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Leonardo Villela Makino

Development of a SCADA application for the integration of a substation in a control center

Florianópolis
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Final report of the subject DAS5511 (Course Final Project) as a Concluding Dissertation of the Undergraduate Course in Control and Automation Engineering at the Federal University of Santa Catarina in Florianópolis.
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This report is dedicated to the future collaborators of the company's Automation Department. I want to share a different perspective on the project basis and documentation.

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RESUMO

A evolução das tecnologias de informação e a introdução da telemetria em 1950 permitiram o desenvolvimento de um primeiro sistema supervisório que pode ser considerado o início dos atuais Sistemas de Supervisão e Aquisição de Dados (SCADA). Além desta tecnologia ter se tornado mais inclusiva, há ainda a expectativa de crescimento do setor de energia em seus diversos segmentos, o que poderá traduzir-se em novas instalações de linhas de transmissão e subestações. Esta ampliação do sistema de transmissão demandará possíveis novas integrações de plantas elétricas a centros de controles, contexto no qual as informações apresentadas neste trabalho se insere. Objetivou-se integrar uma nova aplicação SCADA ao centro de controle de uma empresa a fim de viabilizar a coleta, a supervisão e o controle dos dados operacionais da planta elétrica. Realizou-se também a documentação do sistema, de forma a ressaltar os procedimentos de desenvolvimento que poderão auxiliar na compreensão de outros processos de integração de transmissão futuros. Nas atividades de implementação, realizou-se o levantamento preliminar das informações operacionais da subestação, contextualizando-as com a proposta do projeto, visando a adequada análise dos diagramas unifilares e da lista de pontos SCADA. Nas atividades de documentação, foram ressaltados padrões genéricos de desenvolvimento da aplicação desenvolvida para fins didáticos. A partir da coesão entre os objetos de back-end e front-end, a aplicação pôde ser executada no servidor do centro de controle, para que as funcionalidades vitais fossem testadas e validadas por meio da operabilidade de suas telas. Foram validados dois conjuntos de IHMs que desempenham um papel importante na operação do sistema: o conjunto dos relés de proteção e o conjunto das telas de supervisão e controle do fluxo de energia. A integração alcançou o seu objetivo principal, viabilizando a supervisão e controle de uma subestação de forma remota, estando em concordância com as normas da Agência Nacional de Energia Elétrica (ANEEL) e em consonância com as políticas de operação do Operador Nacional do Sistema Elétrico (ONS). Os objetivos alcançados representam apenas uma parcela do que os sistemas SCADA podem fornecer, cabendo ainda trabalhos futuros que possam explorar as potencialidades das suas outras funcionalidades.

Palavras-chave: Automação. Telemetria. Protocolos de comunicação. Sistemas de transmissão de potência. Operação.

RESUMO EXPANDIDO

Introdução

Nos sistemas de potência elétrica, as primeiras soluções remotas para receber medidas e transmitir telecomandos entre localidades diferentes tiveram início na década de 1940 sendo então denominadas “Controle Supervisório”, operacionalizando equipamentos localizados em subestações afastadas. A evolução das tecnologias de informação e a introdução da telemetria em 1950 permitiram o desenvolvimento de um primeiro sistema supervisório que pode ser considerado o início dos atuais Sistemas de Supervisão e Aquisição de Dados (SCADA). A melhoria contínua do desempenho operacional dos processadores e da capacidade de armazenamento das memórias permitiram aos sistemas SCADA serem cada vez mais confiáveis, bem como evidenciaram-se as vantagens da sua aplicação para Sistemas de Automação de Subestações (SAS). Acompanhando o progresso das telecomunicações, os sistemas SCADA igualmente evoluíram em sua trajetória, tornando-se cada vez mais acessíveis às organizações e alcançando também as pequenas e médias empresas. Além desta tecnologia ter se tornado mais inclusiva, há ainda a expectativa de crescimento do setor de energia em seus diversos segmentos, o que poderá traduzir-se em investimentos de bilhões de reais em novas instalações de linhas de transmissão e subestações até 2027, segundo o Plano Decenal de Expansão de Energia (PDE) 2027 da Empresa de Pesquisa Energética (EPE). Esta ampliação do sistema de geração e transmissão demandará possíveis novas integrações de plantas elétricas a centros de controles, contexto no qual as informações apresentadas neste trabalho se insere.

Objetivos

O trabalho teve como objetivo geral integrar uma nova aplicação SCADA ao centro de controle de uma empresa de médio porte, para supervisionar e controlar remotamente uma subestação de transmissão. Visou-se a conexão automatizada entre subestação e centro de controle, a fim de viabilizar a coleta, a supervisão e o controle dos dados operacionais da planta elétrica, por meio da utilização de um sistema SCADA. Os objetivos específicos foram inteiramente relacionados ao desempenho de funções vitais de uma aplicação, tendo sido executados dentro do ambiente de desenvolvimento do software da fabricante. Assim, consideraram-se os seguintes objetivos específicos: (i) Conexão entre subestação e centro de controle por meio de objetos de driver; (ii) Definição dos alarmes de falhas operacionais; (iii) Geração de histórico operacional; (iv) Montagem das Interfaces Homem-Máquina (IHMs). Ainda, realizou-se também a documentação do sistema, de forma objetiva, para ressaltar os procedimentos de desenvolvimento que poderão auxiliar na compreensão de qualquer processo de integração futuro, de qualquer planta de transmissão de energia, utilizando o software SCADA Elipse E3.

Metodologia

A realização do trabalho dividiu-se em duas partes: implementação e documentação. Nas atividades de implementação, realizou-se o levantamento preliminar das informações operacionais da subestação, contextualizando-se estas com a proposta do projeto, visando a adequada análise dos diagramas unifilares e da lista de sinais SCADA, informações estas que serviram de insumo para o desenvolvimento do projeto. Após aprovação das análises, elaborou-se o cronograma de atividades de desenvolvimento, que compartimentou a integração em dezenas de tarefas, sendo a ordem de execução destas iniciada pelo *back-end*, com as atividades de estruturação de dados, seguida do *front-end*, com atividades de desenho das telas. Nas atividades de documentação, foram ressaltados os padrões de desenvolvimento existentes nas aplicações do centro de controle para o estudo e compreensão da metodologia empregada pela empresa. Após, iniciou-se, no ambiente de desenvolvimento SCADA um novo projeto de aplicação genérico, com o intuito de englobar as principais características e pressupor particularidades de projetos. A partir da composição dos elementos criados na etapa de documentação, produziram-se processos simplificados e generalizados das partes de maior importância para o desenvolvimento de uma nova aplicação.

Resultados e Discussão

A partir da coesão entre os objetos de retaguarda e da parte frontal, a aplicação pôde ser executada no servidor do centro de controle, para que as funcionalidades vitais fossem testadas e validadas por meio da operabilidade de suas telas, sendo estas um dos objetivos do trabalho. A conectividade entre a sala de comando da subestação e o centro de controle, relacionadas à confecção do driver foram validadas com o gráfico de conexão da interface física entre os locais, conforme gerado na tela de comunicação. A sinalização das ocorrências operacionais da planta na Tela de Alarmes validaram a correta detecção de falhas e eventos. As curvas do dia anterior geradas nas Telas de Medições e, suplementarmente, os dados recuperados de tabelas de banco de dados através de comandos SQL, validaram a geração do histórico. Além disso, também foram validados dois conjuntos de IHMs que desempenham um papel importante na operação do sistema: o primeiro conjunto de telas relacionou-se com sucesso com a automação dos relés de proteção em uma IHM de perspectiva macro, contendo todo o sistema de proteção da subestação, viabilizando a supervisão dos setores no formato de painel e em duas IHMs contendo a lista das proteções e apontando, especificamente, o tipo de proteção disparado em questão. O segundo conjunto refere-se às telas de supervisão e controle do fluxo de energia, proveniente dos diagramas unifilares, no qual, se dispôs uma IHM geral englobando os setores de tensão primário e secundário, uma individual para cada setor, e uma para o serviço auxiliar.

Considerações Finais

O projeto alcançou o seu objetivo principal, que era integrar uma nova aplicação SCADA ao centro de controle da empresa para supervisionar e controlar a subestação remotamente, estando em concordância com as normas da Agência Nacional de Energia Elétrica (ANEEL) e em consonância com as políticas de operação do Operador Nacional do Sistema Elétrico (ONS). As contribuições do curso de Engenharia de

Controle e Automação mostraram-se relevantes no engajamento do interesse do aluno para com o ramo de atividade experimentado. As disciplinas específicas proporcionam conceitos e ferramentas de automação que facilitaram o entendimento e desenvolvimento das atividades, e as disciplinas da área elétrica contribuíram com o contexto do segmento de energia e conhecimentos técnicos requeridos na área de eletrotécnica. É importante ressaltar que os objetivos específicos propostos e realizados representam apenas uma parcela do que os sistemas SCADA podem fornecer e que trabalhos futuros poderão explorar as potencialidades das suas outras funcionalidades, tal como a geração de relatórios para serem implementados em demandas semelhantes às deste trabalho.

Palavras-chave: Automação. Telemetria. Protocolos de comunicação. Sistemas de transmissão de potência. Operação.

ABSTRACT

The evolution of information technologies and telemetry in 1950 allowed the first supervisory system to be considered the beginning of the Supervision and Data Acquisition Systems (SCADA). In addition to this technology becoming more inclusive, there is also an expectation of growth in the energy sector in its various segments, translating into new installations of transmission lines and substations. This expansion of the transmission system will demand possible new integrations of electrical plants to control centers, a context in which the information presented in this work is inserted. The objective was to integrate a new SCADA application to a company's control center to facilitate the acquisition, supervision, and control of the electrical plant's operational data. System documentation was also carried out to highlight the development procedures that may help understand other future transmission integration processes. In the implementation activities, a preliminary survey of the operational information of the substation was carried out, contextualizing it with the project proposal, aiming at the adequate analysis of the single-line diagrams and the SCADA signals list. In the documentation activities, generic patterns of development of the application developed for didactic purposes were highlighted. The application could be executed on the control center server based on the cohesion between the back-end and front-end objects. The vital functionalities could be tested and validated through their screens' operability. Two sets of HMIs that perform an essential role in the system's operation have also been validated: protection relays and screens for supervising and controlling the energy flow. The integration achieved its primary objective, integrating a new SCADA application to the company's control center to supervise and control the substation remotely. It allowed attending the services of the Brazilian National Grid (known as SIN - *Sistema Interligado Nacional*) in compliance with the Brazilian Electricity Regulatory Agency (in Portuguese, Agência *Nacional de Energia Elétrica*, ANEEL) rules, and in line with the Operator of the Brazilian Grid (known as ONS - *Operador Nacional do Sistema Elétrico*) policies. It is essential to note that the specific objectives proposed and accomplished represent a part of what SCADA systems can provide. Future work may explore other potential features, such as generating reports to be implemented in demands similar to this work.

Keywords: Automation. Telemetry. Communication protocols. Power systems. Operation.

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LIST OF ABBREVIATIONS AND ACRONYMS

AI	Analog Input
ANEEL	*Agência Nacional de Energia Elétrica*
AO	Analog Output
ARPA	Advanced Research Projects Agency
ASCII	American Standard Code for Information Interchange
CSV	Comma-Separated Values
DI	Digital Input
DO	Digital Output
EPE	*Empresa de Pesquisa Energética*
HMI	Human-Machine Interface
IEC	International Electrotechnical Commission
IEC 104	IEC 60870-5-104
IOA	Information Object Address
IoT	Internet of Things
IP	Internet Protocol
ISO	International Standards Organization
LAN	Local Area Network
ONS	*Operador Nacional do Sistema Elétrico*
OSI	Open Systems Interconnection
PDE	*Plano Decenal de Expansão de Energia*
PLC	Programmable Logic Controller
PS	Power Systems
RTU	Remote Terminal Unit
SAS	Substation Automation System
SCADA	Supervisory Control And Data Acquisition
SIN	*Sistema Interligado Nacional*
SLD	Single-Line Diagram
SME	Small and Medium-sized Enterprise
TCP	Transmission Control Protocol
WAN	Wide Area Network

CONTENTS

1 INTRODUCTION

The world has never been as connected as nowadays. The growth of technological accessibility to Small and Medium-sized Enterprises (SMEs), the rise of the Internet of Things (IoT), and the new wave of Industry 4.0 are evidence of this connected world reaching industries in almost every field.

In the electric power systems, the first remote solutions using points connected from one side to the other side to receive measurements and transmit telecommands began as supervisory control. As a consequence of its first solutions in the electrical system to operate equipment located in remotes substation in the 1940s (RUSSELL, 2015), the introduction and evolution of telemetry-based implementation by the end of the 1950s, the North Electric Company and Westinghouse developed a supervisory system which can be considered the beginning of the SCADA (Supervisory Control And Data Acquisition) systems (UJVAROSI, 2016).

The next important step of the SCADA systems evolution was the appearance of microprocessors that allowed adding other functions and cost-effectiveness (UJVAROSI, 2016). The continuous boost of processor clock speed and memory size allowed the SCADA systems to be real-time and reliable (RUSSELL, 2015). The advantages of real-time observation and control, time-effective maintenance, elimination of manual data collection, and cost-effectiveness were turning clear for power systems purposes.

In the 1990s, the need for a SCADA and Substation Automation System (SAS) to supervise and control load better at a substation starts to increase with the attachment of new systems that also require online information from the network. Furthermore, over the decade, energy companies have been realized this need more and more as it happened with the electric utility company Cass County Electric Cooperative in 1995 (RUDOLPH, 1998).

Besides the rapid growth of communication in offering a considerable amount of data to use, the SCADA systems became more sophisticated, versatile, and mainly reliable to solve various complex problems in almost every field. A history of over 50 years of development to the Supervisory Control And Data Acquisition turns into SCADA's whole concept nowadays (UJVAROSI, 2016).

This project is inserted in the Brazilian electric sector within the transmission power system's scope, which uses the SCADA to intervene in a substation operation. This report's primary goal is to present the explanation and execution of integration between a substation and a control center.

1.1 MOTIVATION

Electrical energy plays an essential role in industrial societies. It is one of the bases of modern society that supports developing human activities and sustainability for countries to keep all aspects of their current social organizations, including education, economy, health, and government. Furthermore, energy consumption has a high capacity to stimulate economic and social development, central to access to clean water, agricultural and industrial production, health care, high-quality education accessibility, employment, and sustained poverty reduction (UN-ENERGY, 2005).

Whether it comes from hydraulic, wind, solar, or other alternative sources, all electrical energy must be planned and used strategically by the government, companies, industries, and society. Moreover, the more efficient the process of generation, transmission, and distribution of electricity, the more consistent the region's economic and social development is supposed to be. Also, to reduce costs, a stable and quality supply, and enhance access to service.

According to the Energy Research Office (EPE - *Empresa de Pesquisa Energética*), in the Ten-Year Energy Expansion Plan (known as PDE - *Plano Decenal de Expansão de Energia* (PDE)) 2027, the Brazilian government intends to increase the integration of different matrices and offer access to electricity more expansively and reliably due to the increase in final consumers expected to 2027 (EPE, 2017).

The expectation for the growth of the Brazilian economy in the medium and long term requires that the energy sector advance ahead of the other areas. In light of this, PDE estimates billions reais of investments in new installations of transmission lines and substations (EPE, 2017), which can also consider additional flows from other energy sources, with a significant share of wind and solar sources, besides hydraulic energy. Moreover, expanding the generation and transmission system implies several potentials new integrations cases with similar attributes. Mainly, by SCADA systems as a vital infrastructure (VALE et al., 2009) that can have thousands of data points and practically make the system failure-proof (UJVAROSI, 2016) in Power Systems (PS) applications.

This context of extension and modernization in the Brazilian electrical sector makes it easier for more small and medium-sized energy companies to act as strategic partners and offer specialized services, which may include remote operation. Consequently, SMEs are also taking advantage of the SCADA technology to increase operational efficiency providing control center operators with real-time data about the network condition and allowing automatic or semi-automatic remote procedures. Furthermore, integrating the SCADA system in control centers presented several benefits until now. It will help even more if industries keep on track the automation technologies evolution as well.

1.2 OBJECTIVES

The main objective is to integrate a new SCADA application in a control center to supervise and control a substation remotely. The first job is to gather information about the project and contextualize it to analyze the single-lines diagrams and the SCADA signal list, which are the project's inputs. Approved these inputs, the next job is to split the main objective is split into dozens of activities. The activities execution follows the specific objectives numbered order, which expresses a back-end to the front-end order.

The specific objectives are related to the application's vital functions and are performed within the software producer's development environment. Each of them seeks to accomplish one functionality like connectivity, detection, storage, and interactivity. In this context, the specific objectives and its functionalities details are:

1. Enable the communication between the control station and substation through the I/O Driver objects and IEC 60870-5-104 protocol (IEC, 2006);
2. Establish alarms to detect and supervise the critical plant's occurrences;
3. Store data on a database to maintain essential records for future analysis and decision making;
4. Create Human-Machine Interfaces (HMIs) to allow users to navigate and operate the application.

The documentation focuses more on the development procedures than the substation technical parameters to help comprehend any energy transmission plant's integration process using SCADA software, in this case, Elipse E3. Firstly, it was necessary to recognize the development patterns adopted in other control centers' applications to the study and comprehend the development methodology. In the software workspace, a generic application was modeled to represent the main characteristics and identify new patterns. The composition of these two materials results in the simplified and generalized processes of the crucial development stages.

1.3 STRUCTURE

The report is divided into five chapters. Chapter 2 summarizes concepts necessary about the integration and the substation operation to have a theoretical background for the development interpretation. It provides the basis of SCADA and communication protocol—also, it indicates which technology the implementation uses between them. Chapter-ending gives the fundamentals of transmission system operation, presenting its functions and elements.

Chapter 3 explains the implementation procedure of the presented framework. It introduces an overview of the integration, illustrates the elements, and connects each self with the specific objectives. The chapter then focuses on an in-depth analysis of the elements, giving their development processes and showing it in the SCADA software. Also, it follows a development order from the back end to the front end.

Chapter 4 presents the project results, as well as the specific objectives validation. It begins displaying the charts of the communication and measurement HMIs to validate the first and second specific objectives. Then, it introduces the control center's supervising and controlling environment, where the HMIs are shown. Finally, the chapter directs the operational HMIs, confirming the third and fourth objective validation.

Chapter 5 summarize the entire development and obtained results. Then, it explains the course's importance and contributions to the integration development. At last, the section ends with a topic regarding future works.

2 THEORETICAL FRAMEWORK

This chapter demonstrates an understanding of the theories and concepts that are relevant to the substation integration topic. The theoretical framework involves two big concept groups. The first group holds the automation engineering concepts explaining SCADA and communication protocols. Moreover, it indicates which technology the implementation uses. The second one supports the power engineering concepts involved in a substation operation. It presents the transmission system operation fundamentals and the principal substation elements.

2.1 SCADA SYSTEMS

SCADA is an acronym for Supervisory Control and Data Acquisition. SCADA systems are commonly used to supervise and control critical processes in industries and infrastructure utilities such as energy distribution and water supply. Its use extends to industrial automation and system that are geographically widespread—A single infrastructure can have thousands of devices spread over hundreds of miles.

The SCADA system refers to the telemetry and data acquisition combination and involves hardware and software constructs (CLARKE; REYNDERS; WRIGHT, 2003). According to (UJVAROSI, 2016), the typical components of SCADA systems are:

Remote Terminal Unit (RTU) is a microprocessor-controlled electronic device that collects digital and analog parameters from the field sensors. It interfaces objects in the physical world to the data acquisition server, connecting data input streams to data output streams, defining the communication protocol, and transmitting data via the telemetry system. Also, it can use messages from the operator workstations to control connected objects;

Programmable Logic Controller (PLC) also gathers information from sensors and actuators, but it focuses on making logic-based decisions for automated processes and machines. It is an industrial digital computer specially designed to operate reliably under harsh industrial environments and can interchange data with supervisory control. The advantage of the PLCs over the RTUs is that they can be used in a general-purpose role and set up for various functions. On the other hand, the PLCs may not be proper for specialized requirements, such as radio telemetry applications (CLARKE; REYNDERS; WRIGHT, 2003);

Human-Machine Interface (HMI) is any device or software that allows an operator to interact with a machine. The HMIs in the SCADA systems are the plant's supervision and control windows present in the operator workstations and supervisory control. It displays the acquired and processed data and allows the operator to perform remote control tasks;

Historian Service is the SCADA part that accumulates time-stamped data, alarms, and other crucial information into the databases. It enables the HMIs to query data and process into graphics, trends, notifications, reports, among other functions with past information;

Telemetry system provides the pathway for connecting remote points to transmit and receive data through a communication channel. The communication channel can be Wide Area Network (WAN) circuits, cable, and wireless systems. Thus, it allows data transfer between the field devices and RTUs and PLCs and between PLCs and the data acquisition server;

Data Acquisition Server accesses the RTUs or PLCs through the communication protocols and client-server architecture and shares its information in the SCADA network. Typically, Local Area Network (LAN) is the communications path between the data acquisition server and the operator workstations. Furthermore, the ethernet is the LAN connection most widely used in the SCADA networks (CLARKE; REYNDERS; WRIGHT, 2003);

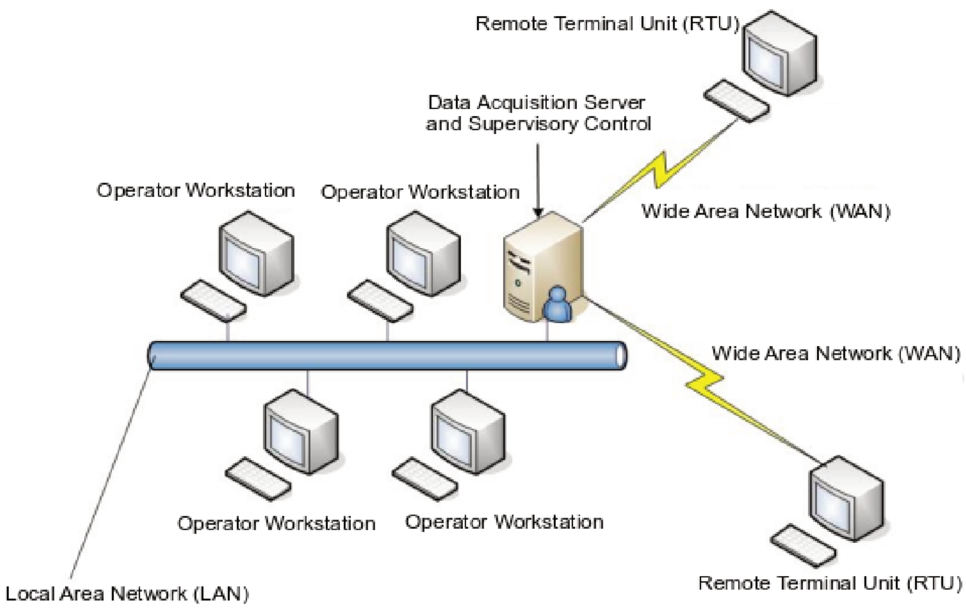
Supervisory Control is the principal part of a SCADA system containing the specific SCADA software and running as a central host server. Also, it can communicate with the field connection controllers and send commands to the field connected devices.

