The Development and Implementation of a Microgrid SCADA System Simulator

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***Abstract*—Shifting the paradigm to decarbonized, distributed renewable future implies changes to conventional principles of power systems operation and requires the implementation of smart grid concepts. Microgrids have been widely recognized as a decentralized approach to successfully integrating renewable energy sources and end consumer empowerment. However, their implementation requires significant improvements and transformation of the distribution system in terms of increased observability and controllability, especially in the context of (near) real-time operation. Supervisory, Control, and Data Acquisition Systems (SCADA) enable system and infrastructure automated monitoring and control and serve as a foundation for advanced management and application of optimization-driven operation. Moreover, the development and testing of the functions mentioned above is a complex task, and today there is still a lack of holistic simulation tools, even though well-established power system simulators exist. The main objective of this paper is to introduce a novel simulation tool developed to simulate the SCADA system used in the Smart Grid Laboratory of the Faculty of Electrical Engineering and Computing for control, integration, and interactions between a microgrid's components. This paper includes simulator system architecture design, implemented functionalities, and future directions. Simulator testing shows successful communication, measurement generation, and meaningful response to commands and reference signals, proving correct functionality. Besides significant value in testing SCADA functionality, designing such a simulator has been of great benefit during restricted access to real-world devices in the Smart Grid Laboratory during the COVID-19 pandemic lockdown.**

Keywords*—SCADA system, simulator, microgrid, smart grid

I. INTRODUCTION

Shifting the power system paradigm to decarbonized, distributed, and renewable future implies changes to conventional operation principles and requires the implementation of smart grid (SG) concepts. In this SG evolution, increased power system integration with information and communication technology (ICT) calls for convenient simulation tools to simulate processes from both domains. Moreover, considering the complexity of power system phenomena and costly equipment and devices (e.g., transformers, lines, and generators), conducting the experiments using real-world machines would be inconvenient, expensive, and dangerous. Hence the requirement for corresponding simulation tools and platforms to emulate real-world devices and their behavior.

Recently, there has been a significant rise in software applications development, which mainly communicate with a SCADA system and rely on data retrieved in the form of measurements from various devices, data visualized in human-machine interface (HMI), and exchanged setpoint values and commands. The development of such an application is an iterative process requiring continuous testing. Consequently, having a tool capable of simulating a SCADA system in their client-server interaction would greatly benefit, accelerate and facilitate the remote development process without the need to be physically present in the laboratory and conducting experiments with real-world devices. This remote aspect was particularly pronounced in the recent times of COVID 19 pandemic lockdown and aftermaths when the physical access to a laboratory is restricted. Likewise, the simulation tool could be practical in the case of more parallel application development processes.

This research aims to develop and implement a new simulation tool to simulate a Supervisory, Control, and Data Acquisition (SCADA) system used in the Smart Grid Laboratory's (SGLab) microgrid. The primary purpose is to create a holistic simulation framework for research, development, and testing, leading to unconstrained experiments and complex SG simulations. Original contributions of this research are the simulator development and implementation, which includes: creating models of microgrid components, implementing the industrial communication protocol, generating measurements and responses on received control signals. Source code is available at [1]. This paper is structured as follows: Section I introduces the topic and motivation and sets research goals. Section II gives a brief and systematic overview of related work and background concepts. Section III proposes a simulator architecture design and software implementation. Section IV offers experimental results and discussion of future work directions. Finally, Section V delivers the conclusion.

II. BACKGROUND AND RELATED WORK

A. Microgrid

From the power system perspective, a microgrid is a single entity acting on external signals, consisting of distributed generation (DG) units, loads, and energy storage systems (ESS) [2]. The coordinated actions of these elements form a cluster in its operation to securely fulfill electricity demands. A microgrid has a single point of common coupling (PCC) to the power grid, usually at a distribution level. The concept of a microgrid was introduced in literature as a solution to the successful integration of distributed energy resources (DER) and is now widely accepted as a solution to technical problems in a decentralized manner and without the need for complex central coordination [2].

