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Design and Development of a SCADA Program for Substations Based on Matlab App Designer and Simulink

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Abstract: This paper presents a method for designing a substation SCADA application based on MATLAB/Simulink integrated with MATLAB App Designer. The substation simulation model is constructed using Simscape Electrical, comprising key components such as grid sources, power transformers, busbars, transmission lines, circuit breakers, disconnectors, and measurement devices. The SCADA software is developed with an intuitive Human–Machine Interface (HMI) that replicates the primary single-line diagram of the substation while incorporating functions for equipment status monitoring, real-time visualization of operational parameters, fault detection and alarm generation, and circuit breaker switching control embedded with an interlocking algorithm between circuit breakers and disconnectors to ensure operational safety. Data exchange between the Simulink model and the SCADA interface is continuously updated in real time via the MATLAB Workspace and a Timer mechanism, guaranteeing seamless synchronization of electrical parameters and equipment statuses. Simulation results on the substation model demonstrate that the software operates stably, exhibits an intuitive interface with fast data refresh rates, and accurately responds to various operational and control scenarios.

Keywords: MATLAB App Designer, SCADA, Substation Automation, Simulink.

I. INTRODUCTION

In the era of digital transformation within the power industry, substations are being progressively upgraded toward automation to enhance power supply reliability, reduce operational expenditures, and improve remote monitoring and control capabilities. Supervisory Control and Data Acquisition (SCADA) systems serve a central role in collecting data, monitoring equipment status, executing switching operations, and supporting decision-making processes for operators [1, 2]. Alongside widely deployed commercial SCADA software, researching and developing SCADA models on simulation software platforms has gained significant attention for training, academic research, and testing control algorithms prior to practical deployment. In particular, MATLAB/Simulink ,with its powerful modeling, simulation, and control integration capabilities , has become an effective tool in studying modern power systems [3].

In recent years, numerous studies have applied MATLAB/ Simulink to model power systems, evaluate operating conditions, design control algorithms, and verify substation automation solutions. However, most existing literature focuses on simulating individual components separately or relies on dedicated commercial SCADA packages. Research leveraging the native MATLAB/ Simulink environment to build a comprehensive SCADA program capable of real-time monitoring, control, and data visualization for substations remains relatively limited [4, 5].

Developing a SCADA program within MATLAB/ Simulink offers several advantages, such as integrating mathematical models with intuitive monitoring interfaces, unifying simulation and control within a single environment, and facilitating the development, testing, and validation of control algorithms before real-world implementation [6, 7]. Furthermore, this platform allows interface expansion with physical hardware via OPC, Modbus, or industrial Ethernet protocols, catering to research on Hardware-in-the-Loop (HIL) systems, Digital Twins, and smart-grid-oriented substation automation [8, 9]. Therefore, developing a SCADA program in MATLAB/Simulink holds both scientific and practical significance, particularly for educational

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institutions and power system research laboratories [10-12].

Addressing these requirements, this paper presents a design method for a substation SCADA program based on MATLAB/Simulink. The program is developed to fulfill primary functions including single-line diagram simulation, real-time operational data acquisition and updating, electrical parameter visualization, switching equipment status monitoring, fault alarming, and remote command execution from the user interface. The effectiveness of the program is evaluated through operational simulation scenarios, proving the feasibility of the solution and its applicability in training, research, and substation automation.

II. SUBSTATION MODELLING USING MATLAB/SIMULINK

2.1 Substation modelling

In this study, the simulated object is a 110/22 kV substation based on a typical configuration currently utilized in power transmission and distribution systems. The station is equipped with two main power transformers, each rated at 40 MVA, which step down the voltage from 110 kV to 22 kV to supply the distribution grid. The dual-transformer layout not only satisfies load capacity requirements but also enhances power supply reliability, allowing operational flexibility, maintenance, and fault handling.

The 110 kV side of the substation is designed using a double busbar with a transfer bus configuration to increase operational flexibility and reliability. This topology enables load transfer between busbars and the isolation of individual components for maintenance without interrupting the power supply. The 110 kV system comprises two line bays connecting to the transmission grid and two transformer bays connecting to the two main power transformers. Each bay is fully equipped with switching devices, disconnectors, current transformers, voltage transformers, and protection systems according to modern substation design standards. The single-line diagram of the substation is illustrated in Figure 1, and the parameters of the components in the diagram are presented in Table 1.

