described.**

**Cuvinte cheie:** *topologie SCADA, arhitectura SCADA, Rapid spanning tree protocol, topologie stea, flux de informații, stație electrică.topologie inel.*

**Keywords:** *SCADA topology, SCADA architecture, Rapid spanning tree protocol, star topology, data flow information, electrical substation, ring topology.*

## I. INTRODUCTION

SCADA is a technology which provides the ability to collect data from one or more remote equipment and transmit a limited set of control instructions to this equipment. With SCADA it is no longer necessary for an operator to stay or frequently inspect those remote controlled locations if they are working normally.

SCADA includes the operator interface and the handling of concrete application data, but it is not limited to that. Some manufacturers offer software packages that they call SCADA and although these are suitable to operate as parts of a SCADA system, as they provide communication links with other necessary equipment, they are not a complete SCADA system [1].

In [2], the authors presented architecture topologies for substation automation system applications with protection, control, monitoring data flows and their performance requirement.

A modern SCADA system (hardware and software) with specific characteristics for electrical substations is presented in [3].

Communication network is a fundamental element in all electrical substation and network performances can have important role on the control process. The automation using IEC 61850 communication protocol is described in [4], [5], [6].

This paper is organized as follows. Section II presents the SCADA architecture, including the main components. The next section is dedicated to the command hierarchy of in the SCADA system. In section IV, the data flow is introduced. The presentation of the star topology is the subject of section V. It is followed by the presentation of the ring topology. A case study with the implementation of the rapid spanning tree protocol in an electrical substation from Romania is described. Finally, some conclusions are formulated.

## II. SCADA ARHITECTURE

Although the equipment components of the entire SCADA system is located in various locations, they are connected as a unified whole, a single system.

As such, the SCADA system concept approach is unitary, not limited to a specific piece of the system.

The SCADA system are presented in Fig. 1 with next components [12]:

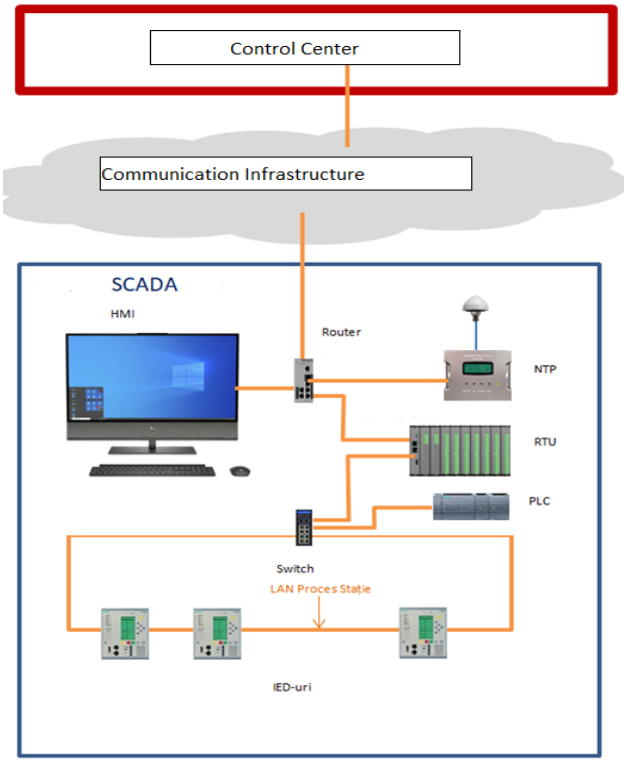


Fig. 1 A typical SCADA system architecture.

- Server
- Router

- Server NTP
- HMI
- Remote Terminal Unit (RTU)
- Intelligent electronic device (IED)
- Control Center
- Communication infrastructure
- PLC

Servers are used in SCADA systems for multi-tasking and real-time database functions. It is responsible for gathering and handing data, providing trends and diagnostic information regarding the operation. Depending on the features, there may also be options to set up predictive maintenance schemes, logistic information and other option [7].

A router which meets the cybersecurity requirements for this type of connection is used for the remote connection to Control Center. The router has a firewall implemented and makes an encrypted VPN tunnel connection to the remote correspondent equipment.

A human-machine interface (HMI) is a user interface that allows the human operator to interact with a system. HMIs are used all over the world in various technologies, ranging from smartphones to power plants.

The HMI running on the SCADA server connects to the SQL database managed by that server.

PLC (Programmable Logic Controller) is still one of the most widely used control system in industry. As the needs to control more devices in the electrical substation, PLCs became distributed and systems became smarter and smaller [8].