Microgrids and other similar entities (e.g., active distribution system, cognitive microgrid, virtual power plant) are considered the main constructive pieces in the SG concept [2]. Microgrid has two modes: grid-connected – synchronized operation with power system or autonomous, stand-alone operation, disconnected from the power system. In the stand-alone regime, the microgrid forms an isolated system (i.e., island) that must be in balance at all times and cover its electrical demands. Otherwise, a microgrid in a grid-connected mode can compensate for its energy deficit from other generating units in the power system or deliver its energy surplus to the power system. In this operation regime, a microgrid is an active participant in energy markets capable of providing ancillary services to other entities such as a system operator. New challenges emanate: a microgrid commonly has a connection to the grid of a distribution level, which is traditionally less observed considering the unidirectional power flows. As a result, the transformation of the distribution system in terms of increased observability and controllability arises, especially in (near) real-time system operation.

The expected microgrid behavior is stable in both operation regimes and a transition between them. Different control strategies can be defined and implemented in both regimes [2]. The two completely different approaches in control system architecture exist: centralized and decentralized. The centralized approach relies on the central controller's data to conduct all calculations and define actions for all the units in one central spot. On the other hand, decentralized control strategies define the local controller's functions and actions for a single unit; other system actions and system variable values are locally unknown. The hierarchical approach compromises the two and combines the desirable characteristics of both - consisting of 3 control levels: primary, secondary, and tertiary. The difference between control levels is the time response, time scales, and infrastructure demands. Therefore, the hierarchical approach is desirable in terms of different time constants and dynamics in the system, including the fast dynamics of output variables and slower dynamics in economic dispatching [2].

B. SCADA system

SCADA is an industrial system with the primary purpose of automated control and monitoring of other system's components utilized in various industries and infrastructures [3]. SCADA system consists of measuring instruments, logical controllers (e.g., programmable logic controller (PLC), remote terminal unit (RTU)), master terminal unit (MTU), communication network, and human-machine interface (HMI) [3].

Measuring instruments consist of sensors acquiring physical measurements (e.g., temperature, pressure, voltage) [3]. Logical controllers are mainly responsible for acquiring the data from measuring instruments, detecting abnormal behavior, (de)activating technical components. MTU is a central component whose role is to send control signals to logical controllers and receive responses, managed by a system operator. MTU and logical controllers communicate via a communication network based on industrial communication protocols (e.g., Modbus, DNP3, Ethernet/IP, IEC 60870-5-104) [4]–[7]. HMI is a programming package with graphical functionalities connecting the human with a system, visualizing the data, and enabling input or output variables monitoring [3].

SCADA system consists of subsystems for data acquisition, data exchange, and a human-machine interface organized in a hierarchical structure [8]. The evolution and development of SCADA systems lead to increasing system complexity caused by: the new and increasing number of system components, interactions between them, increasing quantities of exchanged data, firewall and antivirus use that slow down the system, decrease computing power, and introduce additional delays in data transmission [8]. Consequently, modern SCADA systems are characterized as high complexity and high maintenance systems for many reasons (e.g., control logic, communication protocols, user interface, system security). Despite, the organizations and institutions using the SCADA systems often do not allow delay or loss in data transmission – the system should be reliable enough to perform continuously and within narrow time margins, i.e., in real-time.

C. Simulations in the Smart Grid Environment

Smart grid (SG) presents a term used to describe a complex system consisting of a power system and communication networks components. SG enables the application of distributed control strategies in power systems using controllers, sensors, and actuators [9]. SG development is critical in coordinating various technologies and infrastructure utilized in today's power systems (e.g., microgrids, electric vehicles, renewable energy sources (RES)). SG aims to enable accessible, reliable, and sustainable energy supply in an intelligent environment that integrates the actions of all participants: e.g., generating units, end consumers, system and market operators, and other entities [3], [10]. For the same reason, many global initiatives emerged, intending to formulate and promote a vision of future smart grids [10].

In this transition towards SG, the power system becomes highly intertwined with the ICT infrastructure, and its mutual codependence requires a combined analysis of physical and ICT processes. Furthermore, simulating phenomena from both worlds combined could present significant challenges regarding fundamentally different problem-solving methods such as modeling and simulation [11]. As a result, using a holistic approach in the SG environment is substantial.