The substation model was constructed in MATLAB/Simulink based on the aforementioned structure to fully reflect the operating states of the system. Primary equipmentincluding busbars, transmission lines, power transformers, circuit breakers, and disconnectors, are modeled individually and interconnected in strict accordance with the primary single-line diagram of the substation. This structure facilitates the acquisition of operational parameters, equipment status monitoring, and the execution of control functions from the SCADA software developed in this study. To build a SCADA application dedicated to substation monitoring and control, it is first necessary to develop a simulation model that accurately captures the operational characteristics of the substation equipment. In this study, the model was developed on the MATLAB/Simulink platform integrated with the Simscape Electrical library, enabling the simulation of electrical elements, switching devices, measurement systems, and control signals within a unified environment. The model is based on a typical 110/22 kV substation configuration comprising the following main components: a 110 kV grid source, a 110/22 kV power transformer, high-voltage and medium-voltage busbars, circuit breakers (CBs), disconnectors (DSs), current transformers (CTs), potential transformers (PTs), 22 kV load feeders, and a signal acquisition and measurement system. Equipment is connected strictly according to the schematic diagram of an actual substation to ensure realistic simulation of various operating conditions, such as switching operations, load variations, overloads, short circuits, and power outages. Modeling under this architecture enables the SCADA software to directly access the state variables of each device, facilitating real-time display and control operations.

Table 1: Parameters of the substation components

No.	Element	Parameters
1	Voltage source 1	U = 110 kV; f = 50 Hz; X/R = 7;SCR = 10000 MVA
2	Voltage source 2	U = 110 kV; f = 50 Hz; X/R = 7; SCR = 12000 MVA
3	Transmission line	L = 5 km;R_1 = 0.01273 Ω/km;R_0 = 0.03864 Ω/km; L_1= 0.31831mH/km; L_0= 0.12732 mH/km;C_1= 12.74 pF/km;C_0 = 7.751 pF/km
4	Transformer	S_n = 40 MVA; 115/38,5/24 kV; [R_1,R_2,R_3] = 0,005 pu; [X_{12}, X_{13}, X_{23}] =[0.087 pu,0.166 pu, 0.067 pu];I% = 0.06%; P_0 = 800 W
5	Load 1	U = 22kV; P = 40 MW; Q = 5 MVAR
6	Load 2	U = 22kV; P = 30 MW; Q = 6 MVAR

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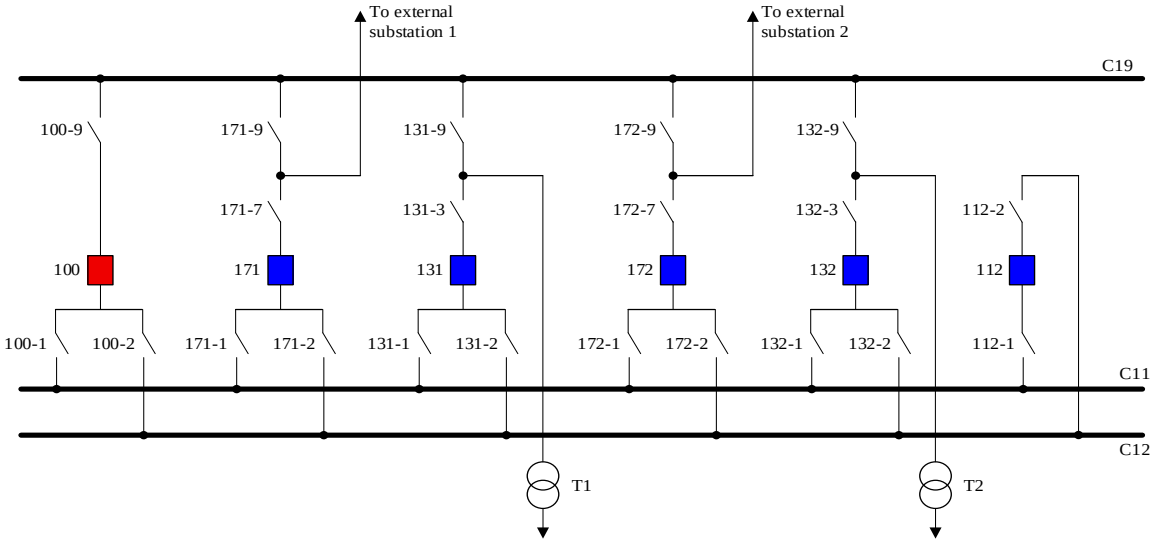