Figure 1 exemplifies a distributed SCADA system across multiple systems. The remote terminal units exchange information with the data acquisition server via WAN communication channel. In this example, a single PC holds the data acquisition server and supervisory control, which usually occurs in smaller SCADA systems. Thus, the PC gathers data from the RTUs and shares it into a LAN network with the four operator workstations.

As stated by CLARKE; REYNDERS; WRIGHT (2003), the SCADA hardware consists of the field instrumentation, field data interface devices presented as RTUs and PLCs, telemetry system, master station(s), and operator workstations. Figure 2 represents the composition of these elements in their hierarchy.

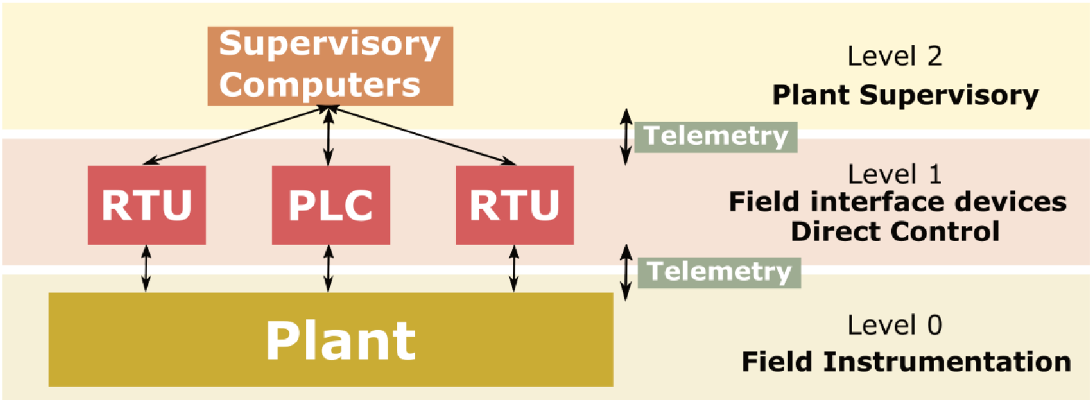
SCADA software is the collection of application programs present in the SCADA systems. It can be proprietary or open-source type. The proprietary is usually developed by the company to communicate with its hardware. The open-source refers to software simultaneously considered free and which allows the user to inspect the source code. Open SCADA software systems can mix different manufacturers' equipment in the same system. The features of SCADA software include:

Figure 1 – Example of a distributed SCADA architecture.



Source: Adapted from UJVAROSI (2016).

Figure 2 – SCADA hardware elements composition in a hierarchy scheme.



Source: Adapted from PUGLIESI (2014).

- User interfaces;
- Graphical displays;
- Alarms;
- Trends;
- RTU and PLC interface;
- Scalability;
- Access to data;

- Database;
- Networking;
- Fault tolerance and redundancy;
- Client/server distributed processing.

2.1.1 Elipse E3

Elipse E3 is a SCADA developed by Elipse Software, a Brazilian industrial automation software producer, focused on network operation and distributed applications. Moreover, it is the SCADA software used for the integration in Chapter 3.

E3 (ELIPSE, 2019) allows a real-time and well-established platform for critical and operational systems like energy generation, transmission, and distribution. Also, it offers an advanced object model, a powerful graphical interface, and connectivity to other applications, communicating with several protocols and devices, which includes both local and geographically distributed systems.

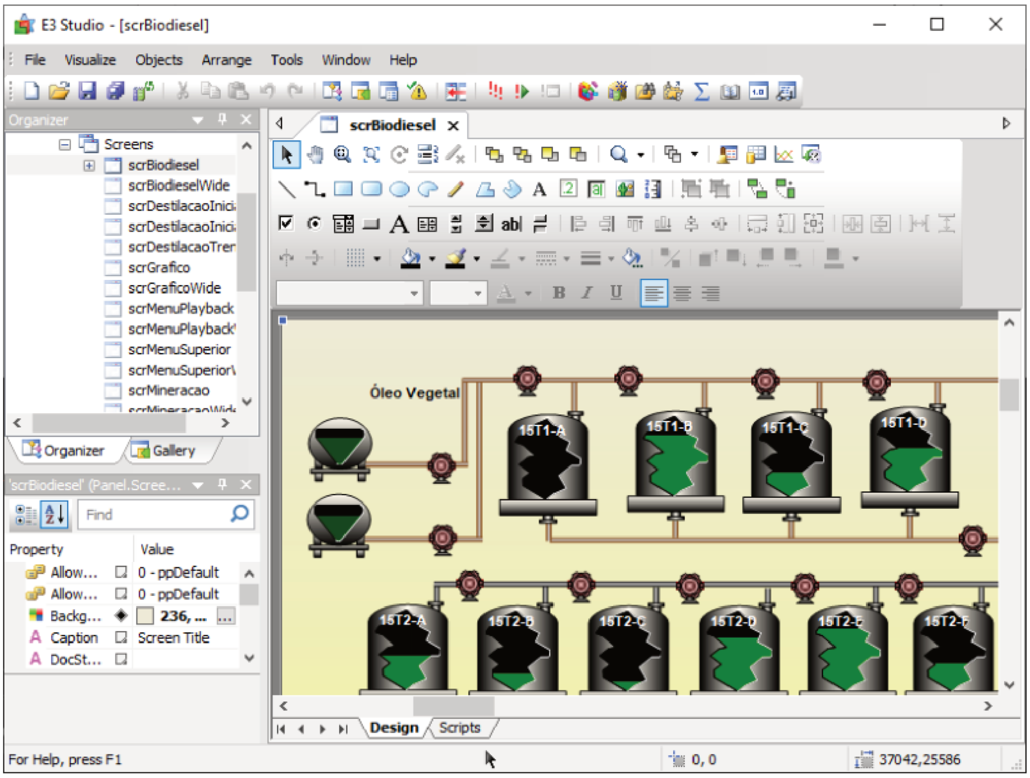
E3 User's Manual states that the E3 package solution is divided into independent computer programs to execute specific activities and functions. E3 computer programs are:

- **E3 Server** is the application responsible for executing real-time communication with external devices. Also responsible for sharing data to the SCADA network;
- **E3 Admin** coordinates the information traffic among all the components. It is the main module that manages the components and allows the execution of distributed objects;
- **E3 Viewer** is the viewing and controlling environment for E3 applications. It is the operational user interface where the HMIs are displayed;
- **E3 Studio** is the development environment. It offers a graphic editor to set up server tasks and create user interfaces, which comes with configured menus and toolbars, as shown in Figure 3. Further, it includes a text editor to code in VBScript language.

2.2 COMMUNICATIONS STANDARDS

Communications standards provide a management structure for data communication to interconnect open systems. Open systems allow equipment from any manufacturer to be accessible to other's manufacturer equipment.

Figure 3 – E3 development environment, E3 Studio, after creating a new project.



Source: Reproduced from ELIPSE (2019, p. 06).

Developed by the International Standards Organization (ISO), the Open Systems Interconnection (OSI) model is a conceptual model that characterizes and standardizes the communication functions. It breaks data communication into seven abstraction layers from the physical implementation communication medium to the highest-level representation of a distributed application data. Each layer holds a class of functionality and interfaces with layers above and below it. Furthermore, some flexibility is allowed so that the system designers can develop protocols for each layer. Thus, the OSI model is an overall framework that defines the functions or services provided at each of the seven layers to define protocols, as illustrated in Figure 4.

In agreement with CLARKE; REYNDERS; WRIGHT (2003), the summary of the layers are:

Layer 1 - Physical defines the electrical signals and mechanical connections at the physical level;

Layer 2 - Datalink is responsible for assembling and sending a frame of data from one system to another;

Layer 3 - Network is responsible for messages routing;

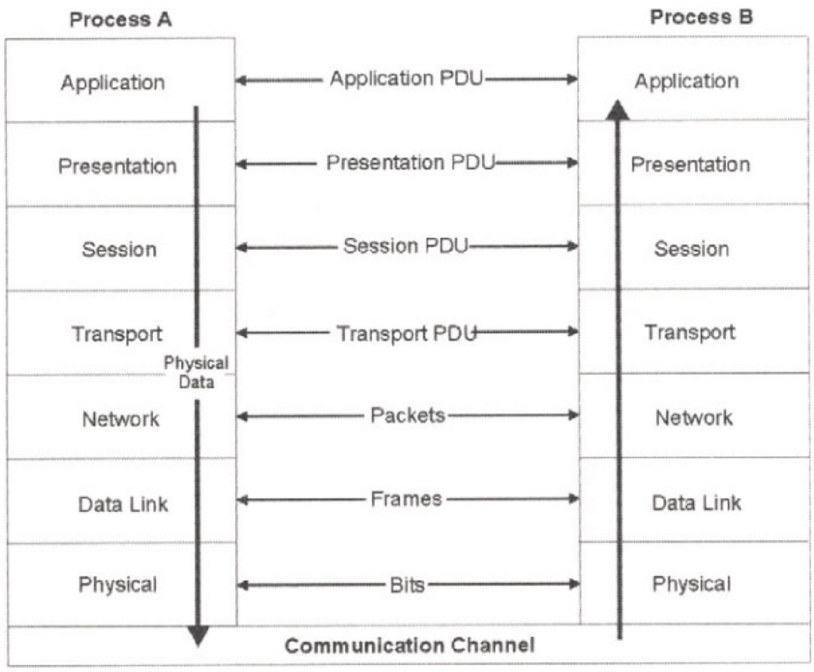
Layer 4 - Transport the management of the communications between the two end systems;

Layer 5 - Session controls communications (sessions) between the users;

Layer 6 - Presentation primarily takes care of data representation, which includes encryption;

Layer 7 - Application is the provision of network services to the user's application programs.

Figure 4 – OSI model full architecture.



Source: Reproduced from CLARKE; REYNDERS; WRIGHT (2003, p. 59).

In addition to the OSI model, the ARPA model (also known as the DoD model) was developed in the USA by the Advanced Research Projects Agency (ARPA). Both serve as models for a communications infrastructure and provide layers of abstractions (CLARKE; REYNDERS; WRIGHT, 2003).

The ARPA model is the communication model used to construct the ARPANet, later known as the Internet. It consists of the following layers:

Layer 1 - Network Interface provides the physical link between devices. Also known as the local network or network access layer;

Layer 2 - Internet isolates the host from specific networking requirements;

Layer 3 - Service supplies the host service requirements;

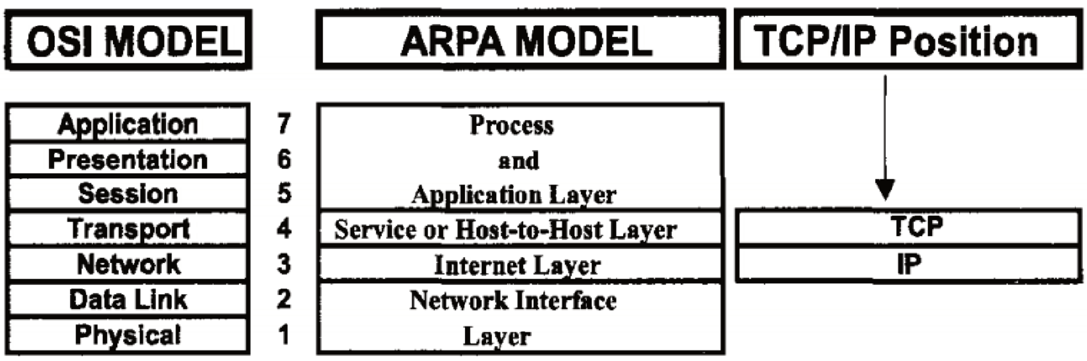
Layer 4 - Process and Application provides user-to-host and host-to-user processing and applications.

In layer 1, LANs interconnects computers over a restricted geographical area, while WANs link LANs separated by large distances using telecommunication technologies. The way the nodes are connected to form a network is the topology. The concept of internetworking allows the interconnection of many different physical networks as a coordinated unit.

A global standard for interconnecting internetwork applications is the TCP/IP. Transmission Control Protocol (TCP) and Internet Protocol (IP), together as TCP/IP is a protocol suite consisting of many interrelated protocols that occupy the upper three layers of the ARPA model, which allows communication across any two interconnected networks.

Whereas the OSI model has seven layers, the ARPA model has four layers. The OSI session, presentation, and application layers are contained in the ARPA process and application layer. The OSI transport layer maps onto the ARPA service layer, while the OSI network layer maps onto the ARPA internet layer. At last, the OSI physical and data link layers map onto the ARPA network interface layer. The relationship between the OSI and the ARPA communications models, showing the TCP and IP components' placement, is shown in Figure 5.

Figure 5 – Comparison between the OSI and the ARPA communications models, showing the TCP and IP components' placement.



Source: Adapted from CLARKE; REYNDERS; WRIGHT (2003).

2.2.1 IEC 60870-5-104

IEC 60870 (CLARKE; REYNDERS; WRIGHT, 2003) refers to a standard produced in several parts between 1988 and 2000 by the International Electrotechnical Commission (IEC) to provide an open standard for controlling electric power applications and other geographically widespread control systems. Its structure is hierarchical, containing six parts published separately in a progressive manner, as shown in Table 1.

Table 1 – IEC 60870 main parts.

Reference	Description	Year
IEC 60870-1	General Considerations	1988
IEC 60870-2	Operating Conditions	1995
IEC 60870-3	Interfaces (electrical characteristics)	1989
IEC 60870-4	Performance Requirements	1990
IEC 60870-5	Transmission Protocols	1990
IEC 60870-6	Telecontrol Protocols Compatible with ISO and ITU-T Recommendations	1995

Source: Adapted from CLARKE; REYNDERS; WRIGHT (2003).

The fifth part, IEC 60870-5, is the part required in the integration. It provides a detailed functional description to define transmission protocols in electric power systems for SCADA communication. It has five sections, IEC 60870-5-1 to IEC 60870-5-5, which specify the protocols' basis and the specifications—also, four companion standards, IEC 60870-5-101 to IEC 60870-5-104 (IEC 104), providing details of the standard for a particular field application and intended for a specific purpose. Table 2 presents IEC 60870-5 standards in its structure.

Table 2 – IEC 60870-5 sections and companions description.

Reference	Description	Year
IEC 60870-5-1	Transmission Frame Formats	1990
IEC 60870-5-2	Link Transmission Procedures	1992
IEC 60870-5-3	General Structure of Application Data	1992
IEC 60870-5-4	Definition of Application Information Elements	1993
IEC 60870-5-5	Basic Application Functions	1995
IEC 60870-5-101	Basic Telecontrol Tasks	1995
IEC 60870-5-102	Transmission of Integrated Totals	1996
IEC 60870-5-103	Protections Communications	1997
IEC 60870-5-104	Network Access using Standard Transport Profiles	2000

Source: Adapted from CLARKE; REYNDERS; WRIGHT (2003).

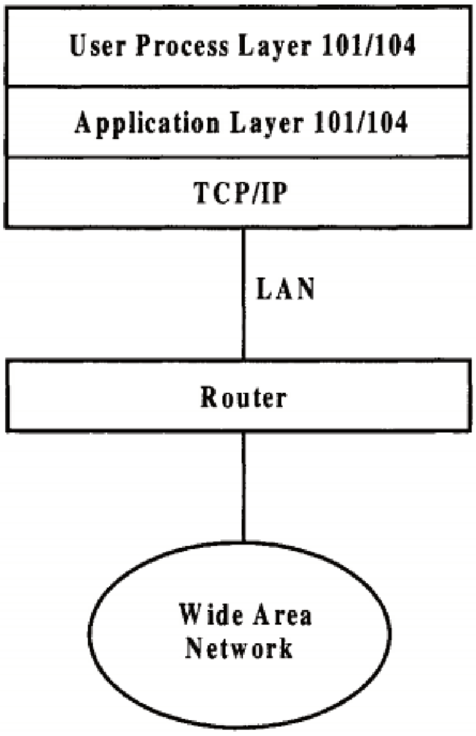
IEC 60870-5-101 provides the first complete working SCADA protocol under IEC 60870-5. It defines the necessary application-level functions and data objects for telecontrol applications operating over geographically broad areas using low bandwidth bit-serial communications. It also covers general communications with RTUs, including data types and services suitable for electrical and substation systems.

IEC 60870-5-102 and IEC 60870-5-103 provide data types and functions to support electrical protection systems, including distance protection, line differential protection, and transformer differential protection.

IEC 60870-5-104 is an extension of the IEC 60870-5-101 protocol with the changes in transport, network, link, and physical layer services to accommodate the complete network access. It enables the communication between the control center and substation via a standard TCP/IP network, which allows connectivity to the substation LANs and routers.

Figure 6 shows the IEC 60870-5-104 (or IEC 104) general communication arrangement of a field device connecting to a local area network. TCP/IP addresses a port number and an IP address for each separate piece of equipment connected to a network. From the LAN, messages can travel directly to other IEC 104 devices on the LAN or via routers to the remotely located equipment such as the control center's data acquisition server.

Figure 6 – General communication arrangement of a field device connecting to a LAN.



Source: Reproduced from CLARKE; REYNDERS; WRIGHT (2003, p. 301).

The integration case uses IEC 104 protocol to establish communication between the control center and substation and remotely cover the substation operation.

2.3 FUNDAMENTALS OF TRANSMISSION SYSTEM OPERATION

Electric energy is produced at power plants and transported over high-voltage transmission lines to utilization points (EL-HAWARY, 2008). The transmission lines' interconnection is the transmission network. In Brazil, its union with the generation system forms the National Grid, known as *Sistema Interligado Nacional* (SIN), in Portuguese.

The transmission system operations' principle is balancing energy production and consumption at all levels and locations (BOLLEN; HASSAN, 2011). As long as the actual consumption and production are predicted, operator intervention is no need in the transmission network. Under other conditions, the transmission network requires active interventions by the operators importing any shortage from somewhere or exporting any surplus elsewhere. When unexpected unbalance occurs, operators can use reserves to cover the energy loss and rebalance the network.

The interventions depend on SCADA systems for sensing, supervising, gathering, and controlling information from distributed devices. The operator interprets measures such as voltage, power, and frequency of the transmission system to control or not the transmission substation equipment like circuit breakers, disconnect switches, and transformers. Therefore, substation specifications and details are essential to transmission system operation.

2.3.1 Transmission Substation

Electric power may flow through several substations at different voltage levels between the power plants and the consumers. A transmission substation allows the transfer of bulk power across the network, connecting two or more transmission lines. Also, it provides electrical power for circuits that feed distribution stations and can work as the transmission lines' endpoints (MCDONALD, 2004).

It combines switching, controlling, and voltage step-down equipment to control power flow between two adjacent power systems and reduce transmission voltage to sub-transmission voltage to feed distribution substations. Chapter 2 covers only the large switching and step-down equipment types, which appear in the HMIs.