Modern power system brings new technologies such as DG, DER, intelligent loads, near real-time operating markets – enabled and empowered with the use of ICT technologies. In addition, ICT technologies enable complex control and optimization strategies to create a more flexible and efficient power system. However, additional complexity, new sources of failure, and security weaknesses emerge to a power system operation requiring a new level of detail in power system simulations. Testing microgrids' complex control and protection functions require specialized laboratories with available devices and machines [12]. Advanced simulation methods and techniques such as hardware-in-the-loop (HIL) prevent damage to high-cost equipment, guarantee safety, and offer various possible testing conditions. The HIL method enables physical components (i.e., power electronics devices) to a simulated grid to observe behavior and response [13]. In power system research, these types of simulations are frequently used to conduct failure tests in a safe environment, in real-time, using the simulation environment without dangerous consequences and effects on equipment.

SCADA systems are often a part of industrial and critical infrastructure. Therefore, it is impractical to conduct experiments on live systems for many reasons: high implementation costs of testing conditions, potential failure risks, and high downtime expenses [14]. SCADA system simulations must support various devices, communication protocols, and software packages integration. These simulation tools and environments are also valuable for user training on conducting control operations [15].

D. Smart Grid Laboratory

Smart Grid Laboratory (SGLab) at the Department of Energy and Power Systems, Faculty of Electrical Engineering and Computing, University of Zagreb, is an advanced power system laboratory established in 2015 and gathers researchers with the common goal of scientific research, professional work, and education in the area of smart grid [16], [17]. The laboratory's primary focus is researching the RES and DER effect on power systems, especially power systems' increased flexibility demands and use of advanced technologies (e.g., ESS, EV, EV's charging stations, demand response aggregation, microgrids, multigeneration systems). In addition, research and development activities of control and optimization methods and approaches are conducted utilizing ICT solutions.

SGLab owns various equipment, and the most notable is a laboratory microgrid consisting of a hydropower plant model with Pelton's turbine, photovoltaic (PV) panels, two controllable DC loads, a bidirectional AC/DC converter for microgrid coupling, and battery energy storage systems (BESS). Detailed component descriptions and parameters can be found in [18]. The laboratory microgrid can simulate an operation of a low-voltage distribution grid.

Proza Net SCADA System developed by Končar KET integrates the microgrid's components and establishes communication between them [19]. Proza Net supports various communication protocols such as IEC 61850, IEC 60870-5-104, Modbus TCP/IP, DNP3 [20], [7], [4], [5]. In this microgrid set, OPC UA and Modbus TCP/IP are used for mutual communication between components [21], [4].

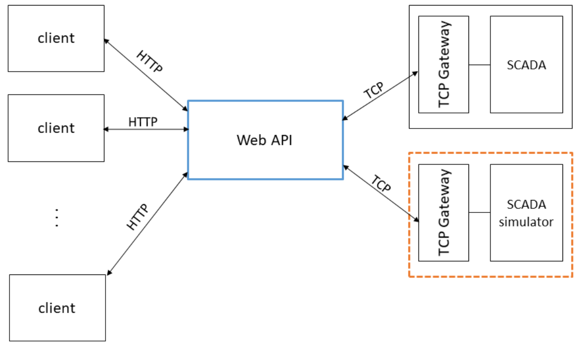

Fig. 1: System conceptual architecture

Client applications developed within the laboratory's activities and projects use the SCADA system as their foundation. Communication of applications with the SCADA system is enabled using the SCADA Web API tool, which uses customized protocol implemented on the TCP/IP network layer: SCADA system is a server, and the SCADA Web API is a proxy.

III. Simulator architecture

As mentioned in Section I, the SCADA system simulator in this research intends to simulate the behavior of a real-world SCADA system, present in the SGLab, called Proza Net, and developed by a Croatian company Končar KET. Fig. 1 shows a conceptual architecture design: the SCADA Web API is represented by a blue rectangle, and the SCADA system simulator is outlined by orange dashed line rectangle. Client applications communicate with a SCADA Web API through HTTP protocol. Furthermore, the SCADA Web API communicates with a TCP Gateway of a SCADA system or SCADA system simulator through TCP protocol. In this communication, the SCADA system or SCADA system simulator presents a server, SCADA Web API presents a proxy, and external applications present clients.