Figure 1: Single-line diagram of the substation

2.2 Element modelling

In Simulink, substation elements are constructed using components from the Simscape Electrical Specialized Power Systems library. The power grid source is modeled using the Three-Phase Voltage Source block, which allows adjustment of voltage, frequency, and phase angle to simulate various operating regimes of the power system. The power transformer is developed using the Three-Phase Transformer (Two Windings) block. Rated parameters including apparent power capacity, voltage levels, short-circuit reactance, and vector group, are specified based on the actual parameters of the surveyed substation. This model enables the evaluation of voltage and current variations under load fluctuations or fault conditions. Circuit breakers and disconnectors are modeled using Three-Phase Breaker blocks, where their open/close states are controlled via logical signals. This facilitates precise simulation of switching operations as well as direct link establishing with the SCADA program. Loads are modeled using the Three-Phase Dynamic Load or Three-Phase Parallel RLC Load blocks. The active and reactive power of the load can be varied over time to evaluate the dynamic response of the monitoring system.

2.3 Controlling and monitoring data

One of the critical requirements of a SCADA system is the capability for real-time operational data acquisition. Therefore, voltage, current, power, and frequency measurement blocks are deployed at all designated monitoring locations. The acquired parameters include: three-phase voltages at busbars, feeder currents, active power, reactive power, apparent power, system frequency, power factor, circuit breaker open/close statuses, disconnector statuses, warning signals, and fault alarms. Measured signals are passed through processing blocks to convert them into RMS or average values based on a specified sampling period prior to transmission to the monitoring interface. This preprocessing reduces noise and ensures the stability of the displayed data. Beyond electrical parameters, the model also incorporates digital (Boolean) status signals to represent the operational state of each substation device.

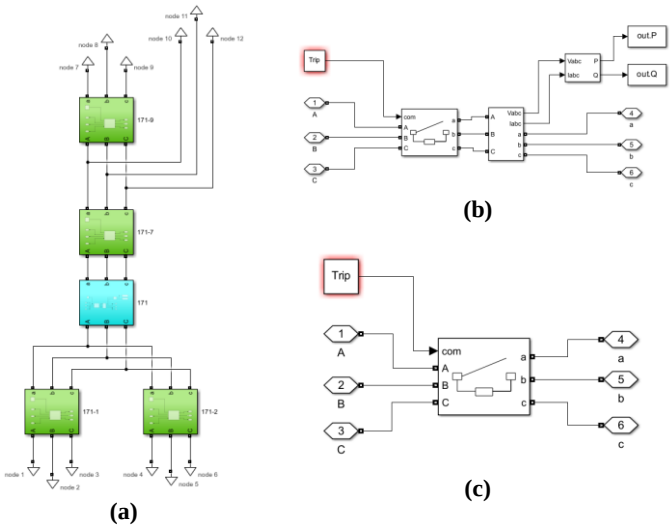


Figure 1: Circuit breaker and disconnector control signals

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2.4 Signal database development

Upon completing the simulation model, all monitored variables are organized into a unified database. Each signal is assigned a tag name, engineering unit, upper and lower limits, as well as an update period. The main data groups include: the analog signal group (voltage, current, power, and frequency); the digital signal group (statuses of circuit breakers, disconnectors, and alarms); the alarm signal group (overcurrent, overvoltage, undervoltage, and power outage); and the control signal group (circuit breaker close command, circuit breaker open command, and alarm reset). Standardizing the database right from the modeling stage simplifies the SCADA interface design process, while facilitating future system expansion or integration with PLCs, RTUs, and IED devices.

III. DESIGN A SCADA PROGRAM USING MATLAB APP DESIGNER

3.1 Overall architecture of the SCADA Program

The SCADA software was developed on the MATLAB App Designer platform to provide an intuitive interface for monitoring and controlling substation equipment. The architecture of the program comprises three main layers: the power system simulation layer based on MATLAB/Simulink, the data acquisition and processing layer, and the Human–Machine Interface (HMI) layer.