To apply the time stamp to all telegrams in the system, a time server is installed which will transmit time signals to the entire system via the network time protocol (NTP). Time stamp resolution applied to all events is 1ms.

The GPS signal will be received by an external antenna, connected with a coaxial cable to the respective time server. This equipment is installed in the SCADA cabinet and is connected to the central system through Ethernet switches. It will provide the necessary NTP telegrams for the synchronization of all SCADA equipment.

Communication infrastructure represents the nodes of a SCADA system which are interconnected through communication buses, constituted in data transmission networks, depending on the surface they cover. The procedures and standard interfaces used are called local networks (LAN- Local Area Network) or networks extended (WAN- Wide Area Network).This equipment related to a certain technological process or a management center that occupies a relatively small area (for example a building or a group of buildings) are interconnected through LANs that use shielded cables with twisted wires as a data transmission medium, coaxial cables or fiber.

The transfer is made through the telecommunications networks based on the generally accepted rules that form the so-called telecommunications protocol. This protocol specifies receiver selection modes, command codes, transmission rates, structure and timing of transmitted messages, etc.

Intelligent electronic device use numerical measurement techniques. Fully digital signal processing provides high measurement accuracy and long-term consistency.

Digital filtering techniques and dynamic stabilization of the measured values ensure the highest degree of security in the determination of protection responses. Device errors are quickly recognized and indicated by integrated self-monitoring [9].

Remote terminal unit is a stand-alone data acquisition and control unit, generally microprocessor based, that monitors and controls equipment at a remote location. Its primary task is to control and acquire data from process equipment at the remote location and to transfer this data back to a central station. It generally also has the facility for having its configuration and control programs dynamically downloaded from some central station.

The Control Centre is the dispatcher's work point for operating SCADA system.

## III. Command Hierarchy of in the SCADA System

The command to the primary equipment can be initiated from multiple locations such as local panel, BCU/BCPU, HMI station, control center, depending on the position chosen for the LOCAL/REMOTE switch. The command hierarchy of primary switching equipment can be illustrated by means of Fig. 2 [12].

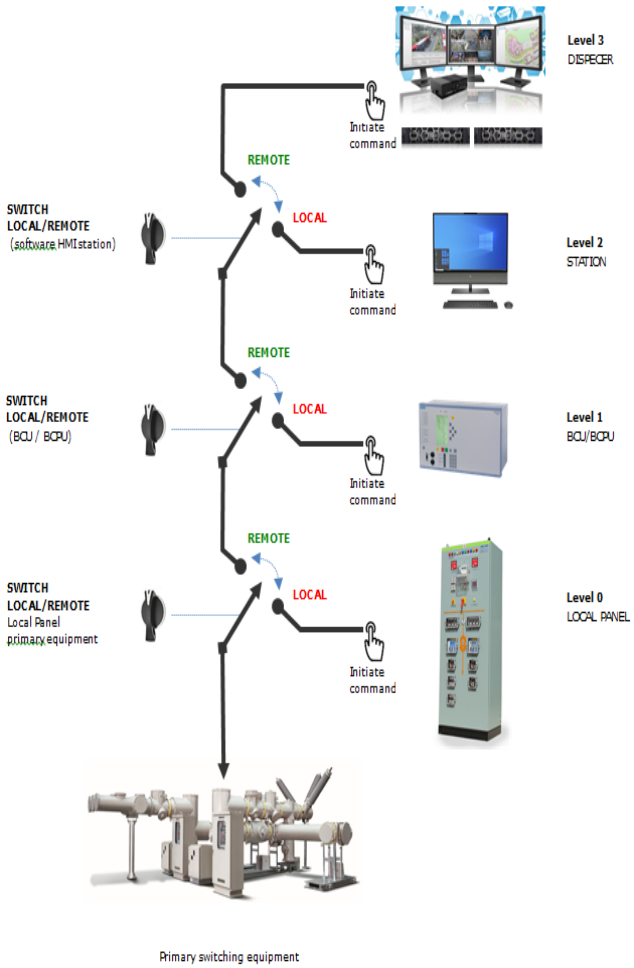


Fig. 2 Hierarchy of command in the SCADA system.

The interconnection between the components of the SCADA system is subject to a philosophy based on four hierarchical levels of the SCADA architecture.

Monitoring of states, measures, alarms will be able to be found and accessed at any of the four levels mentioned.