Simulator development includes the configuration and parametrization of a simulator, machines, and devices present in a lab, measurements, noise - using the configuration file where all the parameters are included, such as noise in the system and the data, the signal type (i.e., discrete or continuous), parameters, and measurement ranges that should not be violated. Moreover, communication interface implementation emulates the real one, and the industrial communication protocol for data exchange at TCP/IP network layer is implemented following the protocol specification. The main value of the simulator implementation is the intelligent way of generating the response – response is generated depending on the received control signal. In other words, measurement generation depends on received values and commands from external sources – client applications.

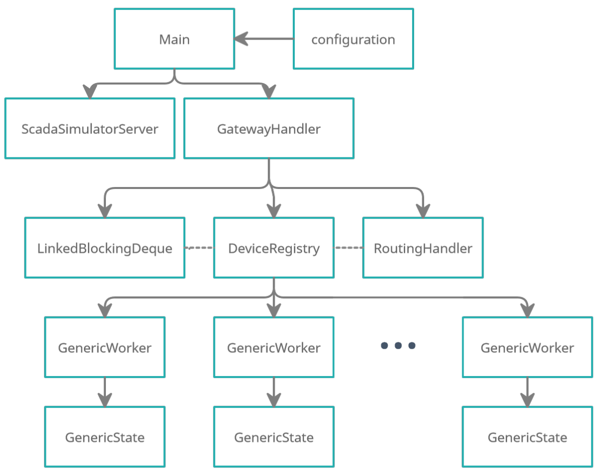

Fig. 2: SGLab SCADA simulator main modules

SGLab SCADA simulator is implemented using the programming language Java (Java SE 11 LTS) and the development environment IntelliJ IDEA. This section contains a short description of the main classes and modules illustrated in Fig. 2, showing the application's modular architecture. Packages regarding the configuration models (config), messages models (models/messages), and the parameters of the message (models/values) are not included here.

Main is the main class and presents the input point for the application. Its functionalities include reading the configuration file and creating Configuration Model, Scada Simulator Server, and Gateway Handler instances.

Configuration model is the module for configuration's structural mapping to variables used in the application where the variable's values are needed.

ScadaSimulatorServer is the module used for creating the web application's interface, developed with web frameworks Javalin and Angular.

The configuration file is written in the YAML markup language for data serialization and configuration files. The configuration file contains all simulator parameters (version, name, authentication data, communication protocol details – gateway port, message length) and the microgrid components parameters. Microgrid components are included in the list, defined with an identification number, name, description, flag for component controllability, two maps with available measurements, and commands of a particular component. A replica of an actual communication interface is created for each microgrid component, including measurements, commands, and parameter values utilized in the measurement generation process.

GatewayHandler is a module that includes implementing the communication protocol at the TCP/IP network layer, PNETGateway Communication Protocol. Firstly, the server socket is opened, and if there is an available client, the communication between the server and the client is established, input and output data streams are created. The input data stream is used for the data sent by a client, and the output data stream for the data sent to a client. The two separate threads are processing the messages in parallel:

- Request messages – AuthenticationRequest, ChangeDataRequest, CommandRequest – messages sent by a client with a request for authentication (prior to the communication establishment), or to change the data value or to execute the command
- Unsolicited messages – DataChangedUnsolicited, StatusChangedUnsolicited – messages sent by a server periodically or after the value was changed

The server processes the requests: reads the message from the input data stream, prepares its response - AuthenticationResponse, ChangeDataResponse, CommandResponse - and sends it to the client by the output data stream. Messages are in the JavaScript Object Notation (JSON) format, UTF-8 standard coded. The general message structure consists of a message type and body. JSON packages are sent in bytes, the first 4 bytes define the message length N, and the rest is the message long N bytes itself.

The server's response depends on a message type, and besides the response construction, the Worker responsible for processing the request is called. Response in the JSON format is written in bytes before sending to the output data stream.

Unsolicited messages processing differs because the server sends them without a client's request. The processing involves taking the message from the queue and writing it to the bytes package before sending it through the output data stream.