The MATLAB/Simulink model simulates primary substation components, including power transformers, busbars, transmission lines, and switching devices. Electrical quantities such as voltage, current, active power, and reactive power are transmitted to the SCADA software for continuous visualization and monitoring. App Designer serves as the framework for constructing the HMI and executing control commands initiated by the operator. When an operator performs a control action via the interface, the software evaluates operating constraints and interlocking conditions prior to dispatching control signals to the Simulink model. Concurrently, the updated equipment status is reflected back onto the GUI. This continuous data exchange ensures real-time synchronization between the displayed interface status and the physical states within the power system model. The overall system architecture operates according to the following cycle (Figure 3):

3.2 SCADA interface design

The SCADA GUI was developed using the graphical components of MATLAB App Designer. The primary objective of the GUI is to visually replicate the single-line diagram (SLD) of the substation while providing comprehensive operational information to the operator. The main layout comprises four dedicated regions: the electrical schematic display, the operational parameter display, the equipment control panel, and the alarm monitoring section.

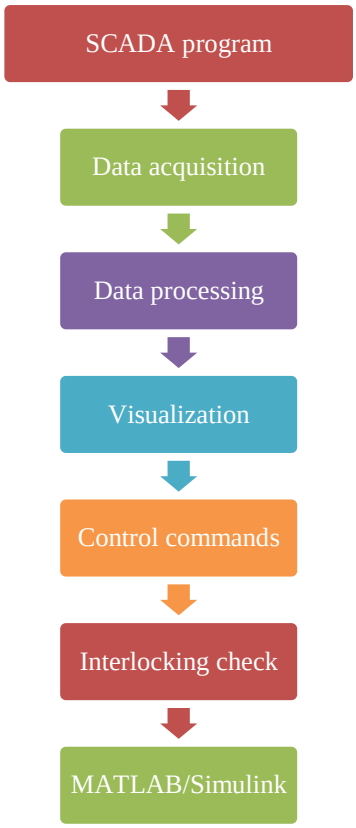


Figure 2: Overall Architecture of the SCADA Program

The substation single-line diagram was constructed in accordance with the 110/22 kV model described in the preceding section. Key primary elements, including busbars, power transformers, transmission lines, circuit breakers (CBs), and disconnectors (DSs), are represented via graphical components on the interface. Equipment operational states are dynamically indicated through distinct graphical symbols and color codes; for instance, the open and closed positions of circuit breakers are visually differentiated, allowing operators to quickly assess the real-time status of the system. In addition to the SLD, electrical parameterssuch as bus voltages, currents, active power, and reactive power of major componentsare presented via numerical indicators and data tables. These parameters are continuously retrieved from the MATLAB/Simulink model at specified

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sampling intervals. This automated data synchronization ensures that the SCADA GUI accurately reflects dynamic system variations resulting from load changes or operator-initiated switching actions.

Figure 4 illustrates the developed substation SCADA graphical interface, which provides a visual representation of the main electrical equipment and switching states of the substation. The interface displays the 110-kV busbar system, outgoing transmission lines, circuit breakers, disconnectors, and connections to the two main transformers. The green and red indicator lights provide real-time information on the operating status of the corresponding switching devices, while the displayed active and reactive power values enable operators to monitor the electrical operating conditions. The interface also incorporates interconnection paths to external substations and the two main transformers, providing an intuitive overview of power flow and equipment status. Overall, the proposed SCADA interface facilitates real-time monitoring, operational supervision, and switching-status management, thereby improving the reliability and effectiveness of substation operation.