Switching equipment (MCDONALD, 2004) allows lines connection and isolation, load switching or not, and interruptions for fault clearance or maintenance. Step-down equipment transforms voltage from high to low or the reverse. Some of the principal equipment for the switching types are disconnect switches and circuit breakers, and for the step-down types are the power transformers. These equipment plus lines compound the principal substation elements, which the descriptions are:

Disconnect Switches are mechanical devices that change connection within a circuit or isolate a circuit from its power source. Switches can be equipped with grounding blades to perform grounding function. Moreover, they provide visible confirmation of the power conduction if it is opened or closed;

Circuit Breakers are mechanical switching devices capable of making, carrying, and breaking currents under normal circuit conditions and breaking currents under specified abnormal circuit conditions such as a short circuit and overload current. They are protections devices used to interrupt fault automatically, switch the load on and off, or cut off a line;

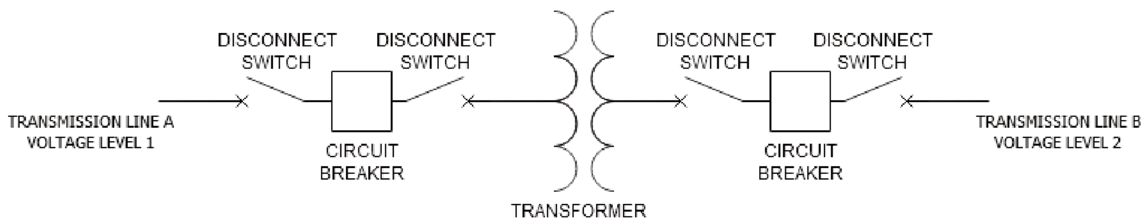
Transformers are static machines that function to transform system voltage from one nominal level to another. A transformer interconnects two different transmission lines or changes voltage levels from transmission voltages to lower distribution voltages;

Lines refers to the conductors designed to carry electricity. Transmission lines carry relatively high voltages, varying from 138 kV up to 765 kV, over large distances with minimum losses.

A simplified form to show the principal substation elements (disconnect switches, circuit breakers, transformers, and lines) and the protections are through the Single-Line Diagrams (SLDs), also known as One-Line Diagram. A single-line diagram is a schematic diagram covering the essentials switching and step-down equipment and its line connections. It shows the relevant information about the system in a high-level view (EL-HAWARY, 2008) and is usually used as input to develop HMIs based on the substation's physical layout.

Figure 7 shows a basic single-line diagram for transmission substation. In this SLD, the circuit breakers on each transmission line help prevent line faults. Disconnector switches on both sides of the circuit breakers and transformer allow the equipment isolation during maintenance. Transformer interconnects the two transmission lines and transforms voltage level 1 to voltage level 2, or reverse.

Figure 7 – Basic Transmission Substation.



Source: Original.

The report's substation intends to expand the distribution energy capacity of a microregion of Rio de Janeiro, Brazil. Its transformer step-down voltage from 500kV to

138kV to interconnect four transmission lines. All its communication information that identifies the inputs and outputs is organized into a SCADA signal list (Figure 8) and accessible by SCADA as a tag, a computer language variable.

Figure 8 – SCADA Signal List Example.

Voltage	Equip. ID	IED	Description	TYPE	IOA
500kV	CB 1	IED 1	Circuit Breaker 1 Position	31	1
500kV	CB 1	IED 1	59 Overvoltage Relay	30	2
500kV	CB 1	IED 1	63 Pressure Switch Stage 1	30	3
500kV	CB 1	IED 1	63 Pressure Switch Stage 2	30	4
500kV	CB 1	IED 1	27 Undervoltage Relay 1	30	5

Source: Original.

3 DEVELOPMENT

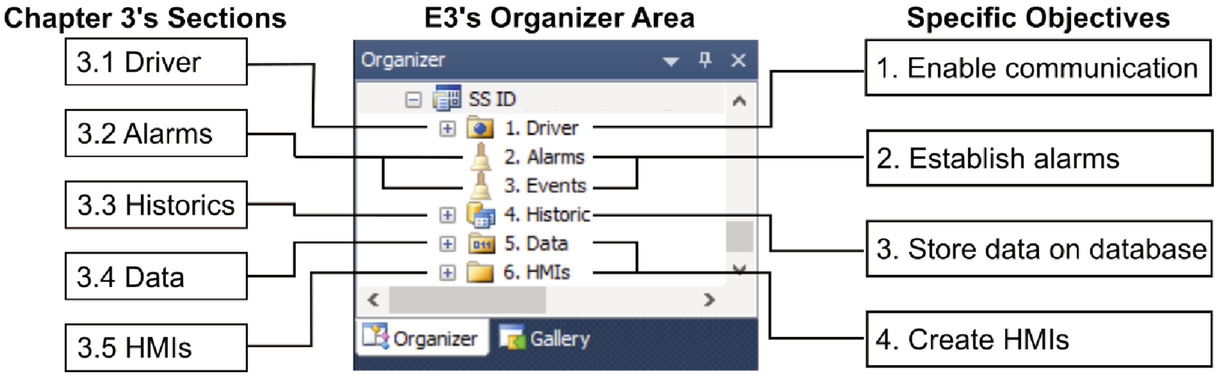
This chapter presents the substation project's development procedures in the Elipse E3 Studio and aims to clarify the processes' resolution in each part of the project through its sections.

Section 3.1 explains the communication objects and their IEC 104 protocol set up. Also, it covers a structure model for the objects and patterns for their names. Section 3.2 classifies the substation's variables registered in the communication objects into operational alarms or events. It explains the alarm objects and the necessary properties to set them up to the project usage. Section 3.3 then deals with data storage through historic objects and their fields. It focuses on the development process steps from the object creation until the data storage on the database.

The fourth and the last part, Section 3.4 and Section 3.5, present, in its larger portion, the objects customized by the user to create the HMIs. Section 3.4 shows the customized data configuration process for command outputs and real-time inputs. Finally, Section 3.5 explains the creation of the HMIs through the screen objects and the linking process with the backend objects and tags. It covers HMIs for measurement, communication, protection, and operational purposes.

It is important to emphasize that it started from a company's project. Therefore, it was preferred for didactic purposes and confidentiality issues to build a generic model project, omitting its confidential data, and protecting business information. Figure 9 shows the generic model project called SS ID (Substation Identification) in the E3 organizer area. The different icons indicate different objects in the organizer below the SS ID name. Further, Figure 9 also correlates them with its section and specific objective. The development chapter explains one by one, starting from I/O Drivers.

Figure 9 – E3's Organizer Area and its relationship with Chapter 3's Sections and specific objectives of the integration.



Source: Adapted from ELIPSE (2016).

3.1 DRIVER

The Elipse E3 Driver allows communication with data acquisition servers, PLCs, and RTUs through its objects (ELIPSE, 2019). In this project, the driver objects necessary to communicate with the substation's local SCADA, and consequently with all equipment, are the I/O Driver, I/O Folder, I/O Tag, and Block Element.

The driver development process starts with the I/O Driver because it is the object that gathers all the other driver objects. It then continues with the folder structure through the I/O Folders, incorporating the I/O Tags and I/O Block Element, and finishing with the object renaming and configuration steps. This process can be interpreted in the following tasks:

1. I/O Driver configuration;
2. I/O Folders structuring;
3. Incorporation of the I/O tags and I/O Blocks;
4. Objects renaming;
5. Tags configuration.

3.1.1 I/O Driver Configuration

Each I/O Driver uses different devices and protocols according to each project requirement and specifications. For this power system automation application, the communication between Elipse E3 and substation's local SCADA occurs through a unique I/O Driver module named Driver, as shown in Figure 9.

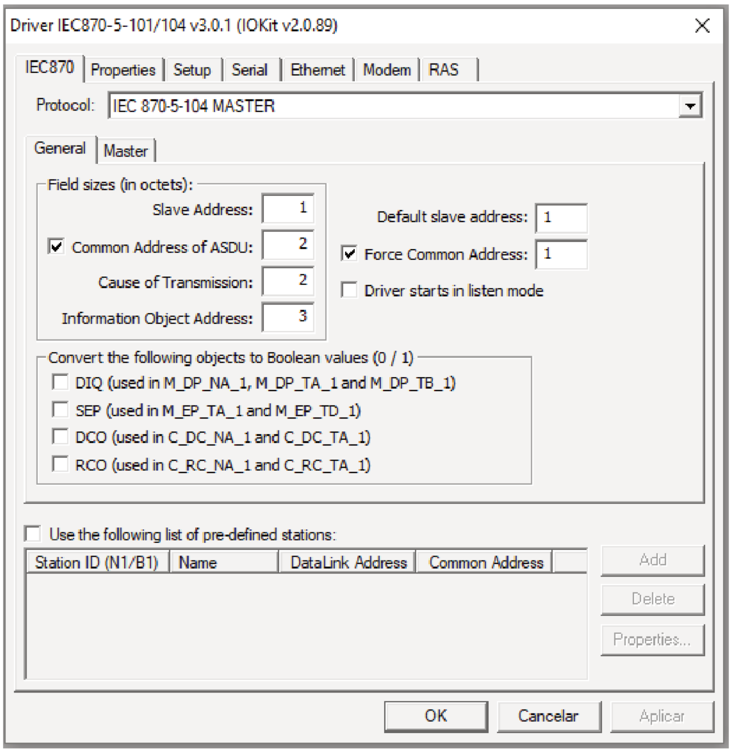
Driver configuration needs two setting steps to allow communication. The first step is importing a dll file containing the IEC870-5 standard. This dll file is available on the software owner site, and it incorporates the Master and Slave's IEC870-5-104 protocols setting. The second one is configuring the individual settings on the I/O Driver Setting Window (Figure 10).

Figure 10 window permits the additional parameter configuration for systems' communication, such as the physical and transport layers and IP addresses. The project's I/O Driver uses the IEC-104 master protocol, ethernet as the physical option, and TCP/IP as the transport option. It also sets the data acquisition servers' IP addresses of the company and the substation.

3.1.2 I/O Folders Structuring

The I/O Folders define groups to organize variables. This object also allows naming as needed and creating subfolders. After configuring the individual settings, the

Figure 10 – I/O Driver Setting Window displayed according to IEC870-5 dll file.



Source: ELIPSE (2016).

next process fills the I/O Driver with I/O Folders following a tree structure, which initiates in the Driver's root directory and advances to the tree's external nodes as illustrated in Figure 11.

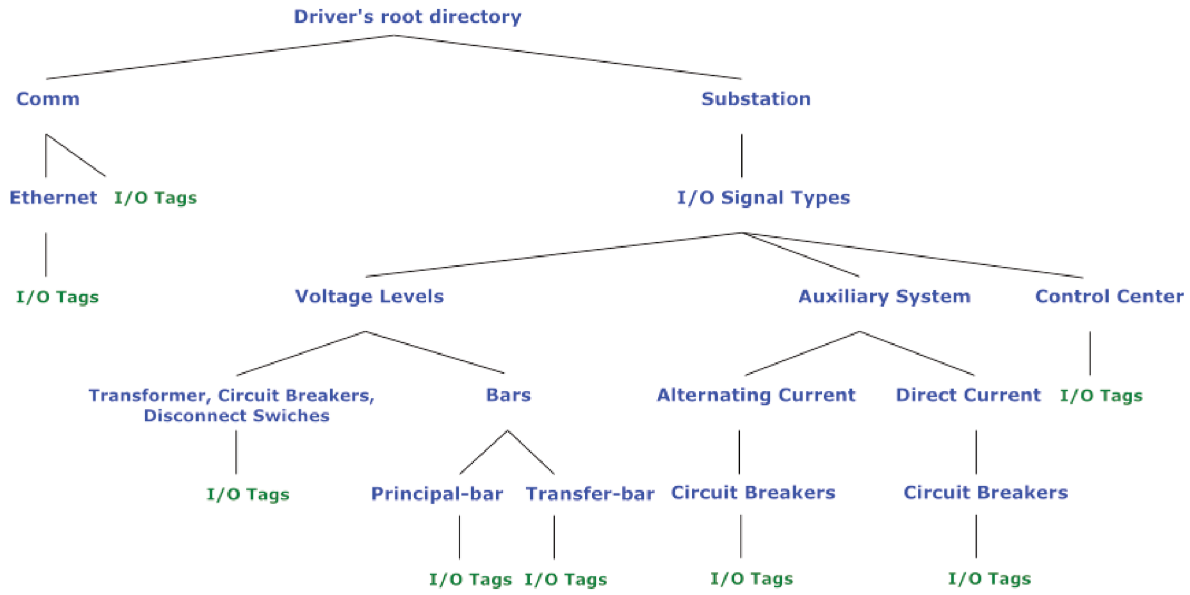
In the Driver directory root, the first folder division is the communication folder (Comm) and substation folder (Substation). The Comm folder organizes I/O Tags, I/O Blocks, and a subfolder to support communication. The communication objects come from IOKIT, a shared component embedded (ELIPSE, 2017) in the IEC870-5 dll file, which allows them to access the physical layer and provide interfaces. The Substation folder organizes tags of the SCADA signal list. It concentrates all the substation's variables in specific groups such as its signal type, voltage level, and equipment. The summary of the signal types node and its child nodes is:

I/O Signal Types carries the different types of signals folders, which can be four types: analog input, analog output, digital input, digital output;

Voltage Level organizes tags according to the level of the operating voltage. For each voltage level folder, it can have folders to organize tags by equipment and bars. Equipment folders refer to transformers, circuit breakers, and disconnect switches folders and bars folders divide tags of the principal and transfer bars;

Auxiliary System organizes the auxiliary system variables. It divides the auxiliary sys-

Figure 11 – Driver's I/O Folder tree struture.



Source: Original.

tem into alternating and direct current systems folders. For each current system type, it carries the circuit breakers folders involving that system;

Control Center contains I/O Tags associated with the substation remote and local operation. These tags are necessary for the digital input and output folders to read and command remote and local status.

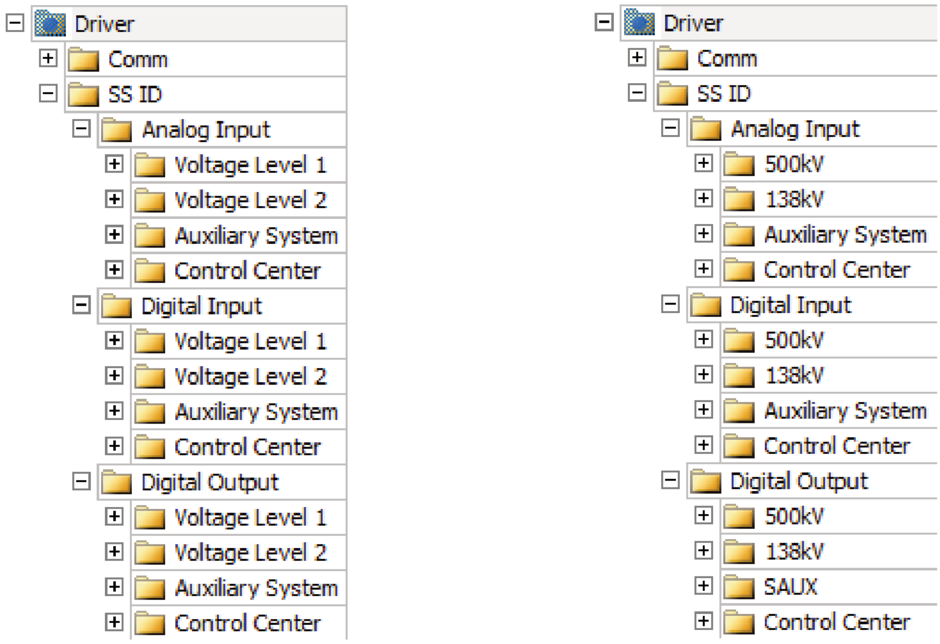
Figure 12 shows the first subfolder layer of the signal types folders, except the analog output folder, for the generic (Figure 12a) and substation (Figure 12b) projects in the E3 workspace. They have two operational voltage levels, one auxiliary system, and the control center acquisition folder. There is no analog output folder in the signal types folders in the company project case because there is no tag of this signal type in the SCADA signal list. The 500kV folder represents the primary power line voltage, voltage level 1, organizing circuit breakers, disconnector switches, and high-level transformer tags. The 138kV folder represents the secondary power line, voltage level 2, organizing transmission lines, bus bars, and distribution-level transformer tags.

3.1.3 Incorporation and Configuration of the I/O Tags and I/O Blocks

The I/O tags are independent variables that enable reading or writing values using an I/O Driver. The I/O Blocks also define information exchange with an acquisition device, but it uses one or more variables as a communication block. Further, depending on the communication method, users can save time communicating using I/O Blocks by obtaining a more extensive number of updates simultaneously than an I/O Tag.

Figure 12 – The first subfolder layer of the signal types folders in the E3 workspace.

(a) Generic project's first subfolder layer. (b) Substation project's first subfolder layer.



Source: ELIPSE (2016).

The I/O Tag filling process can be done by right-clicking on the driver icon, selecting the Insert - I/O Tag option, then entering the number of tags. An option to fill the I/O folders is to enter some tags in the Driver's directory root (Figure 13) and move them to its respective I/O folder. After designating each tag, they can receive names and parameters to associate themselves with the SCADA signal list elements. Figure 13's P columns (P1, P2, P3, and P4) configuration allow selecting the signal type and its specification, which can vary according to the protocol utilized.

Figure 13 – Five generic tags inserted in the Driver's directory root.

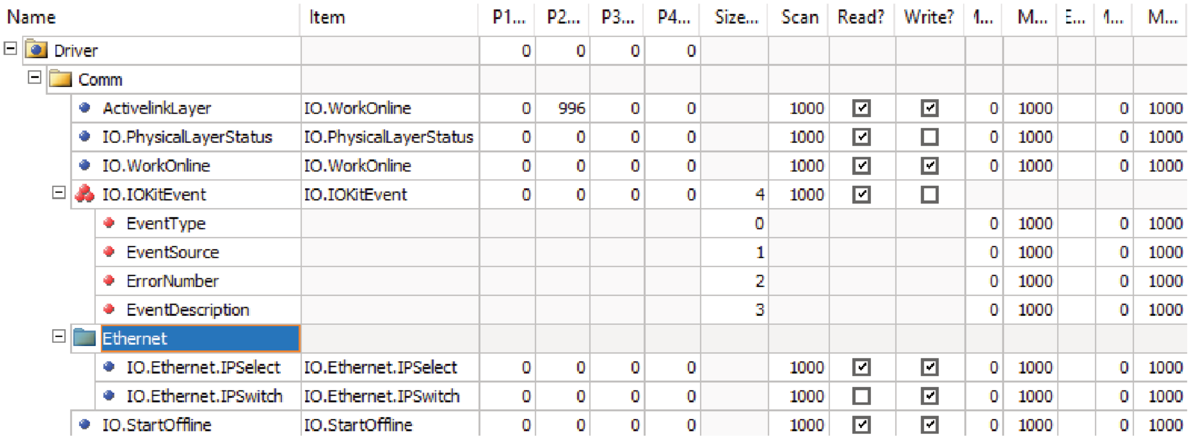
Name	P1...	P2...	P3...	P4...	Scan	Read?	Write?	Min. EU	Max. EU	Min. I/O	Max. I/O
Driver	0	0	0	0							
Tag1	0	0	0	0	1000	☑	☑	0	1000	0	1000
Tag2	0	0	0	0	1000	☑	☑	0	1000	0	1000
Tag3	0	0	0	0	1000	☑	☑	0	1000	0	1000
Tag4	0	0	0	0	1000	☑	☑	0	1000	0	1000
Tag5	0	0	0	0	1000	☑	☑	0	1000	0	1000

Source: ELIPSE (2016).

In this project, just the Comm folder uses an I/O Block object, the IO.IOKitEvent of Figure 14, for the IOkit events generated by various sources on the communication interfaces. On the other hand, there are 2000 I/O Tags that split into 200 (10%)

analog inputs, 1640 (82%) digital inputs, 154 (7.7%) digital outputs, and six (0.3%) communication tags.

Figure 14 – Comm I/O Folder struture in Elipse E3 workspace.



Name	Item	P1...	P2...	P3...	P4...	Size...	Scan	Read?	Write?	1...	M...	E...	1...	M...
Driver		0	0	0	0									
Comm														
ActivelinkLayer	IO.WorkOnline	0	996	0	0		1000	☑	☑	0	1000		0	1000
IO.PhysicalLayerStatus	IO.PhysicalLayerStatus	0	0	0	0		1000	☑	☐	0	1000		0	1000
IO.WorkOnline	IO.WorkOnline	0	0	0	0		1000	☑	☑	0	1000		0	1000
IO.IOKitEvent	IO.IOKitEvent	0	0	0	0	4	1000	☑	☐					
EventType						0				0	1000		0	1000
EventSource						1				0	1000		0	1000
ErrorNumber						2				0	1000		0	1000
EventDescription						3				0	1000		0	1000
Ethernet														
IO.Ethernet.IPSelect	IO.Ethernet.IPSelect	0	0	0	0		1000	☑	☑	0	1000		0	1000
IO.Ethernet.IPSwitch	IO.Ethernet.IPSwitch	0	0	0	0		1000	☐	☑	0	1000		0	1000
IO.StartOffline	IO.StartOffline	0	0	0	0		1000	☑	☑	0	1000		0	1000

Source: ELIPSE (2016).

The tag names derive from the cells of the SCADA signal list Description column (Figure 15a). The Description column's names receive a data manipulation on excel through a macro[1], following Table 3 procedure. First, the macro changes the letter case, then removes the third Table's row special characters and replaces the spaces and special characters with underscores. Next, the macro converts accented letters into their direct American Standard Code for Information Interchange (ASCII) equivalents, insert brackets between strings initiated with numbers, and removes special character duplications. As a result, the Description column names in Figure 15a alter to Figure 15b names.

Following the IEC870-5-104 standard, there is a different configuration involving I/O Tags for each signal type. Therefore, Table 4 presents the signal parameters required in the project, and Figure 16 shows an implementation example of five digital inputs in the E3 workspace.

[1] Macro is a programming code that runs in Excel, usually used to automate repetitive tasks.
[2] The first letter capitalized and the rest as lowercase except for acronym.