Also, the commands of the switching equipment is done independently, but not simultaneously from the four levels:

• Level 0 – PROCESS;
• Level 1 – FEEDER – through the BCUs or BCPUs installed in each high voltage or medium voltage;
• Level 2 – STATION – from the operator interface (HMI) installed in the station;
• Level 3 – CONTROL CENTER – from the SCADA dispatcher system – via a remote connection.

The selection between hierarchical levels is made by using the Local/Remote switches (physical or software) provided for this purpose. Besides the three command levels, in order to illustrate the system philosophy, we consider level 0 as the technological process level, i.e. the primary equipment [3].

- Level 0 – PROCESS

At this level, there is the equipment that directly participates in the production, transport and distribution of electricity, forming the group of primary equipment (separators, switches, current transformers, voltage transformers, etc.).

- Level 1 – FEEDER

This level includes all the digital devices intended to ensure the signaling of alarms and measures from the process equipment, the implementations of the protection functions as well as the control of these equipment where appropriate. In this level, there are different types of digital relays (IEDs) that have specific inputs/outputs/analog for voltage, current, signaling, alarms, protection functions and controls, as needed.

- Level 2 – STATION

At this level, the station RTU collects all the signals from station via the communication network (LAN Process).

Also, through the same LAN, the process can be received for the primary equipment from hierarchical levels higher than the feeder equipment BCU or BCPU respectively HMI station or Control Center.

- Level 3 – Control Center

At the level of the dispatcher, there is the Control Center SCADA system interconnected with the Station SCADA system.

## IV. The Data Flow

In the SCADA system, the information is transmitted on several flows, in a predetermined way, making possible analysis or diagnosis easy. There are three information flows:

• monitoring information – the signals from the process (signals, alarms, etc.). This information is the most numerous and is transmitted from the process to the Control Center – respectively from level 0 to level 3.

• control information – command signals. This information is less and is transmitted from the operating interface (HMI, Control Center, Station or IED) to the process – that is, from level 3 (or 2, or even 1) to level 0.

• GOOSE type information – the signals are transmitted directly (within the Process LAN) from one IED to another. As a rule, certain information necessary for the interlocking logic is transmitted through this information.

## V. Star Topology

Star networks, presented in Fig. 3, are well known for their nodes being located in a shape of a star. There are one of the most commonly network topologies. The way such networks look reminds of a star as there is a central node which is illustrated in the very middle of the network schematics and from this central hub there are other nodes all around this hub connected to it. The central hub is there to transmit the messages to the other nodes and it is the server itself when the peripheral nodes are the clients [8].

The main function of the hub is to control and message all of the functions of the network. It can also be in charge for repeating the data flow. Such configuration can be made with use of the twisted pair cable as well as the optical fiber cable. A coaxial cable can also be used.

The reason of using the star topology is to reduce the impact of a failure for a line in a way of connecting all existing systems to one central node or hub. All of the peripheral, but central nodes can be connected with each other only through the very central node which is the hub in the middle of the star topology drawing.

They all transmit and receive data only in a way of using the central node, there is no other way of their communication.

If there is a fault in a transmission line connecting any of the peripheral nodes to the very central node, it will lead to a result of the isolation of that peripheral node from all other nodes. In this case, all of the rest of the systems will not be affected.

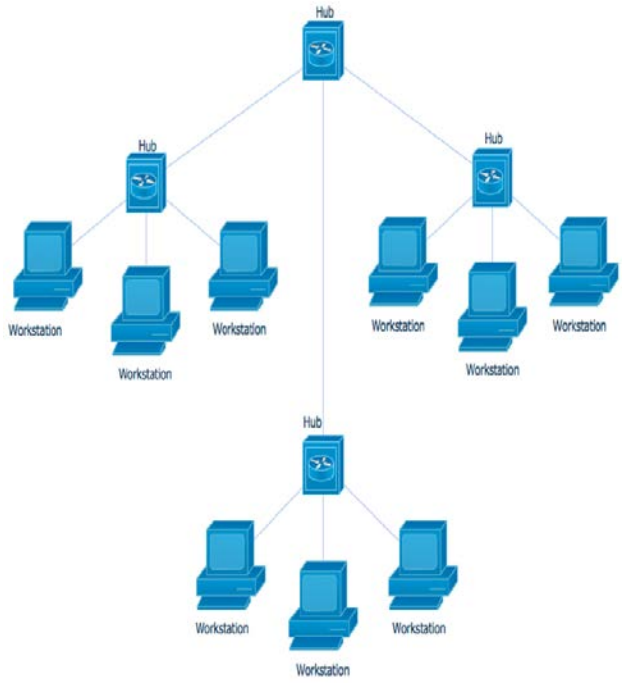


Fig. 3 Star topology.