RoutingHandler is a module representing the router implementation, used to route the request to the corresponding component's Worker for further processing. It contains the internal maps measurementToDevice and commandToDevice with the keys (i.e., measurement or command key) and values (i.e., device's identification number). RoutingHandler can determine which Worker has to process the request using the keys contained in maps. It also returns the Worker's instance to call a method for command processing.

DeviceRegistry is a module taking account of Workers. Each machine or device has its Worker's instance in a separate thread, running simultaneously. So, firstly, the new Worker instances are created, the parameters of components are assigned to them, and all parallel processes start to run in separate threads.

GenericWorker is a module representing the WorkerInterface implementation, used for measurement generation and creating the unsolicited messages, changing the referent values, and processing the commands. Each device receives its configuration parameters for initialization, and the state is being defined – presented by a module GenericState. GenericState consists of variables for all available measurements and the status reflecting the operation state of a device (e.g., on, off, in the transient process).

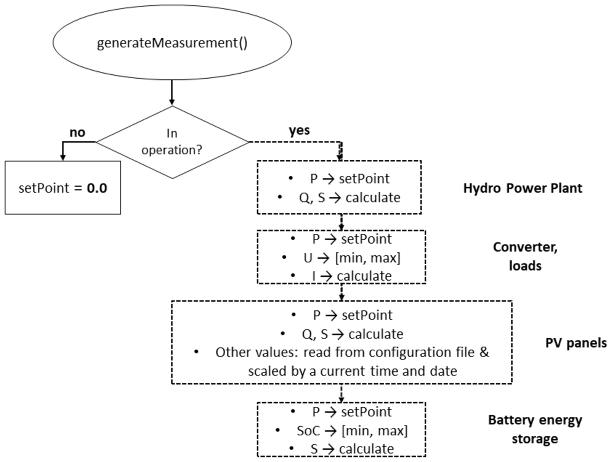

Fig. 3: Measurement generation algorithm

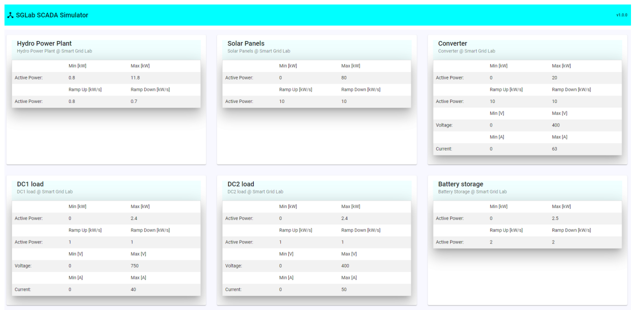

Fig. 4: SGLab SCADA simulator web interface

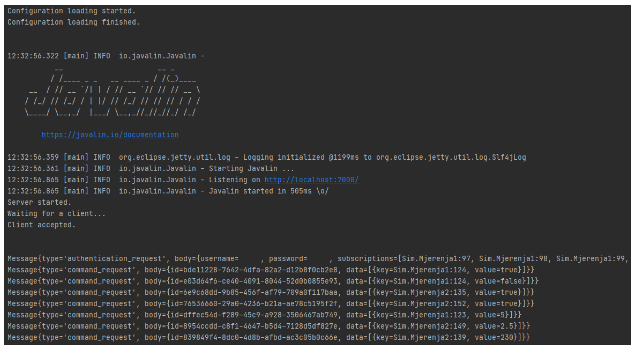

Fig. 5: SGLab SCADA simulator command line output

State initialization depends on a component – the measurements that characterize the device would be initialized to its starting value which is 0.0 for controllable components (i.e., all the microgrid components except the PV's), as the components are off before the corresponding start signal.

The message DataChangedUnsolicited is put in a queue every second for each device to refresh the measured values. The reference value with an added measurement noise is sent if the device is on. Otherwise, 0.0 is sent in the message.

Measurement noise is modeled as a stochastic variable with a normal distribution – the value is approximated based on many imperfections and factors (cumulative contribution of all measurement, mechanical, regulation, and communication system components). The normal distribution is an approximate model for a case of many independent components.