Table 3 – Characters find and replace procedure to manipulate data from Description column cells.

Steps	Find	Replace for
1	Lowercase or proper[2]case word	Uppercase word
2	degree symbol ^{o}, round brackets()	an empty string
3	slash /, backslash \, dot ., hyphen -, space (" ")	Underscore "_"
4	Ã, Â, À, Á	A
5	Ç	C
6	Ê, È, É	E
7	Ì, Í	I
8	Õ, Ô, Ò, Ó	O
9	Names initiated by numbers	[NAME]
10	Special characters duplication, e.g., underscore duplicate	Remove duplication

Source: Original

Figure 15 – Data manipulation, on Excel, of the description column cells content.

(a) The first ten description of SCADA signal list Description column on Excel.

Description
Circuit Breaker 1 Position
59 Overvoltage Relay
63 Pressure Switch Stage 1
63 Pressure Switch Stage 2
27 Undervoltage Relay 1
27 Undervoltage Relay 2
Disconnect Switch 1 Position
Disconnect Switch 2 Position
21 Distance Relay
87 Differential Protective Relay

(b) The first ten description of SCADA signal list Description column manipulated after running a macro on Excel.

E
CIRCUIT_BREAKER_1_POSITION
[59_OVERVOLTAGE_RELAY]
[63_PRESSURE_SWITCH_STAGE_1]
[63_PRESSURE_SWITCH_STAGE_2]
[27_UNDERVOLTAGE_RELAY_1]
[27_UNDERVOLTAGE_RELAY_2]
DISCONNECT_SWITCH_1_POSITION
DISCONNECT_SWITCH_2_POSITION
[21_DISTANCE_RELAY]
[87_DIFFERENTIAL_PROTECTIVE_RELAY]

Source: MICROSOFT (2019).

Table 4 – I/O Tag configuration by the signal type based on the IEC870-5-104 protocol.

Type	P1	P2	P3	P4	Scan	Write	Read	Min UE	Máx UE	Min I/O	Max I/O
AI	0	5	13	IOA	1000	☐	☑	0	1000	0	1000
DI	0	5	30/31	IOA	1000	☐	☑	0	1000	0	1000
AO	-	-	-	-	-	-	-	-	-	-	-
DO	0	11	45/46	IOA	1000	☑	☐	0	1000	0	1000

Source: Original.

Figure 16 – Five digital input tags configuration, based on the IEC870-5-104 protocol, in Elipse E3 workspace.

Name	P1...	P2...	P3...	P4...	Scan	Read?	Write?	Min. EU	Max. EU	Min. I/O	Max. I/O
⊟ Driver	0	0	0	0							
⊞ Comm											
⊟ SS ID											
⊞ Analog Input											
⊟ Digital Input											
⊟ 500kV											
⊟ Circuit Breaker 1											
CIRCUIT_BREAKER_1_POSITION	0	5	31	1	1000	☑	☐	0	1000	0	1000
59_OVERVOLTAGE_RELAY	0	5	30	2	1000	☑	☐	0	1000	0	1000
63_PRESSURE_SWITCH_STAGE_1	0	5	30	3	1000	☑	☐	0	1000	0	1000
63_PRESSURE_SWITCH_STAGE_2	0	5	30	4	1000	☑	☐	0	1000	0	1000
27_UNDERVOLTAGE_RELAY_1	0	5	30	5	1000	☑	☐	0	1000	0	1000

Source: ELIPSE (2016).

3.2 ALARMS

The objects present in this section allow the Elipse SCADA to supervise plant occurrences classifying them as Alarms and Events (A&E). Alarm objects have similar functionalities to the driver objects. The Alarm Configuration gathers all the alarms objects at the root directory. Areas act as folders and Alarm Sources perform the alarm objects principal purpose, which is, to supervise I/O Tags as alarms and events.

The alarms development process can be summarized into five big tasks:

1. Arrangement of the Alarm Configuration and Alarm Areas;
2. Alarm sources Incorporation;
3. Rename Objects;
4. Configure Alarm Sources properties;
5. Establish alarm source condition.

3.2.1 Arrangement of the Alarm Configuration and Alarm Areas

Like the I/O Driver, in the scope of grouping a specific type of object, the Alarm Configuration is an object created at the root of the project that gathers Areas and Source Alarms. The development of the substation project requires two Alarm Configuration objects. The first one, Alarms, organizes the alarms, and the second one, Events, organizes the events.

These two Alarm Configuration objects, at SS ID project's root directory in E3 Organizer, are available in Figure 9. Double-clicking on any of the Alarm Configuration objects will open a tab in the workspace. This tab is the interface that allows the developer to create Areas and Digital Alarms.

An Area allows grouping a set of alarm sources and other areas. This object has the same characteristics and functionality as the I/O Folders but has its applicability to the alarm objects.

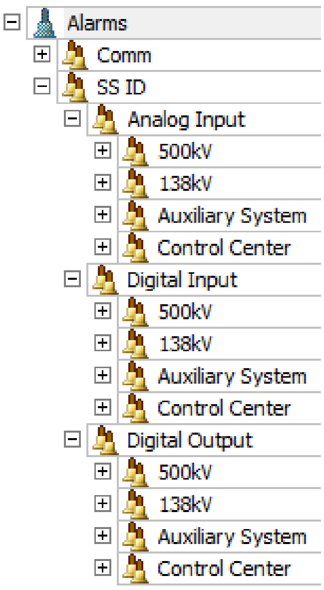
In the substation project, both Alarms and Events arrangement follows the same folder division applied to the Driver. Thus, the first area added to the project is the substation area (SS ID), followed by the signal type area, following Figure 11 tree structure. Figures 17a and 17b show the same area structures for Alarms and Events following the same folder structure as Figure 12b.

3.2.2 Alarm Sources

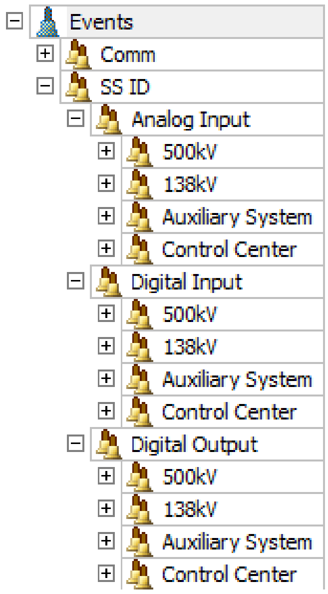
Alarm Sources, which include the events, supervise a plant's occurrences according to specific conditions through an alarm expression. In Elipse E3, these alarms are

Figure 17 – The first subarea layer of the signal types areas in the E3 workspace.

(a) The first subarea layer of the signal types to Alarms.



(b) The first subarea layer of the signal types to Events.



Source: ELIPSE (2016).

Analog Alarm, Dead Band Alarm, Digital Alarm, Discrete Alarm, and Rate of Change Alarms. The substation project use only Digital Alarms, which is the only object covered in this section.

The Digital Alarms are objects used for occurrences computed from rising (-1 or True) or falling (0 or False) of the digital variables. The setting of the Event property available in the alarm property establishes a digital alarm into an alarm or event, as shown in Figures 18a and 18b. Alarms represent plant occurrences that require an operator response because it could cause operational problems. On the other hand, events represent standard system.status messages and command notifications.

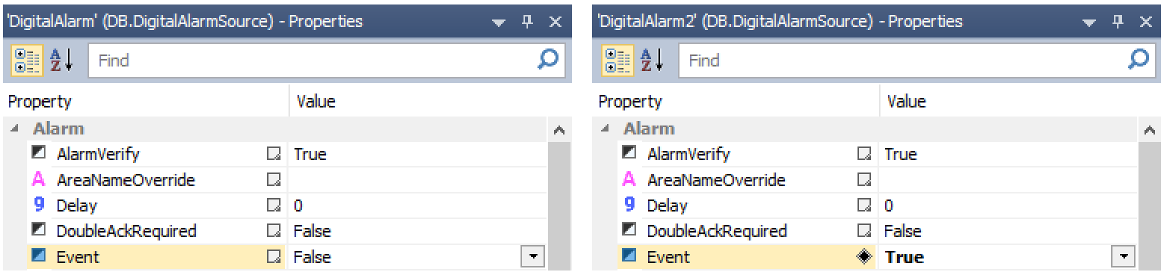
In addition to setting the object's alarm/event, the Source, DigitalMessageText, DigitalReturnMessageText, Name, Digital, and DigitalSeverity properties are established on all the objects too. The overview of the digital alarm configuration for these properties is available in Table 5. The details of each property and a configuration example are available in sequence and Figure 19.

The Source property characterizes the circumstance that causes occurrences. In other words, it is the comparison between the value of an I/O Tag and a known number (X^3). Therefore, the developer uses the PathName of an I/O tag with the addition of a ".Value" to extract its numeric value, an equals sign to compare two states, and finally a known number to the expression to return the true or false state to trigger or not an

[3] X being the value that triggers the alarm. Usually filled with numbers between 0 and 3.

Figure 18 – The Event property of Digital Alarm object setting.

(a) Digital alarm set as alarm. (b) Digital alarm set as event.



Source: ELIPSE (2016).

Table 5 – Digital Alarm object configuration.

Property	Setting
Source	“I/O Tag PathName”+“ .Value=X”
Digital	True
DigitalMessageText	SS ID - Identification - Alarm - Actuated
DigitalReturnMessageText	SS ID - Identification - Alarm - Not Actuated
DigitalSeverity	0, 1 or 2
Name	Object’s name

Source: Original.

alarm/event.

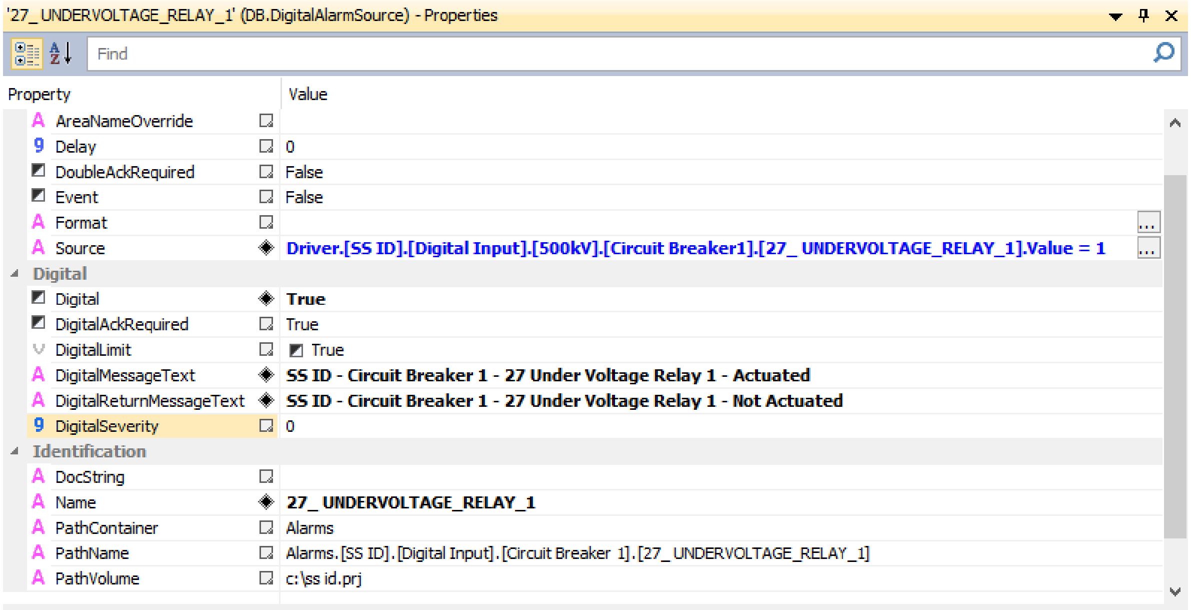
By default, the Digital property, to detect occurrences, is disabled. For this reason, the setting in all objects needs to be True, and as a consequence, enabling the verification of digital alarms.

The DigitalMessageText property allows displaying personalized texts to users in the active alarm condition, that is, when the condition “I/O Tag’s Pathname.Value=X” is satisfied. The personalized text appears to the operators. Therefore, the message has the standard of Table 5. In its structure, the word Actuated, the acronym SS ID, and the hyphens are fixed words. The words “Identification” and “Alarm” are replaceable words that use Title[4] Case typology, as explained in sequence:

- Identification: Identify a group of alarms of specific equipment, generally following the Area division name;
- Alarm: The alarm or event definition, generally following the tag name.

[4] First capital letter and the rest lower case except for acronym and minor words.

Figure 19 – The digital alarm configuration of the circuit breaker 1 to the protection 27 tag in the Property List window.



Source: ELIPSE (2016).

The DigitalReturnMessageText property allows displaying personalized texts to users in the non-active alarm condition when when the condition “I/O Tag’s Pathname.Value=X” is not satisfied. The guidelines for filling in the object are the same as DigitalMessageText, except for the fixed word Actuated, which for this property should be replaced by Not Actuated.

The DigitalSeverity property identifies occurrences at severity levels, 0, 1, and 2, representing High, Medium, and Low, as summarized in Table 6.

Table 6 – The severity levels and its descriptions for alarms and events.

Level	Severity	Alarm	Event
0	High	ANSI Protective relays Equipment disarrange state Faults	Equipment standard state
1	Medium	Operational error Equipment defect	Interlock states
2	Low	Communication failure	Command notification

Source: Original.

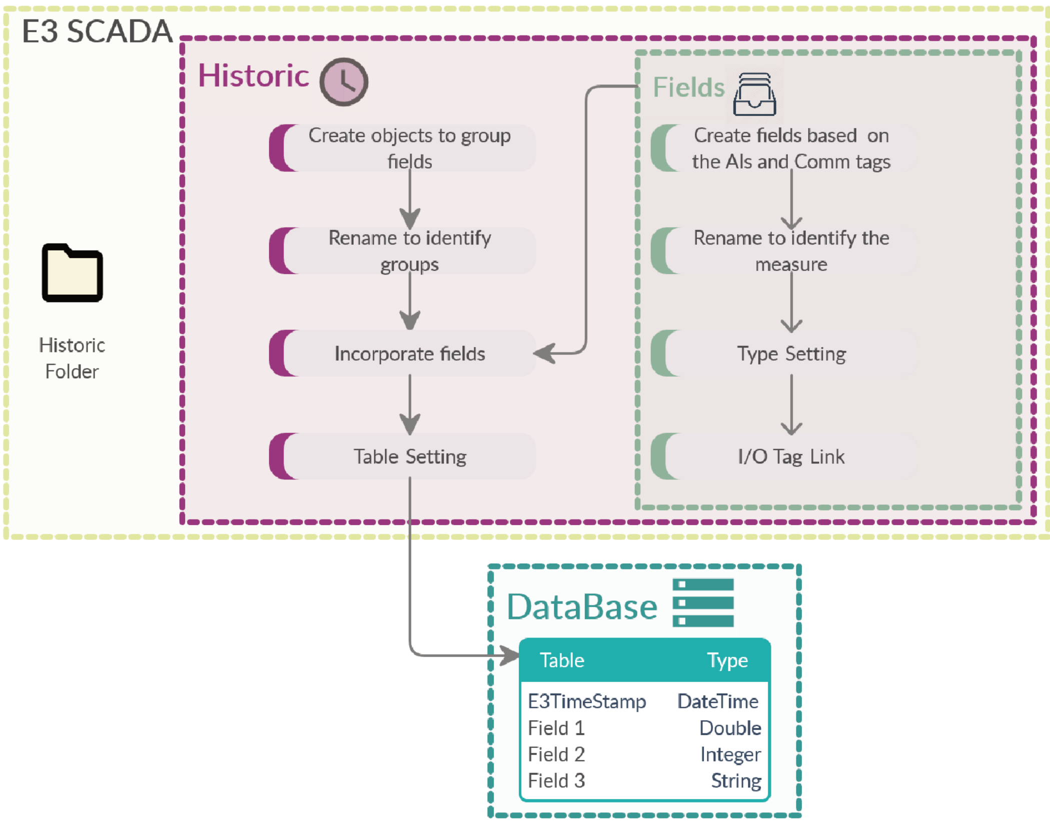
At last, the Name property identifies the name of the digital alarm object. This name does not appear for operators, being handled only by developers. For this reason, the name of each digital alarm is the same as its respective I/O Tag.

3.3 HISTORICS

Historic objects allow E3 SCADA storing process data for future analysis. Each history can create or use a table in the database with indexes that store time or expressions. When creating a historic, Elipse E3 automatically inserts a time index called E3TimeStamp to display the date and time of values obtained through the "I/O Tag PathName.Value" expressions.

The substation project aims to store analog and communication data, and both go through the same development process. Following Figure 20 process representation, a folder organizes histories created to group indexes with common characteristics, and for this reason, the renaming step identifies a group. After structuring the groups, the developer must create the indexes, name them identifying a measure, set the data type, and associate it with a tag. Completing all the previous steps, the developer must configure information in Table Setting Window (Figure 21) of each history to the E3 generate the database structure.

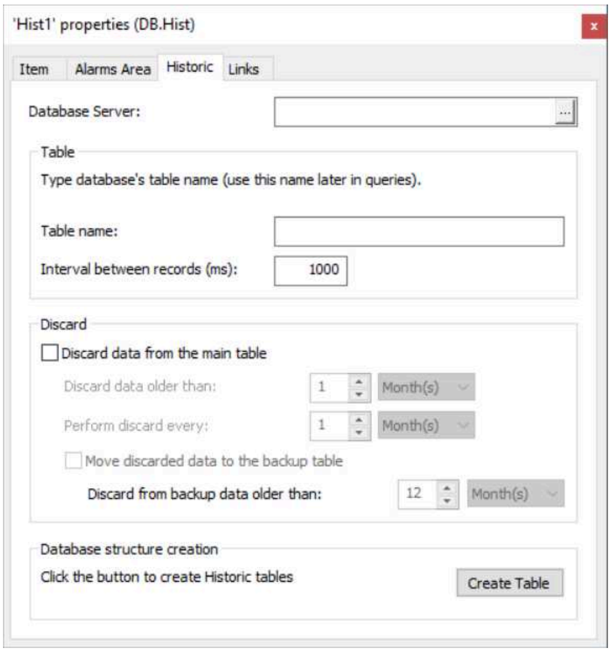
Figure 20 – Historic development process steps.



Source: Original.

Figure 22 represents these steps in E3 Studio, with the left-side being the Historic steps and the right-side being the field steps. The objects, on both sides, have generic

Figure 21 – Table Setting Window.



Source: ELIPSE (2016).

names (Figures 22a and 22b). For manipulation reason, they go through the renaming step in Figure 22c and 22d. These names have the substation identification to separate it from the other projects during the global searches, and the group name, for an internal organization, refers to a set of measures. On the right side, a field named as a measure is enough because it will attribute a unique table in the database. The field information types are date and time, integer, double, and string. Figure Xe measure fields receive their tags' value expression as the link parameter and set as double type.

The E3TimeStamp is date and time type and does not receive link parameters because E3 automatically records the date and time. The incorporation is the repeating procedure of creating, renaming, setting, and linking fields to all group variables. In the configuration window, the developer fills the Database Server with Database Pathname, choose a table name, which can be the same as the historical object, an interval record, and click on the Create Table button.

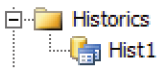
In the substation project, five histories (Figure 23) were necessary to organize tags of auxiliary system, communication, bars, transmission lines, transformer. Each historic has its grouping justification that was directly related to its name as detailed below:

SS ID Auxiliary System stores analog inputs values of the alternating and direct current systems;

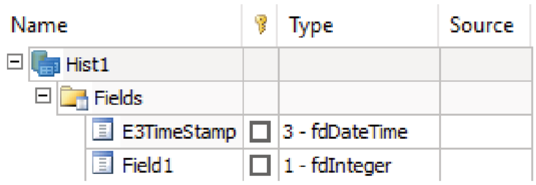
SS ID Communication stores values related to the quality and status of the communication signal;

Figure 22 – Historic development process steps on Elipse SCADA.

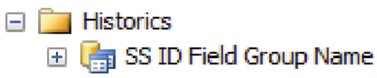
(a) Historic Step 1 - Creating.



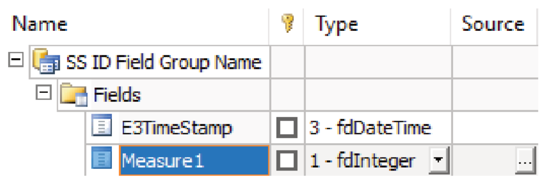
(b) Field Step 1 - Creating.



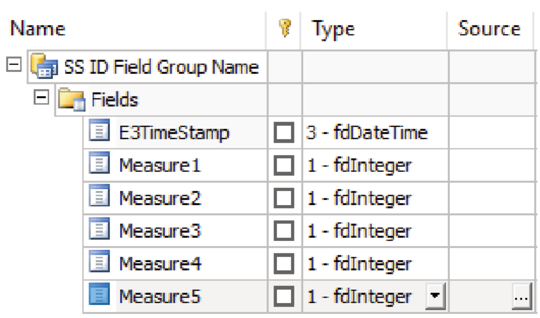
(c) Historic Step 2 - Renaming.