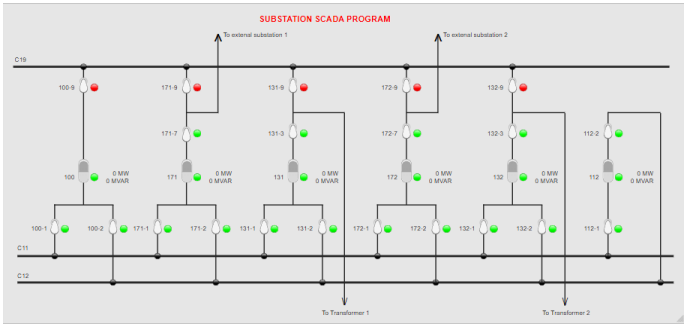


Figure 3: SCADA interface

Table 2 summarizes the operating states of 27 switching elements monitored by the proposed substation SCADA system. The results show that the switching states are clearly classified into Close and Open conditions and represented by blue and red colors, respectively, allowing operators to quickly identify the status of each device. The main circuit breakers 171, 172, 131, 132, and 112 are in the closed state, while circuit breaker 100 is open. For feeders 171, 172, 131, and 132, the corresponding disconnectors exhibit a consistent switching pattern, with the 1 and 7 disconnectors closed and the 2 and 9 disconnectors open. In particular, all switching elements associated with feeder 100 are open, whereas those associated with feeder 112 are closed. These results demonstrate that the SCADA program can effectively display and distinguish the operating states of individual switching devices, providing operators with clear and intuitive information for monitoring and controlling the substation.

Table 2: Status of circuit breakers and disconnectors

No.	Element	Status	Color
1	171	Close	Blue
2	171-1	Close	Blue
3	171-2	Open	Red
4	171-7	Close	Blue
5	171-9	Open	Red
6	172	Close	Blue
7	172-1	Open	Red
8	172-2	Close	Blue
9	172-7	Close	Blue
10	172-9	Open	Red
11	131	Close	Blue
12	131-1	Close	Blue
13	131-2	Open	Red
14	131-7	Close	Blue
15	131-9	Open	Red
16	132	Close	Blue
17	132-1	Close	Blue
18	132-2	Open	Red
19	132-7	Close	Blue
20	132-9	Open	Red
21	100	Open	Red
22	100-1	Open	Red
23	100-2	Open	Red
24	100-9	Open	Red
25	112	Close	Blue
26	112-1	Close	Blue
27	112-2	Close	Blue

Figure 5 shows the SCADA interface demonstrate the effectiveness of the developed monitoring and control system in providing real-time information about the operating status of the electrical substation. The interface clearly presents the status of circuit breakers, disconnectors, and other electrical elements, allowing operators to quickly identify the current configuration of the system. The color-coded status indicators, such as blue for the closed state, provide an intuitive representation of the equipment status and improve the readability of the single-line diagram. In addition, the interface enables the operator to monitor changes in equipment states and verify the interlocking

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conditions between circuit breakers and disconnectors. These results confirm that the proposed MATLAB/Simulink-based SCADA interface can provide a simple, visual, and effective solution for monitoring and controlling substation operation.