Generating measurement process depends on a component: each component has different measurements, and the algorithm is presented in Fig. 3. In the case of starting the power plant or device, the reference value or a setpoint of active power (P) is set to a minimum possible value according to configuration. Then, apparent power (S) is calculated using the active power and power factor values, and the reactive power (S) can be calculated using the power triangle. For components with voltage and current measurement, voltage is set to a random value between a minimum and a maximum value, and the current is calculated using the relation between active power and voltage.

IV. Results

Developed simulation tool testing was performed using the SCADA Web API – the tool used in communication with the SCADA system in the SGLab's environment. The web interface of the application SGLab SCADA Simulator is included in Fig. 4, showing the parameter ranges of a particular microgrid component in a table form. In addition, the proof of correct functionality is given in Fig. 5, showing the simulator command line output:completed the reading of the configuration file, initiated the Javalin web application and the server, established the client connection, received messages from the client.

The configuration file accomplished the configuration of the simulator, microgrid components (devices and machines), and measurement ranges. Successful communication of SGLab SCADA Simulator and SCADA Web API indicates proper implementation of industrial communication protocol on TCP/IP network layer. One more indicator of correct behavior is measurement generation – it begins at a corresponding signal, not at the application start per se. Generated measurements prove the valid implementation of communication interfaces mapped to existing laboratory SCADA system's communication interfaces. Furthermore, all the measurements are within defined ranges.

The results included here prove that with a relatively simple model of microgrid elements and a few parameters, it is possible to generate meaningful measurements that can be further employed in developing various client applications based on the SCADA system operation. The developed simulation tool has a modular architecture – the system upgrades with new models, parameters, microgrid components are possible in a simple manner – adding to a configuration file with minimal changes in the code. One more advantage is that the implementation is not constrained to existing components – machines or devices that are not part of the current microgrid setup can also be included, and the interactions can be observed. Finally, the independent architecture modules contain models for the communication protocol and the data specification - therefore, it is possible to add support for other communication protocols. The most perspective upgrade we see is the potential of adding the support for existing tools and libraries, enabling the dynamic modeling of microgrid components and observing phenomena under much smaller time scales. Moreover, the mentioned upgrade would enable holistic modeling and simulation approach, besides primary level control demonstrated in this paper. For a more detailed approach to measurement generation, the historical data from the laboratory's SCADA system can be utilized. Parameter identification and values should be examined for a more precise measurement and data noise modeling. It is essential to identify the data deviations from given reference values and model them conveniently.

In the future, we plan to expand the simulation tool with the additional electrical grid parameters to simulate power flow and advanced SCADA functions.

V. Conclusion

This paper presents the implementation of a novel simulation tool to simulate the behavior of a SCADA system used in the Smart Grid Laboratory for microgrid control, monitoring, and data acquisition.

The analysis of related work in the field was conducted, which determined that the simulation in the SG environment requires a holistic approach in terms of simulating the phenomena from the power system and ICT domains, causing increased complexity and additional issues in mutual interactions simulation.

Successful implementation of communication protocol enables the communication with client applications developed and used in the research and professional work of SGLab. The simulation tool is successfully parametrized using the configuration file – parameters correspond to actual devices and machines in an existing laboratory setup. Measurement generation is done intelligently – meaningful values are generated to respond to a control signal (reference values or commands). Values are within defined ranges.

The results presented in this paper demonstrate the correct functionality of a developed application: observable in the communication interfaces (replicas of existing interfaces) and generated measurements. Additionally, the implementation described in this paper is modular, the system updates are easily attainable, and additional research paths are given.