Extended star is a type of network topology, where a network, based upon the physical star topology, has one or

more repeaters between the central nodes, which also can be called the “hub” of the “star”.

In this network topology, the peripheral or so called “spoke” nodes, the repeaters, are being used for extending the maximum transmission distance of the point-to-point links between the central node and the peripheral nodes.

If these repeaters are replaced with hubs or switches, then so called hybrid network topology is created.

Distributed star is a commonly used type of network topology that has individual networks based on the physical star topology and connected in a linear fashion with no central or top level connection point [10].

## VI. RING TOPOLOGY

The protection and control system in modern substations is becoming more and more digital: therefore the performance of the protection and control system depends on successful communication of data between devices.

This requires that the communications network is highly reliable and highly available.

Just as with the protection and control system, the communications network needs to eliminate single points of failure.

Bypassing or accounting for the failure of a network element should introduce as short a time delay in message transmission and reception as possible, with zero delay ideal.

The traditional network method for availability, presented in Fig. 4, is to use a ring topology, so any network node has two paths to communicate around the network [13].

Network switches are connected to create a physical ring. Networks are composed of Ethernet switches that use a store and forward method to pass data, forming a virtual connection between switch ports.

Ethernet switching does not permit a virtual connection that forms a complete ring, so there are always specific ports on switches configured to be virtually open.

These specific “open” ports therefore won’t forward any data. This means for any data transmission there is a normal point-to-point path through the network.

On the failure of a network link in this point-to-point path, the network will reconfigure to a new point-to-point path through the network by closing virtually open ports as appropriate [11].

Rapid Spanning Tree Protocol is a ring topology communication method.

The basic protocol behind this is Spanning Tree Protocol (STP) as defined by IEEE 802.1D.

Network reconfiguration time using STP may take minutes. IEE 802.1w (2) defines Rapid Spanning Tree Protocol (RSTP), which speeds up reconfiguration time to seconds.

Continuous supervision of power equipment/machinery is provided by SCADA systems implemented in the power systems and which are computer-based tools, using power dispatchers to assist them in controlling the operation of complex power systems [11].

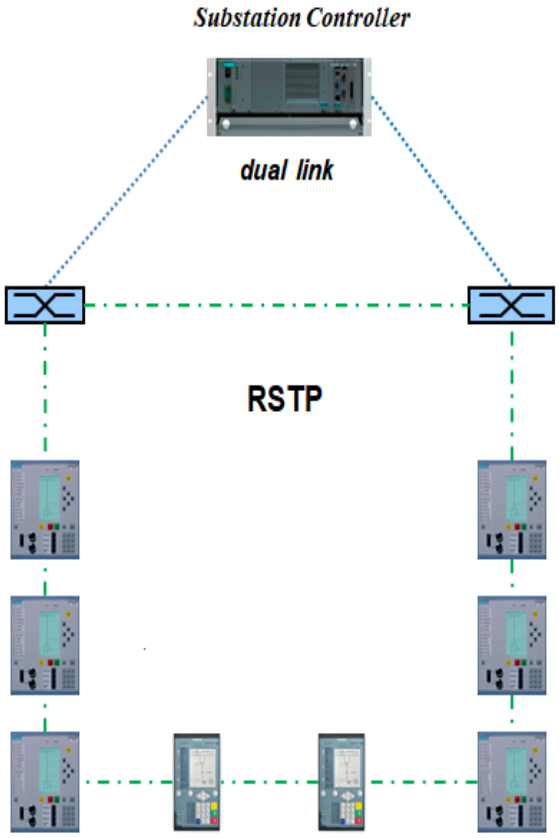


Fig. 4: Ring topology.

Fig. 5 is associated to a case study in an electrical substation from Romania. It presents a screen capture in real-time with ring topology.

It is shown how it works when there is one single fault in the communication system.

In the electrical substation, if any device is fault, the ring topology operates normal, without problems, but with star topology, the electrical substation can’t be operated (if the central workstation is unavailable). This is one of the main advantages of the ring topology.

In Fig. 5, the blue line means the link is good and the telegrams go to each device (switch, bay control unit, bay control protection unit).

The white line indicates that the link is broken between devices and one of these is faulty.

Such a situation is illustrated in the Fig. 5, where the unavailable device is red and the communication is failed. In this case, the telegrams change the direction communication with the rest of available devices.

Another situation is where the bay control unit is red in the 20 kV station, but the line is blue (communication is ok). In this case, the device was removed physically and the optical fiber was extended to the next device.