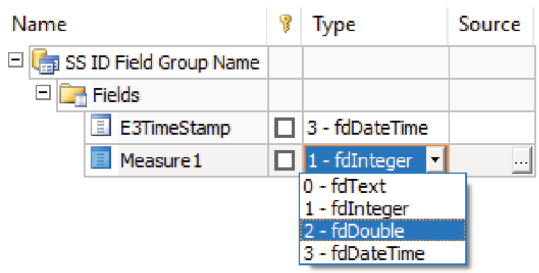
(d) Field Step 2 - Renaming.



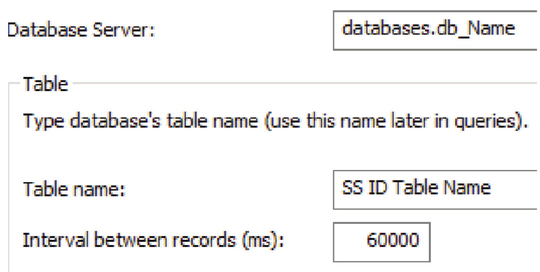
(e) Historic Step 3 - Fields incorporation.



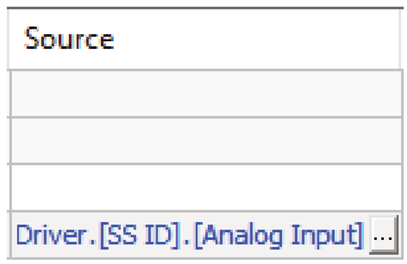
(f) Field Step 3 - Type Setting.



(g) Historic Step 4 - Table generation.



(h) Field Step 4 - I/O tag link.



Source: ELIPSE (2016).

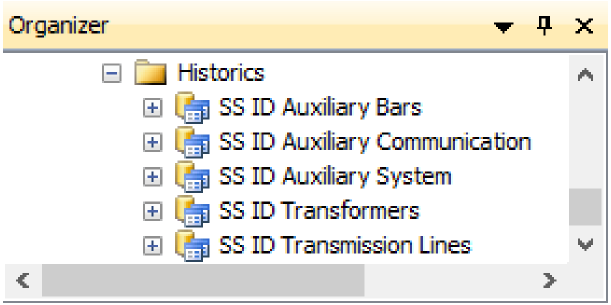
SS ID Bars contains the 500 kV and 138 kV bus bars voltages and frequencies;

SS ID Transmission Lines stores analog inputs values of the transmission lines circuits;

SS ID Transformers stores analog inputs values of the primary and secondary voltage transformer level.

Except for communication, the fields mostly store measurements of active and reactive power, currents, and voltages. Some groups can include additional variables like temperatures and tap positions for the transformers, levels of standby fuel and recti-

Figure 23 – Substation historics objects in E3 Organizer.



Source: ELIPSE (2016).

fier battery for the auxiliary systems, apparent power and frequency for the transmission lines, and any other particular measure in any group.

Figure 24 represents the transformer secondary voltage level fields of the substation project. Transformers historical has the usual central measures: active and reactive powers, currents and voltages, and additional measures like frequency, tap position, and synchronizing differences for voltage, angle, and frequency.

Figure 24 – The first six fields of the transformers historic object in the E3 workspace.

Name		Type	Source
SS ID Transformers			
Fields			
E3TimeStamp	☐	3 - fdDateTime	
Active Power	☐	2 - fdDouble	Driver.[SS ID].[Analog Input].[500kV].[Transformer 1].ACTIVE_POWER.Value
Reactive Power	☐	2 - fdDouble	Driver.[SS ID].[Analog Input].[500kV].[Transformer 1].REACTIVE_POWER.Value
Frequency	☐	2 - fdDouble	Driver.[SS ID].[Analog Input].[500kV].[Transformer 1].FREQUENCY.Value
Voltage BC	☐	2 - fdDouble	Driver.[SS ID].[Analog Input].[500kV].[Transformer 1].VOLTAGE_BC.Value
Current Phase B	☐	2 - fdDouble	Driver.[SS ID].[Analog Input].[500kV].[Transformer 1].CURRENT_PHASE_B.Value

Source: ELIPSE (2016).

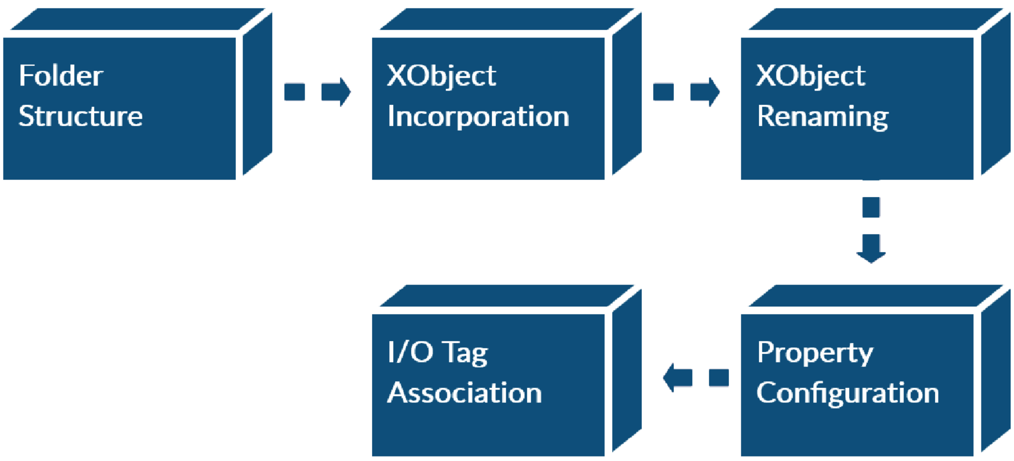
3.4 DATA

Data refer to the system's internal execution variables and data structuring objects that aim to perform calculations, associations, checks, records, among other uses. For intrinsic functions like counting, value simulation, storage, and timing, E3 utilizes the Counter, Demo, Internal, and Timer tags, and for specific objectives, E3 offers the XObjects.

XObjects allow developers to create and structure their data. One or more XObjects compose a data library intended to attend a specific purpose established by the user. The substation project uses XObjects to structure and standardize commands and the use of real-time information, in addition to a unique XObject to store the XControls color pattern.

The composition of data objects in the Organizer is similar to driver and alarm processes because it has an organizational structure at the root directory filled with folders and data. From this object, the development process of the commands and real-time follow Figure 25 steps.

Figure 25 – Data development process steps.



Source: Original.

The first step, folder structure, is the folder arrangement necessary for organized incorporation of XObjects. The Incorporation step creates data in proper directories, but all objects receive generic names. Therefore, the third step renames all of these names according to a standard. The fourth step fills the properties with technical information, and the I/O Tag association is an extension of this configuration, omitted in some objects. This step involves writing the I/O Tags Pathnames and may require the expression manipulation ("Pathname +. Value = X") to achieve a specific objective.

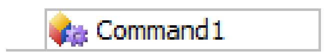
3.4.1 Commands

This object structures data of controlled equipment that allows the storage of identification parameters, description of states and commands, interlocking conditions, and connect I/O digital output tags through their properties. Based on the Figure 26 data development process steps, the folders' organization follows the driver structure. The objects' incorporation corresponds to the digital output tags because each command object links to one output tag. After the inclusion step, the rename has the standard "Equipment ID - Command," The configuration receives the parameters cited in the first sentence of this paragraph. The association activity is pasting the digital output pathname and handling the digital input pathname to express Command conditions. For instance, one of the requirements for opening a disconnect switch is its opening authorization signal. This condition characterizes by the I/O tag is 1. Therefore, in the Association tab, its expression is "PathName +. Value = 1" which consequently returns True when the condition is satisfied.

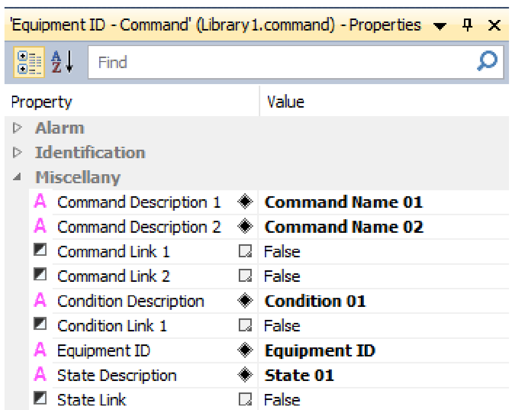
Figure 26 – Command data development process steps.

(a) Step 1 - Folder Structure.

(b) Step 2 - XObject Incorporation.

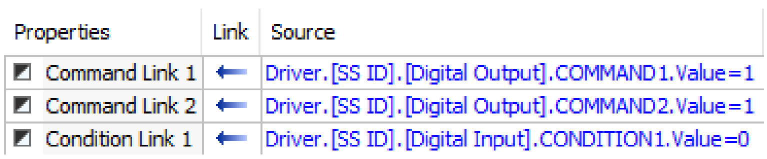


(d) Step 4 - Property Configuration.



(c) Step 3 - XObject Renaming.

(e) Step 5 - I/O Tag Association.



Source: ELIPSE (2016).

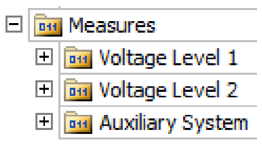
3.4.2 Real-Time

Real-time objects structure data that is continually refreshed by I/O Tags or can operate all the time on screen. Their varieties are the XObjects of measures, protections, protection managers, and interlocks.

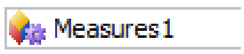
The first XObject, Measures, structures several analog inputs to display data in a measurement window. Their folders' structure consists of voltage levels and auxiliary system, and its objects are incorporated according to each division type. The object name has the standard "Measures - Group Name," where the word Measures is a fixed word, and Group Name is a replaceable word. The configuration receives the name, format, and unit of each I/O Tag associated with the object, usually more than 5.

Figure 27 – Measures data development process steps.

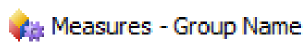
(a) Step 1 - Folder Structure.



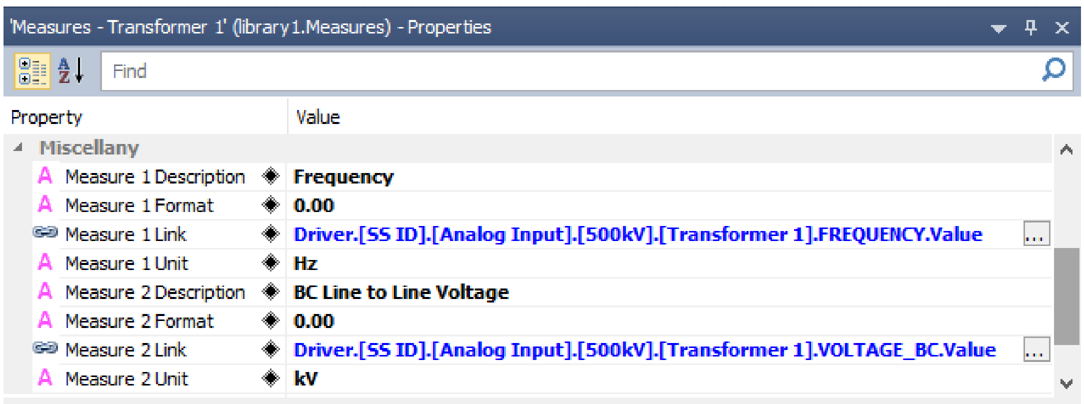
(b) Step 2 - XObject Incorporation.



(c) Step 3 - XObject Renaming.



(d) Step 4 - Properties configuration and association example.



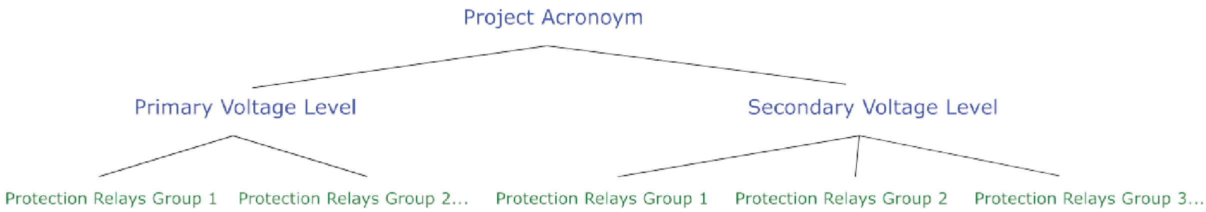
Source: ELIPSE (2016).

Protection and Manager objects structure protection data. Figure 28 presents the protection and manager development process. It starts in Figure 28a, drawing the substation system into a hierarchical tree, in which the root node represents the substation and its two children the voltage levels. These nodes use the manager object to signal whether a protection relay is active on any of its external nodes. The children of the primary and secondary voltage level, also identified as leaf nodes, carry protection relays I/O tags groups. The protections have the name pattern "Protection - Identification," where the identification receives leaf name for the protections, while managers receive the "Manager - Identification" pattern, as shown in Figure 28b. Managers link their children's pathname (Figure 28d). In contrast, Protections link to I/O Tags (Figure

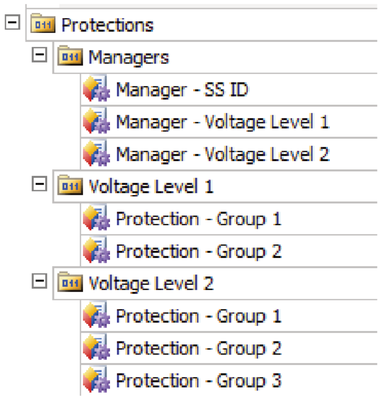
28c).

Figure 28 – Protections development process.

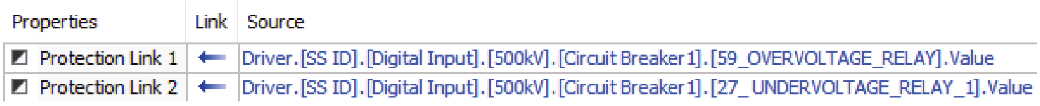
(a) The hierarchical tree structure of protection relays.



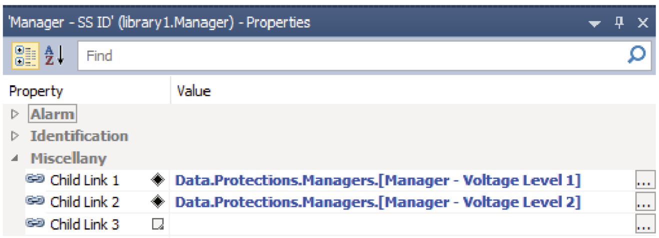
(b) Folder and object structure.



(c) Protection linked with two protection tags.



(d) Manager SS ID linked its two children.



Source: ELIPSE (2016).

The interlock object is the simplest to manipulate since its steps of folder structure, renaming, and joining XControl follow the same as the command process. Furthermore, no need to configure properties or associate I/O Tags.

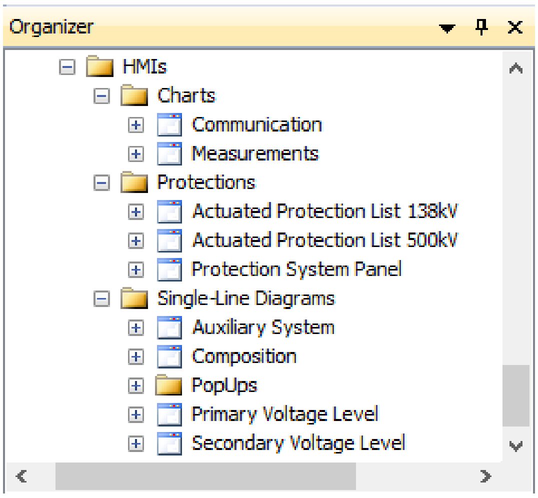
3.5 HUMAN-MACHINE INTERFACES

This section covers the different human-machine interfaces present in the development of the substation project. The HMIs were classified by types and separated by folders in the E3 Studio, which are:

- Charts;
- Protections;
- Single-line diagrams.

Each folder type carries screens added with graphical objects that result in human-machine interfaces in the Viewer. The folders and screens discussed in this section are available in Figure 29.

Figure 29 – Screen folder structure in E3 Organizer.



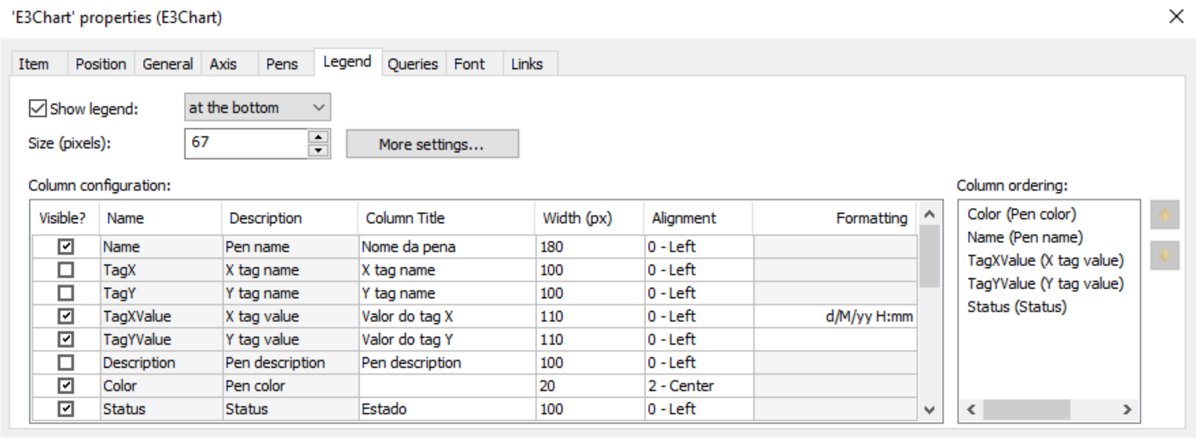
Source: ELIPSE (2016).

3.5.1 Chart Screens

The communication and measurement screens display I/O tag curves over time. The graphs are displayed using an E3Chart and aim to provide one or more I/O tags' behavioral history. These screens' composition required E3Chart, checkboxes, command buttons, and texts to query data in a database.

The E3Chart is responsible for displaying graphics in real-time, as well as data saved in histories. The substation project demanded using one E3Chart on each screen—however, several adjustments were made in Figure 30 window tabs. Properties like Name and ScaleFont received E3Chart and Arial (8), and the E3Chart's appearance assumed a dark mode according to Table 7 color parameters.

Figure 30 – E3Chart properties window opened in the Legend tab and configured to display the pen details.



Source: ELIPSE (2016).

Table 7 – Appearance properties and its values to arrange a dark mode of the E3Chart.

Property	RGB Color Value
Back Color	255, 255, 255
Fore Color	80, 80, 80
Horizontal Grid Color	80, 80, 80
Vertical Grid Color	80, 80, 80
Background Grid Color	40, 40, 40

Source: Original.

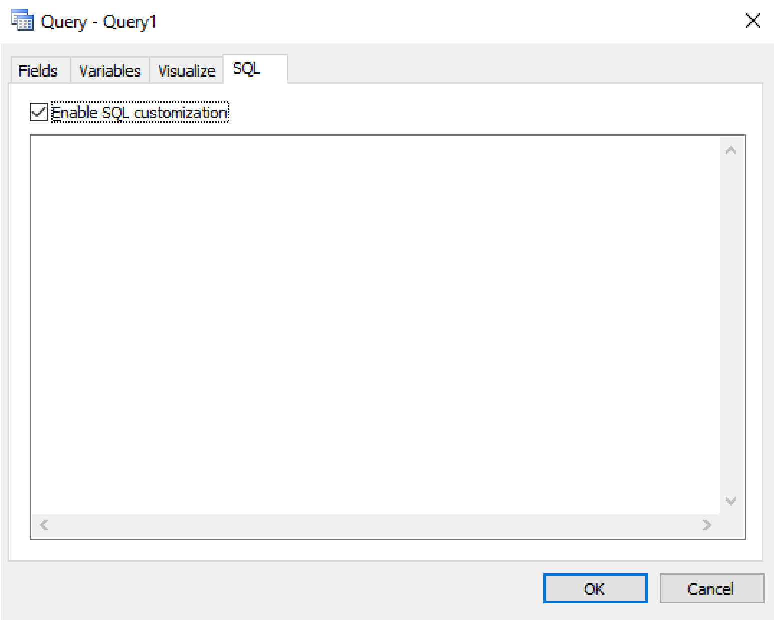
The Legend tab of the E3Chart property window enables the E3Chart to display details of a visible pen. The available items are several, but using the color, name, the value in X and Y, and state columns were necessary for the substation project. In addition to the columns' selection, the checkbox "Show legend" is marked, resulting in the Figure 30 configuration. The Color column illustrates a square filled with the pen color, the Name column displays the pen name named in the Pens tab, the X and Y Tag Value columns display the axis values at a specific point, and the State column shows the number of points in real-time and by the query field.

E3Chart's Queries allow E3 Viewer to display the historical tag values stored in a database. In the Queries tab, it is possible to create or remove query objects, in addition to configuring them by clicking on the configuration button, which opens the Query window, as shown in Figure 31.

In the Query window, E3 Elipse allows the developer to query without programming using the Fields tab, set values for variables for some purpose using the Variables tab, query programming SQL, and check the result of the queries, either through the

Fields or SQL tab, on the View tab. When there is a query through the Fields tab and the SQL tab, E3 gives preference to the SQL tab.

Figure 31 – Query setting window opened at SQL tab.



Source: ELIPSE (2016).