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References

[1] "SGLab SCADA Simulator." [Online]. Available: https://github.com/lucijamatulin/SGLab-SCADA-simulator
[2] D. E. Olivares, A. Mehrizi-Sani, A. H. Etemadi, C. A. Cañizares, R. Iravani, M. Kazerani, A. H. Hajimiragha, O. Gomis-Bellmunt, M. Saeedifard, R. Palma-Behnke, G. A. Jiménez-Estévez, and N. D. Hatziargyriou, "Trends in Microgrid Control," *IEEE Transactions on Smart Grid*, vol. 5, no. 4, pp. 1905–1919, Jul. 2014.
[3] P. I. Radoglou-Grammatikis and P. G. Sarigiannidis, "Securing the Smart Grid: A Comprehensive Compilation of Intrusion Detection and Prevention Systems," *IEEE Access*, vol. 7, pp. 46 595–46 620, 2019.
[4] "The Modbus Organization." [Online]. Available: https://modbus.org/
[5] "Overview of DNP3 Protocol." [Online]. Available: https://www.dnp.org/About/Overview-of-DNP3-Protocol
[6] P. Brooks, "Ethernet/IP-industrial protocol," in *ETFA 2001. 8th International Conference on Emerging Technologies and Factory Automation. Proceedings (Cat. No.01TH8597)*, vol. 2. Antibes-Juan les Pins, France: IEEE, 2001, pp. 505–514. [Online]. Available: http://ieeexplore.ieee.org/document/997725/
[7] "IEC 60870-5-104:2006+AMD1:2016 CSV | IEC Webstore." [Online]. Available: https://webstore.iec.ch/publication/25035
[8] S. Ghosh and S. Sampalli, "A Survey of Security in SCADA Networks: Current Issues and Future Challenges," *IEEE Access*, vol. 7, pp. 135 812–135 831, 2019.
[9] H. Palahalli, E. Ragaini, and G. Gruosso, "Smart Grid Simulation Including Communication Network: A Hardware in the Loop Approach," *IEEE Access*, vol. 7, pp. 90 171–90 179, 2019.
[10] F. Li, W. Qiao, H. Sun, H. Wan, J. Wang, Y. Xia, Z. Xu, and P. Zhang, "Smart Transmission Grid: Vision and Framework," *IEEE Transactions on Smart Grid*, vol. 1, no. 2, pp. 168–177, Sep. 2010.
[11] I. T. F. o. I. T. f. S. Tools, S. C. Müller, H. Georg, J. J. Nutaro, E. Widl, Y. Deng, P. Palensky, M. U. Awais, M. Chenine, M. Küch, M. Stifter, H. Lin, S. K. Shukla, C. Wietfeld, C. Rehtanz, C. Dufour, X. Wang, V. Dinavahi, M. O. Faruque, W. Meng, S. Liu, A. Monti, M. Ni, A. Davoudi, and A. Mehrizi-Sani, "Interfacing Power System and ICT Simulators: Challenges, State-of-the-Art, and Case Studies," *IEEE Transactions on Smart Grid*, vol. 9, no. 1, pp. 14–24, Jan. 2018.
[12] Y. Huo and G. Gruosso, "Hardware-in-the-Loop Framework for Validation of Ancillary Service in Microgrids: Feasibility, Problems and Improvement," *IEEE Access*, vol. 7, pp. 58 104–58 112, 2019.
[13] P. C. Kotsampopoulos, V. A. Kleftakis, and N. D. Hatziargyriou, "Laboratory Education of Modern Power Systems Using PHIL Simulation," *IEEE Transactions on Power Systems*, vol. 32, no. 5, pp. 3992–4001, Sep. 2017.
[14] C. Queiroz, A. Mahmood, and Z. Tari, "SCADASim—A Framework for Building SCADA Simulations," *IEEE Transactions on Smart Grid*, vol. 2, no. 4, pp. 589–597, Dec. 2011.
[15] S. Carullo and C. Nwankpa, "Interconnected power systems laboratory: a computer automated instructional facility for power system experiments," *IEEE Transactions on Power Systems*, vol. 17, no. 2, pp. 215–222, May 2002.
[16] "Home - ZVNE." [Online]. Available: https://www.fer.unizg.hr/zvne
[17] "Home - Smart Grid Laboratory - SGLab." [Online]. Available: https://sglab.fer.hr/
[18] "Equipment - Smart Grid Laboratory - SGLab." [Online]. Available: https://sglab.fer.hr/sglab/equipment
[19] "Software Platforms and Projects." [Online]. Available: https://www.koncar-ket.hr/upravljacki-centri/it-rjesenja/
[20] "IEC 61850:2021 SER | IEC Webstore | LVDC." [Online]. Available: https://webstore.iec.ch/publication/6028
[21] "Unified Architecture." [Online]. Available: https://opcfoundation.org/about/opc-technologies/opc-ua/