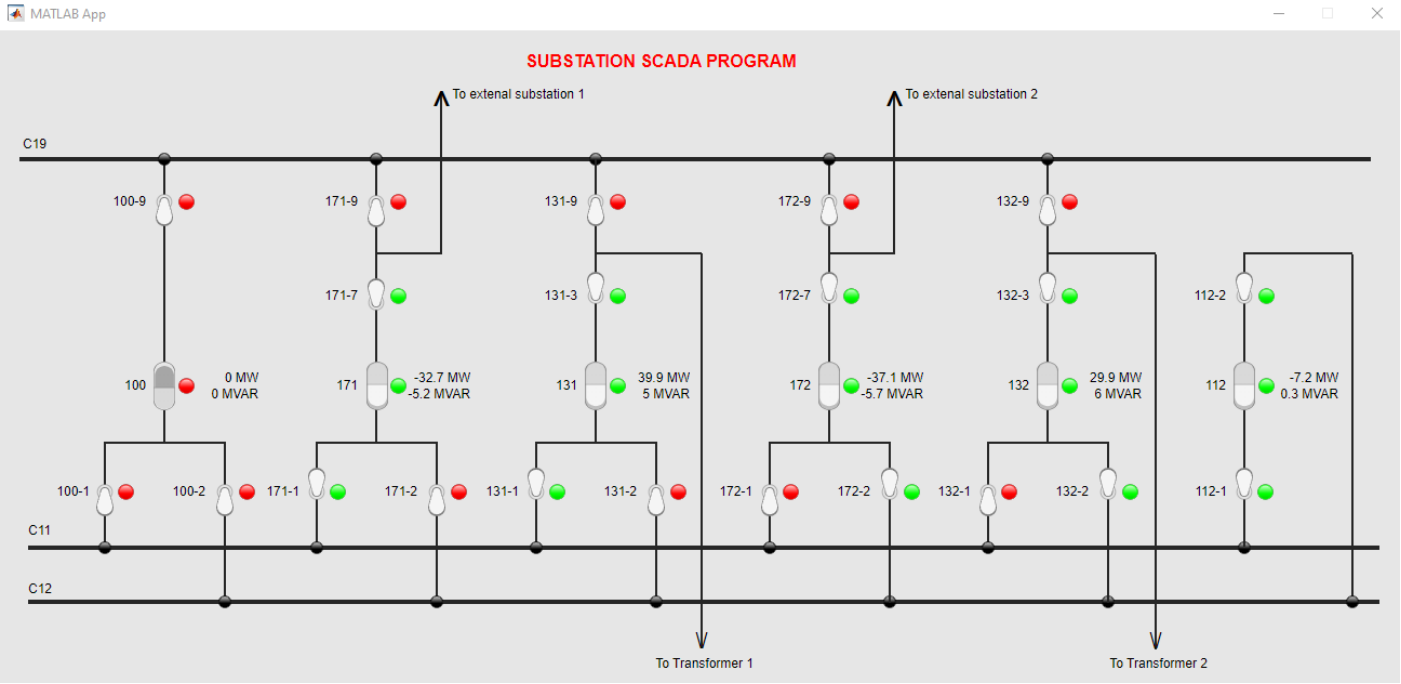


Figure 4: Normal operating mode

The results displayed on the SCADA interface demonstrate the effectiveness of the developed monitoring and control system in providing real-time information about the operating status of the electrical substation. The interface clearly presents the status of circuit breakers, disconnectors, and other electrical elements, allowing operators to quickly identify the current configuration of the system. The color-coded status indicators, such as blue for the closed state, provide an intuitive representation of the equipment status and improve the readability of the single-line diagram.

Furthermore, the developed interface allows the operator to observe changes in the switching states of electrical equipment directly on the graphical interface. The system also incorporates the interlocking logic between circuit breakers and disconnectors, thereby preventing inappropriate switching operations and enhancing operational safety. When a switching command is executed, the corresponding equipment status is updated immediately on the SCADA interface, providing visual feedback to the operator.

The simulation results also show that the proposed SCADA system can accurately reflect different operating configurations of the substation. This capability is particularly useful for monitoring the switching sequence, checking equipment status, and supporting the analysis of abnormal or unintended operating conditions. The clear visualization of the electrical system helps reduce the operator's dependence on manually interpreting numerical data and improves the overall efficiency of substation supervision.

Overall, the obtained results confirm that the proposed MATLAB/Simulink-based SCADA interface provides a simple, flexible, and effective solution for monitoring and controlling substation operation. The developed approach can also be further extended by integrating real-time measurement data, alarm functions, historical data storage, and communication protocols to support practical SCADA applications in modern power systems.

IV. CONCLUSION

This paper presents the design and development of a substation SCADA program built on MATLAB App Designer integrated with Simulink, establishing an intuitive, flexible, and scalable tool for monitoring and control. The developed software enables real-time visualization of the operational status of major substation equipment while continuously updating key electrical

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parameters including voltage, current, and power via dynamic data exchange with the Simulink model. Furthermore, the system incorporates control capabilities for circuit breakers (CBs) and disconnectors (DSs) integrated with interlocking logic algorithms, ensuring that switching sequences strictly comply with standard substation operating procedures. Simulation results demonstrate that the application operates reliably, exhibits fast response times to control commands, and accurately reflects equipment states and electrical quantities under diverse operating conditions. Featuring a user-friendly graphical user interface (GUI) and a modular software architecture, the system offers high scalability for integrating additional functionalities or adapting to various substation configurations, making it well-suited for academic instruction, research, and the validation of power system control algorithms.

The research findings confirm that MATLAB App Designer is a suitable, cost-effective platform for developing SCADA applications for substation simulation and operational monitoring, thereby reducing reliance on expensive commercial SCADA software in educational and research environments. Integrating the simulation model and the monitoring interface within a unified environment streamlines algorithm validation, provides students and researchers with hands-on insight into power system operation principles, and establishes a robust framework for advanced power system studies.

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