A pen connects a data point, derived from real-time tags or query fields, with a data sequence to display a curve in E3Chart. The Pens tab, found in the E3Chart properties window in Figure 30, allows adding or removing a pen from the pen collection. The pen collection varies in three types: real-time, historical, and historical and real-time. This project just uses historical and real-time pens based on the configuration of Table 8. The vertical axis link displays the data in real-time, directly receiving the Pathname value from a tag. The Query, Vertical Axis Field, and Horizontal Axis Field properties connect histories to graph. Therefore, they receive parameters related to the control center database.

The second component of these screens is the checkbox. A checkbox inserts or not, data into E3Chart through checked and unchecked states. The data to be displayed can be just real-time data or in conjunction with its historical through query objects. Figure 43 details its appearance configuration and arrangement on the screen. The Name property has the identification pattern cbx_Item_n, where n is a number in ascending order as the number of checkboxes increases, as shown in Figure 32b. In Communication Screens cases, the number n keep incrementing with the addition of the new column. It is worth mentioning that it is the Caption property, which allows displaying text next to a checkbox, and has the variable's name displayed on the chart. Hence, the captions in Figure 32b are for educational use for the correct configuration of the checkbox name property.

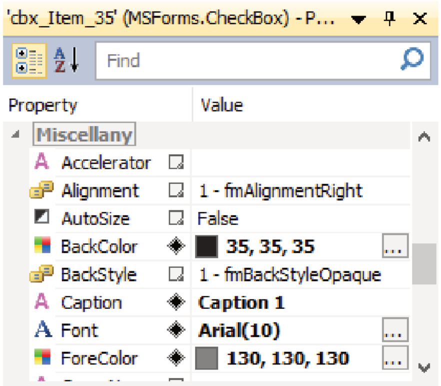
Table 8 – Pen object configuration.

Property	Guideline
Pen Name	SS ID - Identification - Measure
Style	Background-color black, line thickness 2 pixels, and any color allowed to the dash color except for black and repeated dash colors used in other pens
Vertical Axis Link	“I/O Tag PathName” + “.Value”
Query	Query’s name
Vertical Axis Field	Query’s measure column name
Horizontal Axis Field	E3TimeStamp

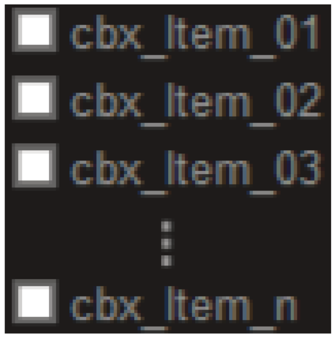
Source: Original.

Figure 32 – Checkbox appearance setting and vertical arrangement.

(a) Checkbox Appearance Settings.



(b) Vertical ascending checkbox naming rule.



Source: ELIPSE (2016).

Also, a checkbox has two scripts for on start running and click events. The first script, Listing 3.1, sets the checkbox to receive the value False, which means unchecked as an initial parameter, joins it with the pen at row 3, and removes the graph’s visibility at the penultimate row. The second script, Listing 3.2, associates the pen to the respective checkbox, makes the curve visible at row 3, and adjusts the X and Y axes of the E3Chart. This script allows the E3Chart to insert and fit a curve when clicking on a checkbox.

Listing 3.1 – The checkbox script code, in VBScript language, for on start running events.

```
1        Sub cbx_Item_01_OnStartRunning()
2              Value = False
3              Set o_pena = Screen.Item("E3Chart").Pens.Item("SS
   ID - Identification - Measure")
```

```
            o_pena.Visible = False
    End Sub
```

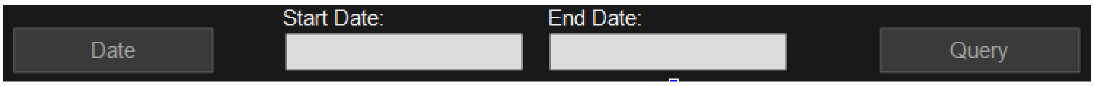
Listing 3.2 – The checkbox script code, in VBScript language, for on click events.

```
    Sub cbx_Item_01_Click()
            Set o_pena = Screen.Item("E3Chart").Pens.Item("SS ID - Identification - Measure")
            o_pena.Visible = Not( o_pena.Visible )

            Screen.Item("E3Chart").FitAll(1)
    End Sub
```

The third component of these screens is the command button, which performs specific actions when pressed. Both of them have two buttons, Date and Query, to assist in the query, as shown in Figure 33. The Date command button displays four text messages to inform the start and end query date. Besides, the Query command button triggers the graph. The two buttons perform these actions when the click event occurs on them, so when a user presses and releases the left mouse button on a button, a code activated by a click runs in E3 and displays the result on the screen.

Figure 33 – Date and Query Command buttons, and among them, four labels objects to inform the start and end date of a query.



Source: ELIPSE (2016).

The last component present in both screens to assist in a query is the Label graphical object that displays a text message on the screen. Each screen has four text boxes between the previous paragraph's buttons (Figure 33) and the text boxes that name a group of checkboxes.

3.5.1.1 Measurement Screens Layout

The graphs displayed on these HMIs refer to analog measurements, divided into electrical power and thermal quantities, considered relevant for decision making. The electrical power quantities can involve the voltages, currents, and active and reactive powers. On the other hand, the thermal quantity concentrates the transformer temperature variables. The arrangement of graphical objects is similar for all measurement screens regardless of the unit of measurement. The measurement screens consist of the E3Chart on the top left, the buttons and the four labels centered on the base, and the checkboxes with an entitle text above them in the center-left corner, as shown in Figure 34.

Figure 34 – Generic measurement HMI in E3 workspace.

Source: ELIPSE (2016).

The query objects use the SQL script of Listing 3.3 to search for data and display it in time. This script starts by selecting E3Timestamp and a specific measure at row 1 using the SELECT command, restricts the query's selection to data that has a value above 80 in quality through the WHERE, and orders the data collection, with the ORDER BY, ascendingly using the ASC subcommand. Therefore, Listing 3.3 allows queries to collect a measurement's history and timestamp ordered from the oldest to the most recent points, filtering uncertain and right quality signals.

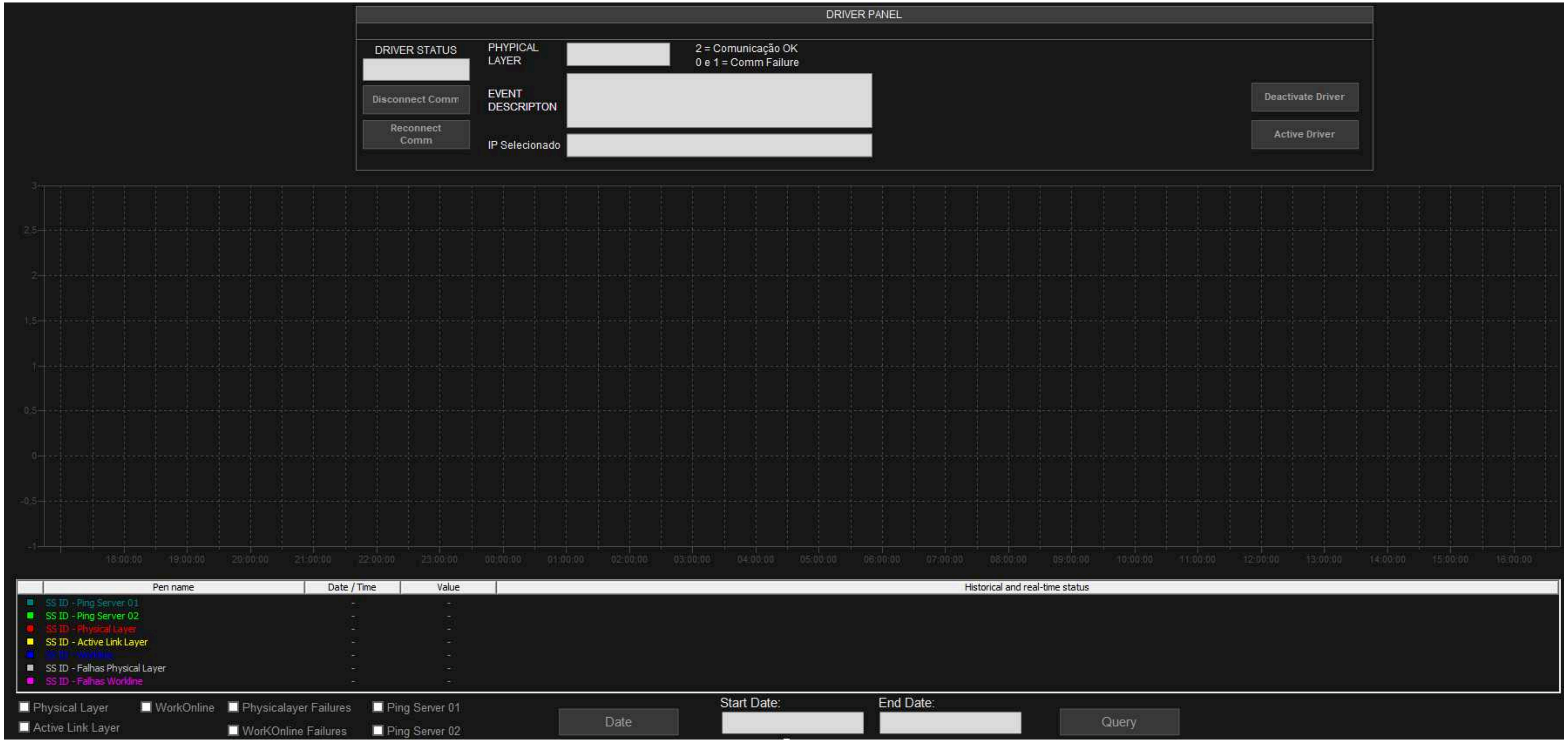
Listing 3.3 – SQL Script to query measures in measurement HMIs.

```
1         SELECT [SS ID Identification].E3TimeStamp,[SS ID
    Identification].Measure
2         FROM [SS ID Identification]
3         WHERE [SS ID Identification].Measure_Quality > 80
4         ORDER BY [SS ID Identification].E3TimeStamp  ASC
```

3.5.1.2 Communication Screen Layout

The curves displayed on these screens refer to communication variables between the SCADAs of the control center and the substation. These variables allow the visualization of the physical level curve, server link, and the status of their failures through the Workline Failures. Further, the screen also allows the operators to send commands to the driver's communication through the panel's buttons at the center-top, as shown in Figure 35.

Figure 35 – Communication layout Screen in E3 workspace.



3.5.2 Protection

Protection relays detect problems, such as abnormal conditions and equipment failures, with power system components, isolate them to protect people, minimize damage to equipment, and improve system stability. The protection screens indicate the protection relays actuated through the panel and actuated protection list screens.

The protection panel screen proposes an overview of the protection system following the Figure 28a tree structure to signal whether a protection relay is active on any of its external protection nodes.

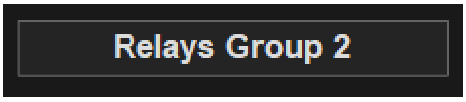
The actuated protection list screen proposes a large-scale view of the substation protection system in block list format, signaling all protection relays' activities. Each voltage level node is a screen, and each protection relay group is a block containing all the group's tags listed and signalized.

3.5.2.1 Protection System Panel

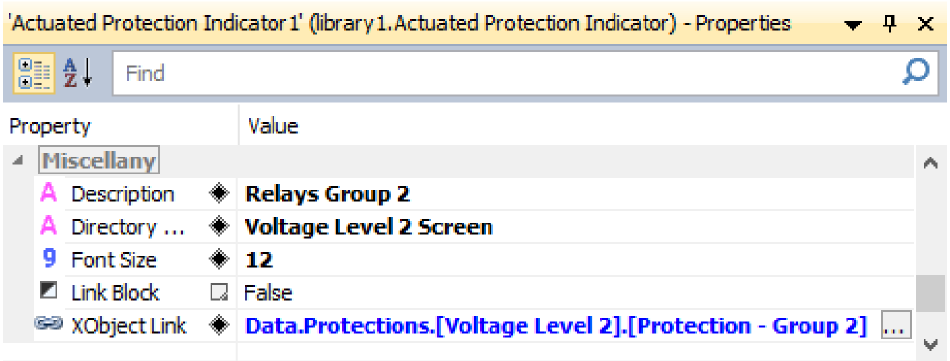
This object has a rectangular shape (Figure 36a) of various sizes to relate its hierarchical dependence to its size directly. From the largest rectangle, the root node, and the smallest rectangles, the external nodes. In the properties of Figure 36b properties, the Directory Link associates the directory of a screen. The Link Block enables or does not the Actuated Protection to open the directory's screen when left-clicking above it. The Description property displays the text in the central part of the rectangle, and the Font Size sets the text font. The last one, XObject Link, associates the protection XObject with the XControl.

Figure 36 – The graphical design and properties of the Protection Indicator XControl.

(a) Graphic design of the Actuated Protection Indicator on the screen.



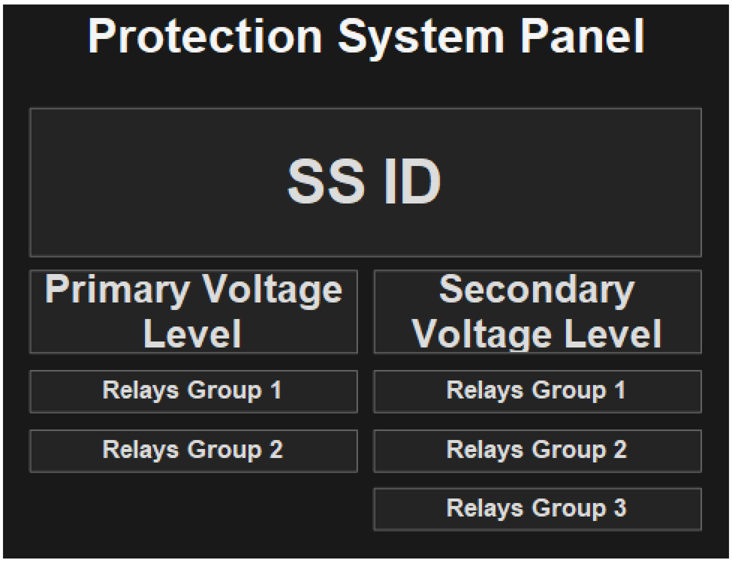
(b) Actuated Protection Indicator property list.



Source: ELIPSE (2016).

The screen assembly process begins with the label's insertion in the central part of the top and the Actuated Protection Indicator object, named with the project acronym, below it. The arrangement of all its internal nodes must not exceed its width for aesthetic reasons. For this reason, the first layer of nodes, Primary and Secondary Voltage Levels, have a width and height slightly less than half the width and height of the SS ID and a side-by-side alignment positioned below the first XControl. The external nodes have the same width as the object of their previous node, but at half their height, and the position follows one below the other, in no specific order, aligned vertically to its preceding node. The result of this arrangement is available in Figure 37.

Figure 37 – Generic protection system panel layout.



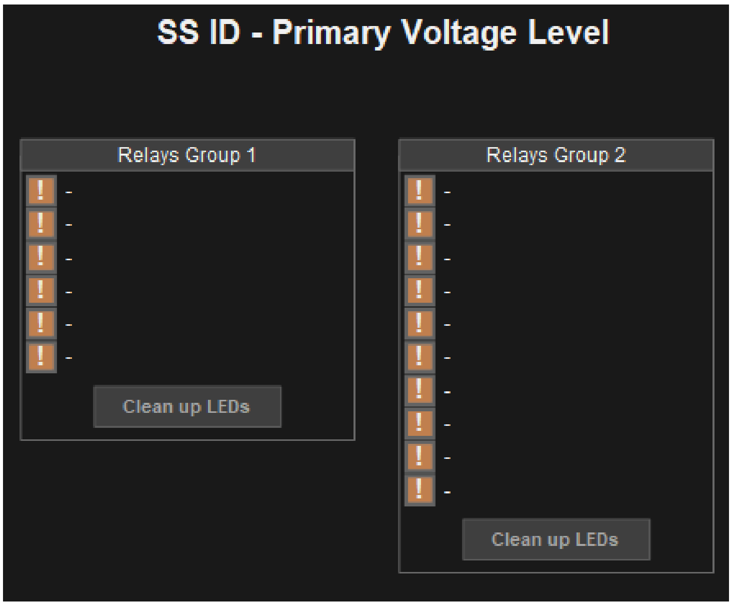
Source: ELIPSE (2016).

3.5.2.2 Actuated Protections List

The screen construction process begins with the label's insertion in the same position as the panel, indicating the project's acronym and the voltage level addressed. So there is a screen for each voltage level with the same development procedure, which is, using XControls to mount protection list blocks and repeating the process until organizing all the protection relays tags. This block consists of a header, a background panel, and a group of LED objects. Also, a control button that cancels the signaling of the LEDs.

The block assembly begins with the insertion of the background panel set with estimated size, following along with the header at its top informing the group name, the LED group below it configured for the number of tags, and the command button centered at the bottom of the panel. At last, the background adjustment size and the alignment of the components. In the case of two or more blocks, their arrangement seeks to be centered side by side on the screen, as shown in Figure 38. After the layout arrangement, each block links with the Section 3.4 protection XObjects through the XObject Link property.

Figure 38 – Protection relays list block.



Source: ELIPSE (2016).

3.5.3 Single-Line Diagrams

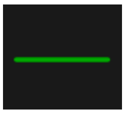
This type of screen is a graphical representation of the single-line diagrams in Elipse E3 added with blocks that aim to aid the operators' system energy flow supervising. Both graphical representation and block parts complement each other because the first part allows a qualitative reading of the system. The second one provides a quantitative interpretation of the data.

These screens' graphical representation considers only lines connected to motorized circuit breakers, disconnectors, transformers, standby generators, rectifiers, and batteries, which implies the rest of the diagram lines' omission. Lines and its components, and all equipment mentioned in the previous sentence have an equivalent XControl (Figures 39 and 40) without the need for adjustment, except for the line length. Including no need for additional programming code, just its properties setting.

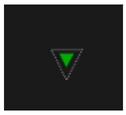
The blocks can display analog and digital values and organize the command and measurement buttons. Its content, also developed entirely by XControls, can be the analog display together or not with a measurement button or LEDs, added by a caption, accompanied or not by command buttons. The measurement button, when pressed, opens a window showing all the analog measurements involved in that block, so the button accompanies the block if all the displays are not attainable to fit on it.

Figure 39 – SLD line and its components in the Elipse E3.

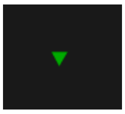
(a) Line.



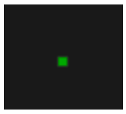
(b) Hyperlink arrrow line.



(c) Energy flow indicator line.



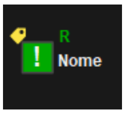
(d) Line node.



Source: ELIPSE (2016).

Figure 40 – SLD Equipment XControls in Elipse E3 Workspace.

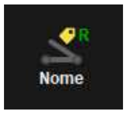
(a) Circuit Breaker.



(b) Transformer.

(c) Rectifier.

(d) Disconnector.



(e) Standby generator.

(f) Rectifier's battery.

Source: ELIPSE (2016).

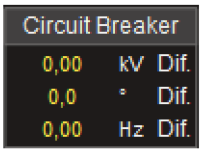
For instance, Figure 41a block does not attend a measurement button because the circuit breaker has only three I/O tags to indicate its analog measurements. In contrast, Figure 41b block accompanies a measurement button because this transformer has more than ten analog measurements, being the three phases of its current and voltage, active and reactive power, frequency, and temperature measures.

A command button accompanies an LED if there is a digital output I/O Tag corresponding to that state. Figure 42 block, for example, has the top LED (86BF) referring to a readable and controllable variable, besides the variable associated with the second LED (86B) just allows readings.

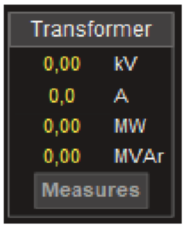
The arrangement of these XControls and blocks allows the construction of the composition, auxiliary system, and voltage level screens. The drawing process follows the single-line diagram documents, and the pop-up buttons and blocks are close to the

Figure 41 – Analog display blocks.

(a) Analog display blocks without measurement button.

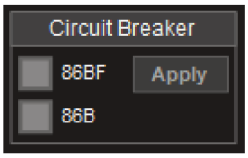


(b) Analog display blocks with measurement button.



Source: ELIPSE (2016).

Figure 42 – Circuit breaker LED block.



Source: ELIPSE (2016).

component, which is referring to.

3.5.4 Pop-ups

The pop-up screens, small windows triggered by a button that appears suddenly over the Viewer, are screens containing information upon protections of synchronism-check, manual transfer or selector device, and AC-Reclosing, which correspond to the 25, 43, and 79 (Figure 43a) of the ANSI/IEEE Standard Device Numbers. It also matches the Cmd and Temp buttons (Figure 43b), holding the transformers' commands and temperature measurements.

Figure 43 – The Command buttons that triggers the pop-up windows.

(a) Three buttons, 25, 43, and 79, for circuit breaker pop-ups.

(b) Command and temperature button for the power transformers pop-ups.

Source: ELIPSE (2016).

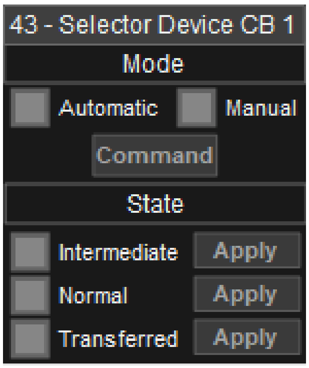
For both pop-up types, the development procedure begins with an initial windows size estimates, header and sub-header customization, graphical objects inclusion, and finish with the windows size adjustment and graphical objects alignment. The specifications for each pop-up type are presented in the following.