The reason for the red device is that this one was not deleted by software from the graphical interface.

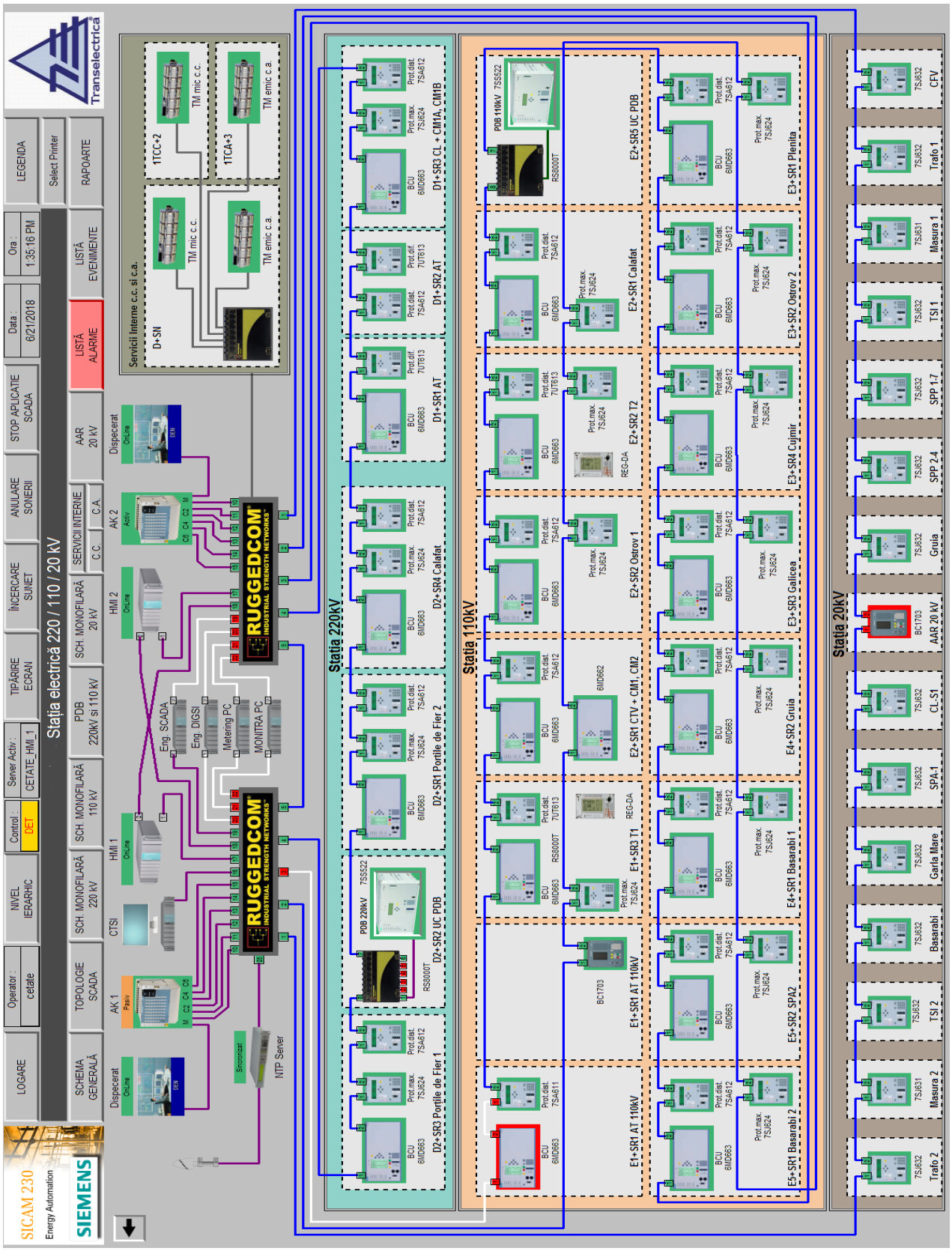


Fig. 5 RSTP implemented in an electrical substation.

## VII. CONCLUSIONS

This paper shows that, by replacing the star topology with ring topology using the rapid spanning tree protocol in a SCADA system, there are many advantages.

By means of a case study in an electrical substation from Romania, the proper real-time operation of the system is illustrated when there is a fault in the communication system.

The availability of the system is higher using the ring topology than the star topology, and the fundamental function of a SCADA system to guarantee and remotely control the installations and power networks in order to ensure its maintenance and reliability is achieved.

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