3.5.4.1 Circuit Breaker Pop-ups Layout

These pop-ups' header identifies the ANSI device number and its description, followed by the circuit breaker identification. A sub-header called Mode and, in addition to the buttons 43, a second sub-header entitled "State." The arrangement of LEDs is directly related to the digital type (double point or single point) of a digital input tag. For double points, two LEDs side by side represent the two different states of the tags. On the other hand, one LED on the left represents single point tags indicating if a state is activated or not.

The existence of buttons command and apply on these pop-up screens depends on digital output tags for a given LED on the screen. In addition to its existence, these buttons' arrangement depends on the digital type of LED. The buttons that control double points are arranged centralized and just below the two LEDs. In contrast, the buttons that control single points; its arrangement aligns with the right with the LED. Figure 44has a double point tag for automatic and manual states followed by its command button and three single points for the protection states followed by their Apply button.

Figure 44 – Selector device relay pop-up for the circuits breaker 1.

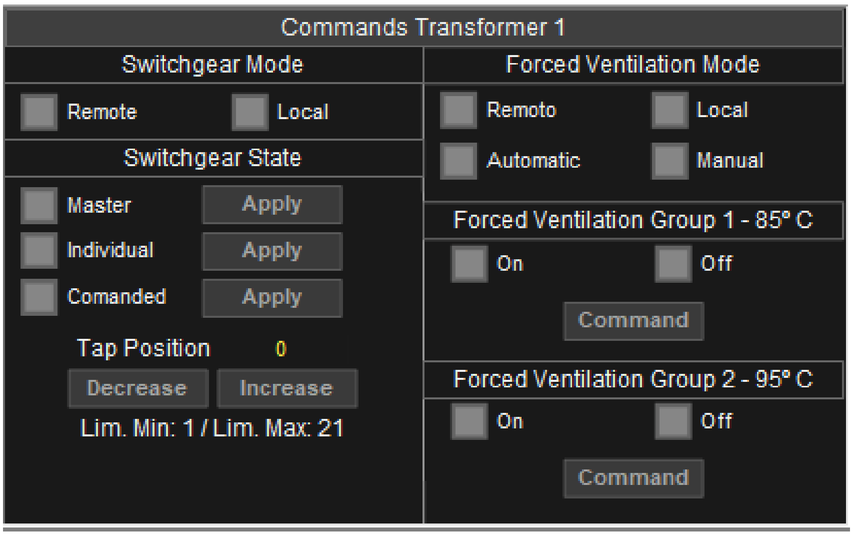


Source: ELIPSE (2016).

3.5.4.2 Transformer Pop-ups Layout

The transformer command and temperature pop-ups have a different layout and objects, except for the header. The command pop-up shows switchgear and forced ventilation states and their command buttons. The organization of LEDs and command buttons follows in blocks titled by sub-headers. The displays and labels referring to tap information follow within each block just below the switchgear states, as shown in Figure 45.

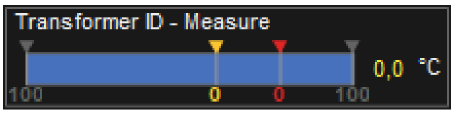
Figure 45 – Command pop-up to the Transformer.



Source: ELIPSE (2016).

The temperature pop-up has just one header object and temperature display objects. The temperature display XControl (Figure 46) aims to represent temperature analog measurements inside a rectangle limited by minimum and maximum values, inform measure value in real-time, and assist as an alarm for a specified temperature. The number of this object is consistent with the I/O tag transformer temperatures number, and since the substation driver has nine transformer temperature measures, the pop-up owns nine displays.

Figure 46 – Temperature display object used in temperature pop-ups.



Source: ELIPSE (2016).

4 RESULTS

This chapter presents the substation project results through E3's supervising and controlling environment, E3 Viewer. The project originated 11 HMIs: four single-line diagrams, three measurements, three protections, and one communication. Also, 13 Pop-ups were developed: two for synchronism-check (button 25), five for the manual transfer or selector device (button 43), four for the AC-Reclosing Relay (button 79), one for the transformer commands, and one for the transformer temperature measures.

Section 4.1 focuses on displaying the charts of the communication and measurements HMIs to analyze the connection between the control center and substation and the data stored in the database. Moreover, it allows validating the specific objectives of communication and data storage.

Section 4.2 presents the substation operational HMIs and explains its functionalities. It shows the single-line diagram HMIs with differents pop-ups opened on it and their operational functionalities. Then it reveals the substation protection system through the panel and the actuated protections list. It also presents the alarms environment and displays the substation's alarms and events on it, validating the alarm establishment's specific objective.

It is important to emphasize again that it is a company's project. Therefore, it was preferred for confidentiality issues to omit confidential data. Further, the HMIs may have words in Portuguese because of the company's standards.

4.1 SUBSTATION'S CHARTS

Once all development stages are interacting well, and without errors, E3 can run E3 Viewer, allowing users to watch their application's execution and control it when appropriate.

In the Communication HMI presented in Figure 35, it is possible to check the communication variables chart. The curves on it allow checking the failures, connection, and ping. Table 9 shows the principal communication variables states. An appropriated connection between the local SCADA and control center SCADA must be connected with the substation servers (ping curves equal 1). The physical layer curve must be in 2 (connected state), and the driver online (WorkOnline curve in 1).

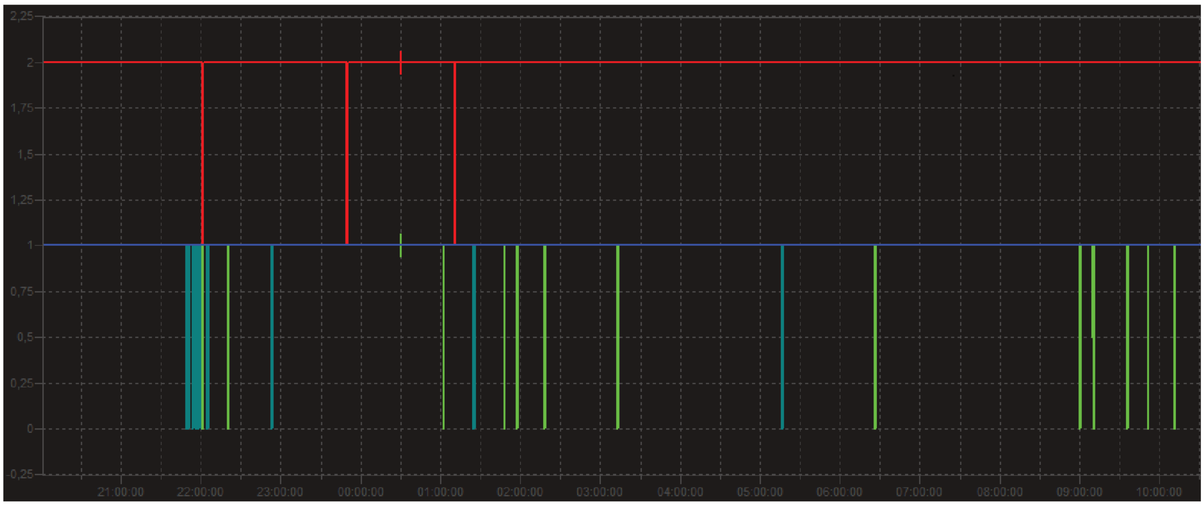
Figure 47 chart displays the states of communication variables. The red curve indicates the physical layer state, the blue curve indicates the workonline state, and the teal and lime curves indicate the principal and backup server connection. On the other hand, there are instantly connection lost states indicated by the teal and lime curves in 0. Moreover, Figure 47 chart allows for validation of the connectivity, developed in the driver section, between the substation control room and the control center through the communication graphics, as generated on the communication HMI.

Table 9 – States of the physical layer, driver, and substation servers connection.

Value	Physical Layer	WorkOnline	Ping
0	Stopped	Driver Offiline	Server Disconnected
1	Initiated but not connected	Driver Online	Server Connected
2	Connected	-	-

Source: Adapted from (ELIPSE, 2017).

Figure 47 – Communication variables chart.



Source: Adapted from the company's HMIs.

The curves of the previous day generated in the Measurement HMIs and the data retrieved from database tables through SQL commands validated the history's generation. The Visualize tab of the Query window (Figure 31) allows querying data to validate the historic specific objective. Figure 48's query uses Code 3.3 with the substation identification as the table parameter and the transformer's active power as the measure to query the transformer's active power analog inputs.

The usual way to check the data history of analog measures by users is through the measurements HMI. In the Measurements HMI layout presented in Figure 34, it is possible to plot curves with the analog input queries.

The substation project required three measurement HMIs for the transformer electrical power measures, transformer thermal measures, and transmission lines electrical power measures. Figure 49 shows two charts from different measurement screens. Figure 49a's plot carries the alternating current Phases A, B, and C and active and reactive powers of the transformer in the Transformer Measurement HMI. A different query example from another Measurement HMI is Figure 49b's plot, which carries the transformer oil temperature of the phases A, B, and C.

Figure 48 – Transformer active power analog measurements queried from the database.

E3TimeStamp	
20/11/2020 17:20:23	31,7526226043701
20/11/2020 17:21:23	31,3522148132324
20/11/2020 17:22:23	31,252628326416
20/11/2020 17:23:23	31,47802734375
20/11/2020 17:24:23	31,7108955383301
20/11/2020 17:25:23	31,7108955383301
20/11/2020 17:26:23	31,8252983093262
20/11/2020 17:27:23	31,4350547790527
20/11/2020 17:28:23	31,4973449707031
20/11/2020 17:29:23	32,0478897094727
20/11/2020 17:30:23	32,0478897094727
20/11/2020 17:31:23	31,8813514709473
20/11/2020 17:32:23	31,9898223876953
20/11/2020 17:33:23	31,4824333190918
20/11/2020 17:34:23	31,4824333190918
20/11/2020 17:35:23	31,322208404541
20/11/2020 17:36:23	31,8442878723145
20/11/2020 17:37:23	32,3881874084473
20/11/2020 17:38:23	32,0726051330566
20/11/2020 17:39:23	32,5209655761719
20/11/2020 17:40:23	32,0304832458496
20/11/2020 17:41:23	32,578067779541
20/11/2020 17:42:23	32,1760940551758
20/11/2020 17:43:23	31,8375225067139
20/11/2020 17:44:23	31,8761329650879
20/11/2020 17:45:23	31,8761329650879
20/11/2020 17:46:23	31,9864559173584
20/11/2020 17:47:23	31,9864559173584
20/11/2020 17:48:23	32,055046081543
20/11/2020 17:49:23	32,055046081543
20/11/2020 17:50:23	32,1399993896484
20/11/2020 17:51:23	31,8103065490723
20/11/2020 17:52:23	31,5564842224121
20/11/2020 17:53:23	31,8901786804199
20/11/2020 17:54:23	31,8901786804199

Source: ELIPSE (2016).

4.2 OPERATIONAL HMIS

As the Control Center Viewer handles multiple projects, it needs an arrangement that supports all projects' screens. For this reason, the navigation within it occurs through integrated screens, as shown in Figure 50. Top and Lateral Menu screens carry mainly hyperlinks components to allow the Principal part to display the HMIs of several projects.

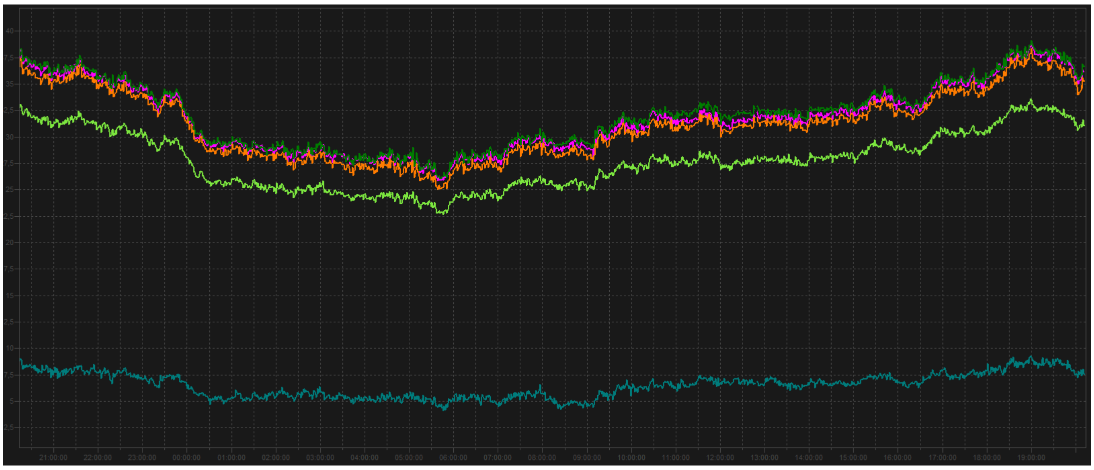
The Lateral Menu is a screen filled with XControls in a block format with a hyperlink function that allows access to a specific project identified with its ID. These blocks are square, organized in columns and lines. As this project integrates a transmission substation, its position is in the transmission column, and its order is according to the alphabetical sequence of other projects. Figure 51 portrays the Lateral Menu with a with the substation project inside it.

When clicking on the SS ID block, E3 refreshes top and principal screens, which allows the operator to view the project home screen in the principal area and choose a specific HMI through the upper menu.

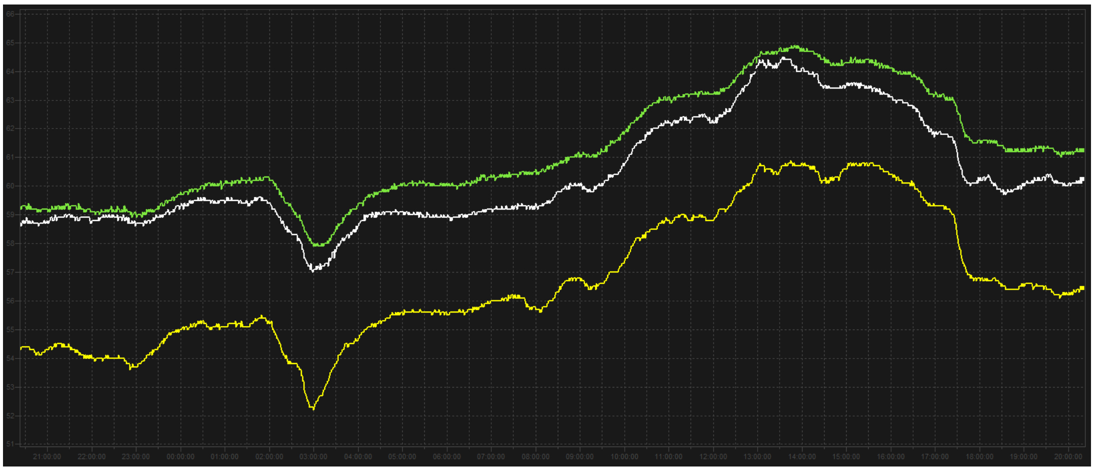
The top screen identifies the control center, user, date, time, and location through

Figure 49 – Electrical power and thermal quantities measurements charts of the transformer.

(a) Alternating Current Phases A, B, and C and Active and Reactive Powers of the Transformer.



(b) Transformer oil temperature chart of the phases A, B, and C.

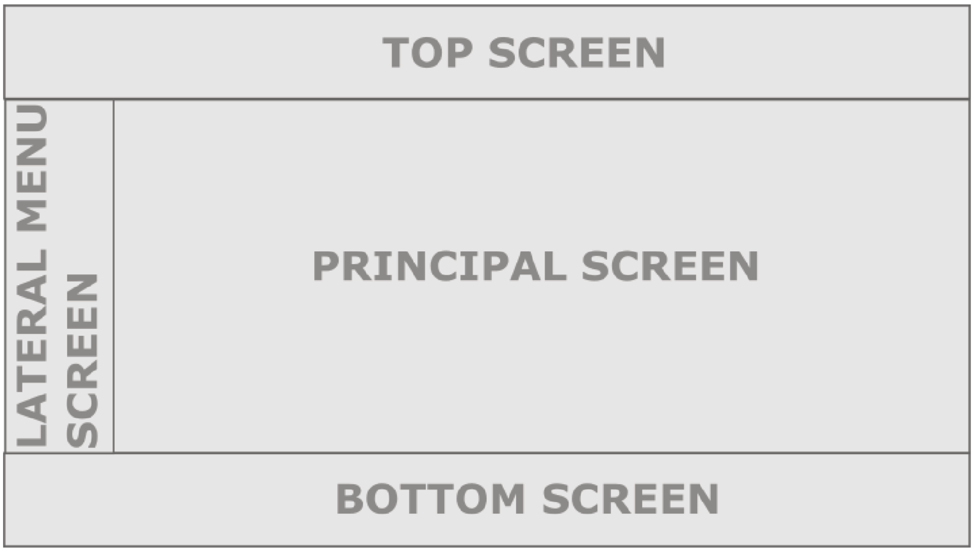


Source: Adapted from the company's HMIs.

its header. Furthermore, the upper menu loads tabs for choosing the HMI type (Single-line diagrams, protections, or charts) and the screen. For instance, Figure 52's choice signals protection HMI type and select the panel HMI. As a consequence, Figure 50's Principal Screen area displays Figure 53's HMI.

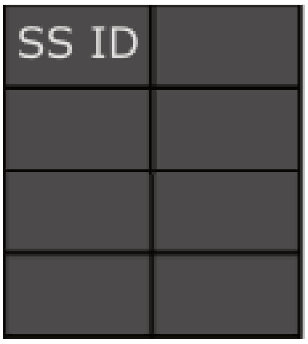
Figures 53, 55, and 54 show the substation's protection HMIs. The protection system panel supervises the abnormal conditions and equipment failures of the 500kV and 138kV sectors. The 500kV sector required six protection relays groups used by six actuated protection indicators (Figure 36a) in the panel and six blocks in the 500kV actuated protection list HMI (Figure 54). The 138kV sector required nine protection relay

Figure 50 – Control center E3 Viewer screens layout.



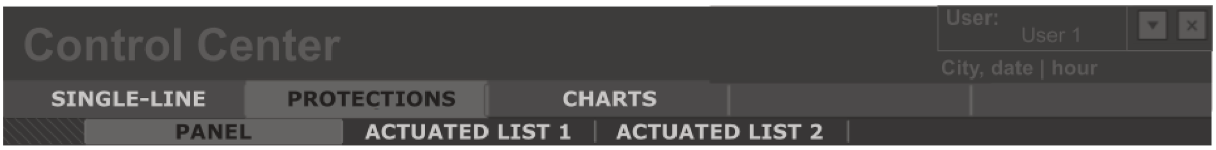
Source: Original.

Figure 51 – Lateral Menu representation containing the SS ID project block.



Source: Adapted from the company's HMIs.

Figure 52 – Top screen representation containing the header lowed by the upper menu.



Source: Adapted from the company's HMIs.

groups, and similarly to 500kV's groups, they were used by the panel and protection list's XObjects. The actuated protection list of the substation's 138kV section is available in Figure 55.

Accessed by the Single-line tab of Figure 52's upper menu, Figures 57, 58, 59, 60 show the single-line diagram HMIs. The compilation HMI (Figure 57) holds the principal SLDs elements of the 500kV and 138kV. Also, Figure 57 shows a circuit breaker and a command window highlighted in red color to demonstrate the command dynamic.

Figure 53 – Substation protection system panel.

Source: Adapted from the company's HMIs.

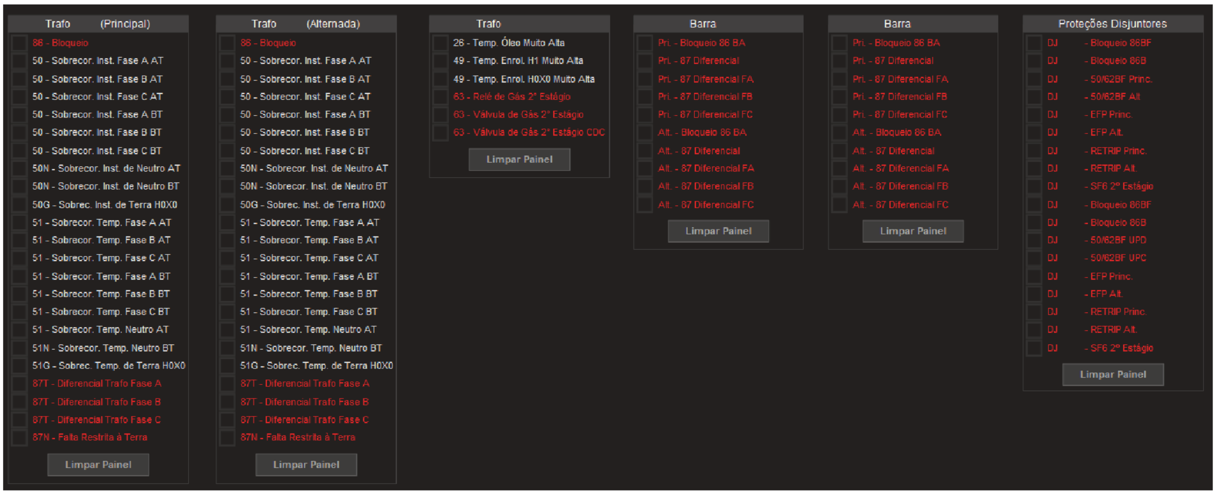
The user left-clicks above a circuit breaker to open the command window, which uses the command Xobject parameters to arrange the LEDs and indicate the command conditions. Then, the user analyses the condition, select the open or close command, and confirm it by left-clicking in *Confirmar*.

Figure 58 shows the single-line diagram of the 500kV sector. This HMI contains the 500kV principal elements and its tag blocks. The transformers pop-ups of command and temperature are accessed similarly to the command window. The transformer command operates the switchgear states (left-column) and the forced ventilation (right-column) by ABC phases. The temperature pop-up displays the temperature of two conductors and oil by ABC phases.

The secondary line voltage (Figure 59) contains four distribution transmission lines, a tie, two bus bars, and distribution-level transformer circuit. The four transmission line circuits are located below the horizontal lines, the bus-bars. Each circuit has 3 tag blocks and two pop-ups to support reading and writing in the circuit breakers and transmission lines tags. The Tie is the circuit that connects both bus bars to allow more flexibility in operation. It is located above the bus bars and on the left of the distribution-level transformer circuit.

The *Serviço Auxiliar* Screen (Figure 60) refers to the Auxiliary System HMI, which covers the alternating and direct current equipment. The alternating current

Figure 54 – Actuated protection list of the substation's 500kV section.



Source: Adapted from the company's HMIs.

Figure 55 – Actuated protection list of the substation's 138kV section.

Source: Adapted from the company's HMIs.

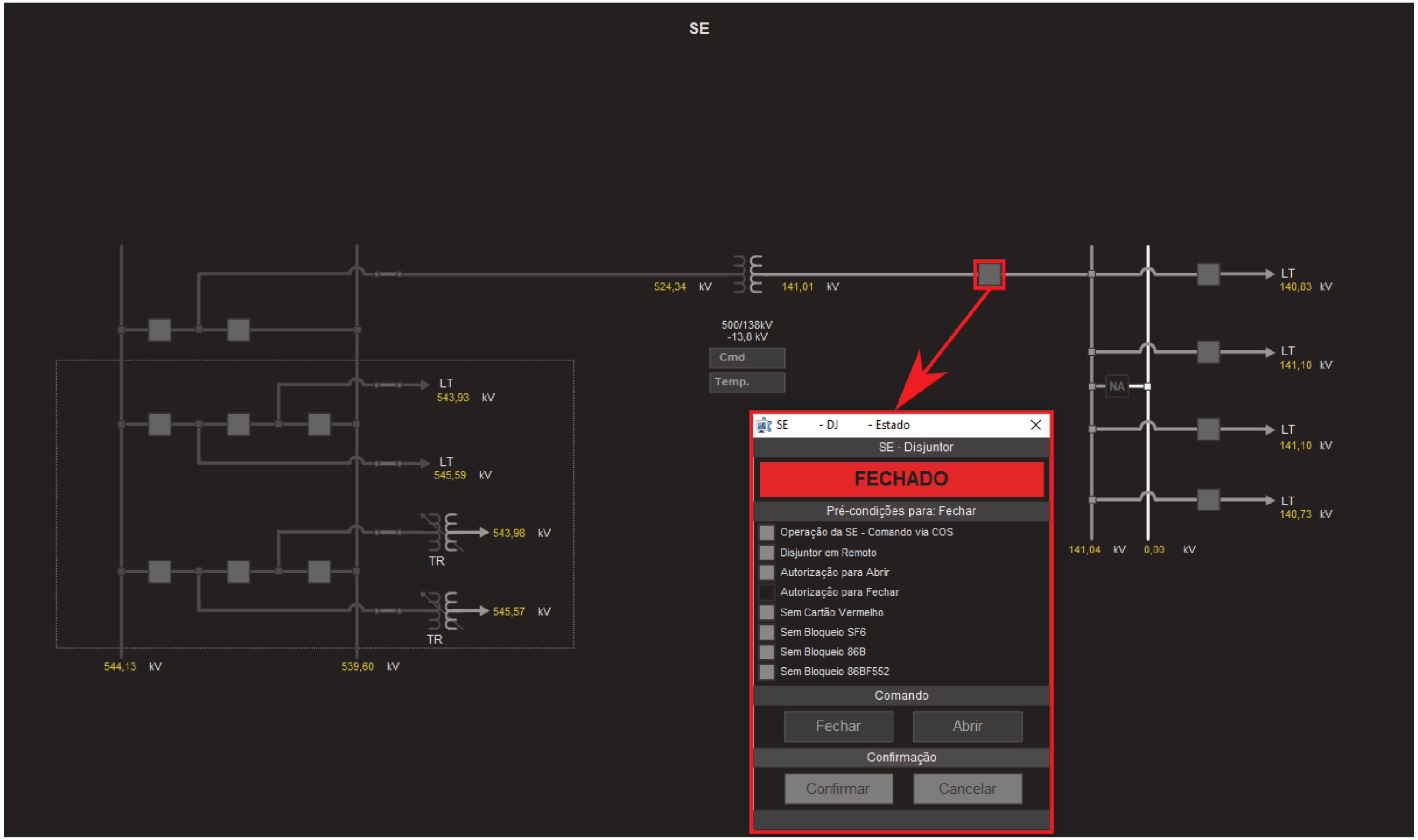
system is above the RET1 and RET2 Blocks and the direct current system below them. The Measure window highlighted shows up after left-clicking on the Measurement Button and displays the auxiliary system transformer analog variables.

The alarms and events can be supervised by Figure 50's bottom screen, alarms (Figure 61) screen, and events screen (Figure 62). They notify the alarms and events of all projects in real-time, showing the date and time of the control center and plant, area path, and the parameter of the digital message text property of an alarm through an E3Alarm. Figure 56 represents this lower screen with a generic alarm notification on its first line. Also, Figures 61 and 62 show the substation's alarms and events.

Figure 56 – Bottom screen representation.

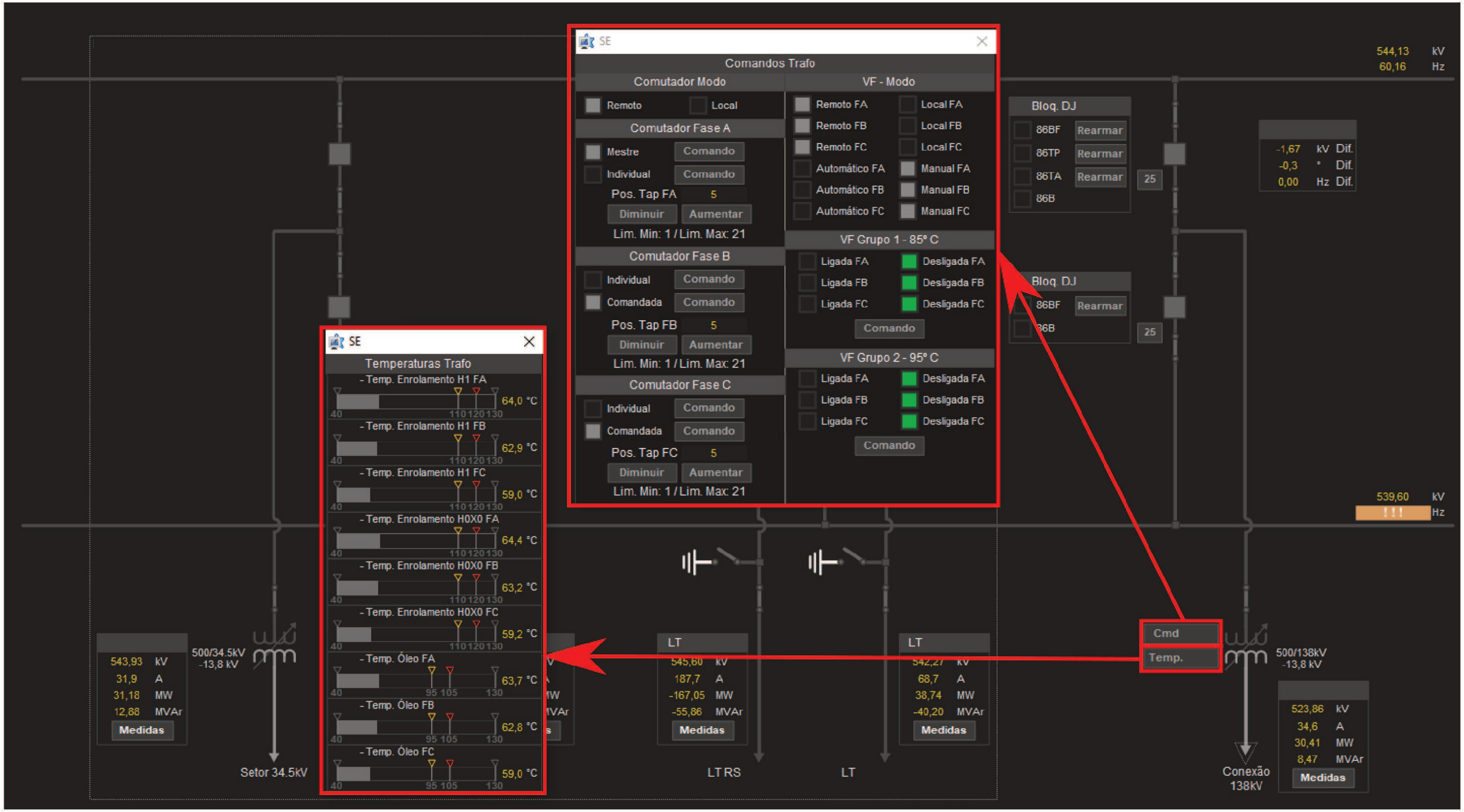
Source: Adapted from the company's HMIs.

Figure 57 – Single-line diagram of the 138kV and 500kV sectors with a command window opened.



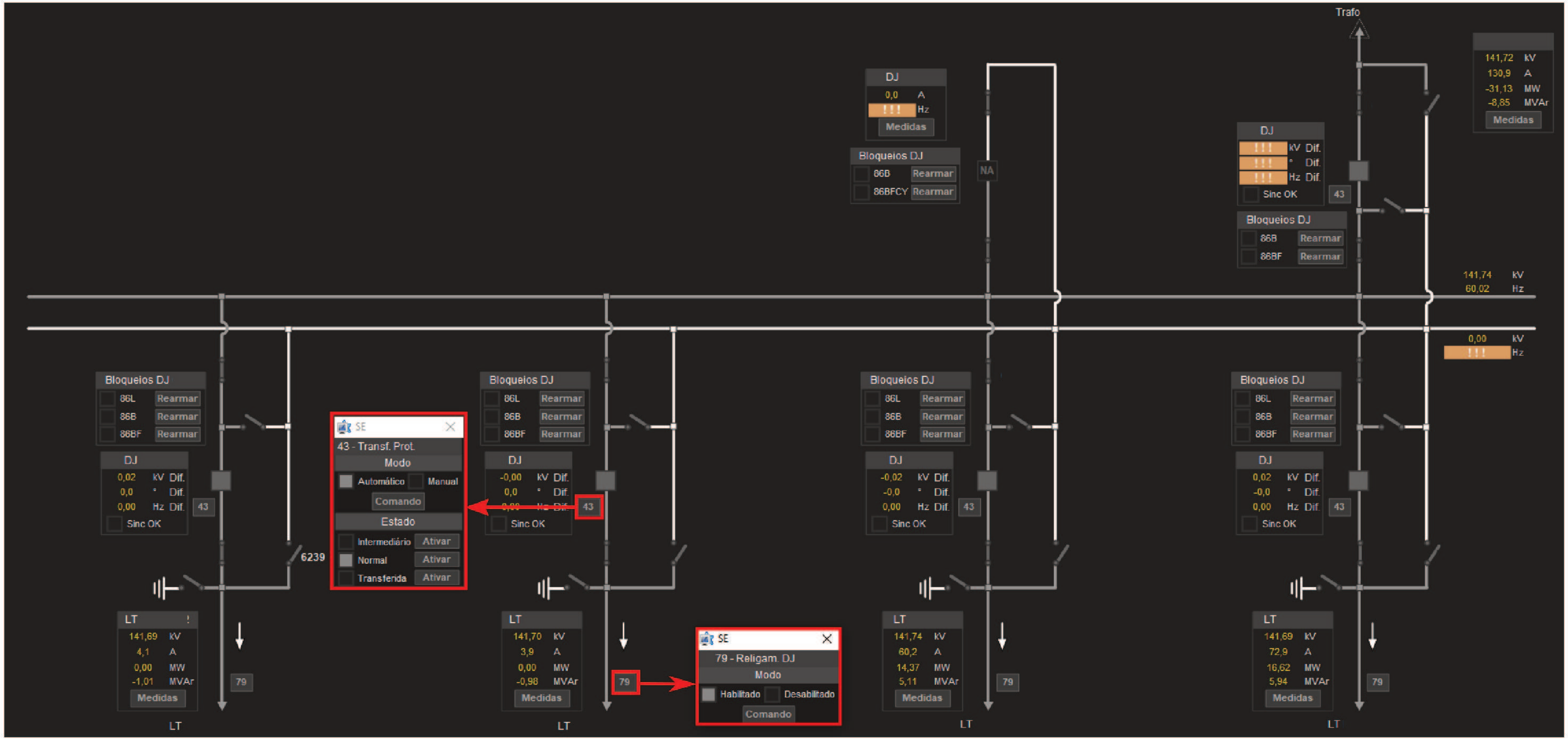
Source: Adapted from the company's HMIs.

Figure 58 – Single-line diagram of the 500kV sector with the transformer pop-ups opened.



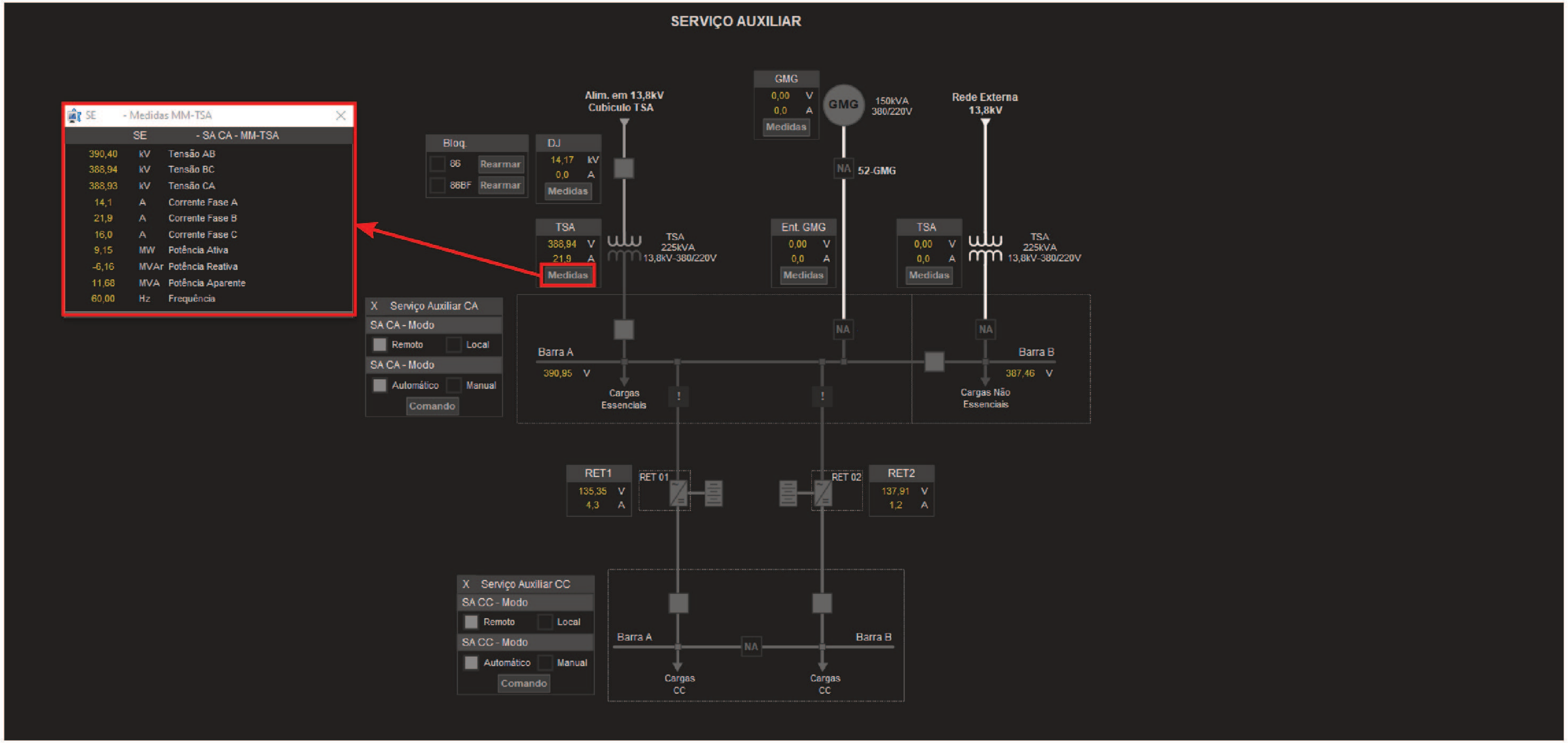
Source: Adapted from the company's HMIs.

Figure 59 – Single-line diagram of the 138kV sector with two circuit breakers pop-ups opened.



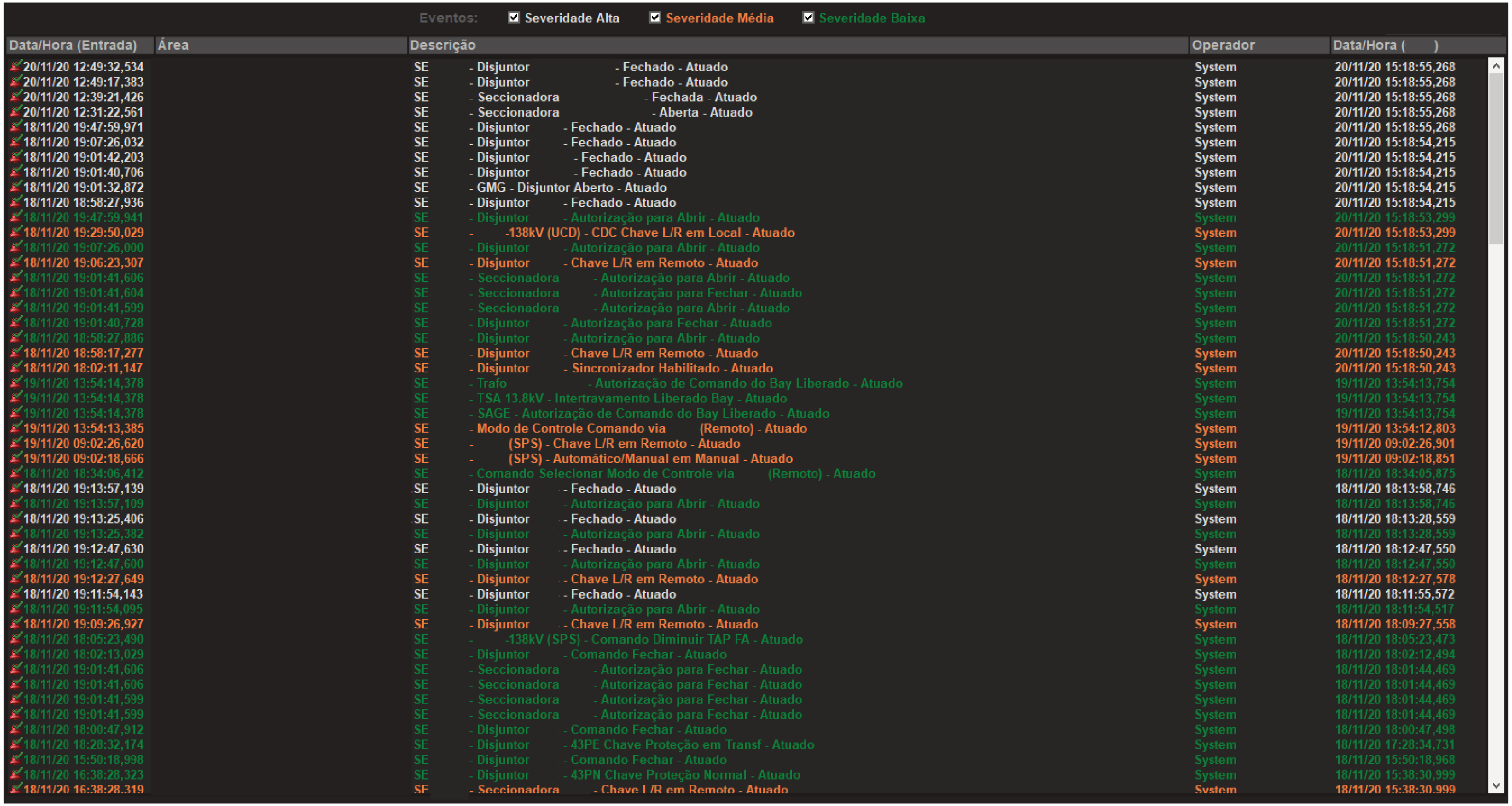
Source: Adapted from the company's HMIs.

Figure 60 – Substation's auxiliary System Single-line Diagram with a measures window opened.



Source: Adapted from the company's HMIs.

Figure 61 – Events Screen filtered by the substation's events.

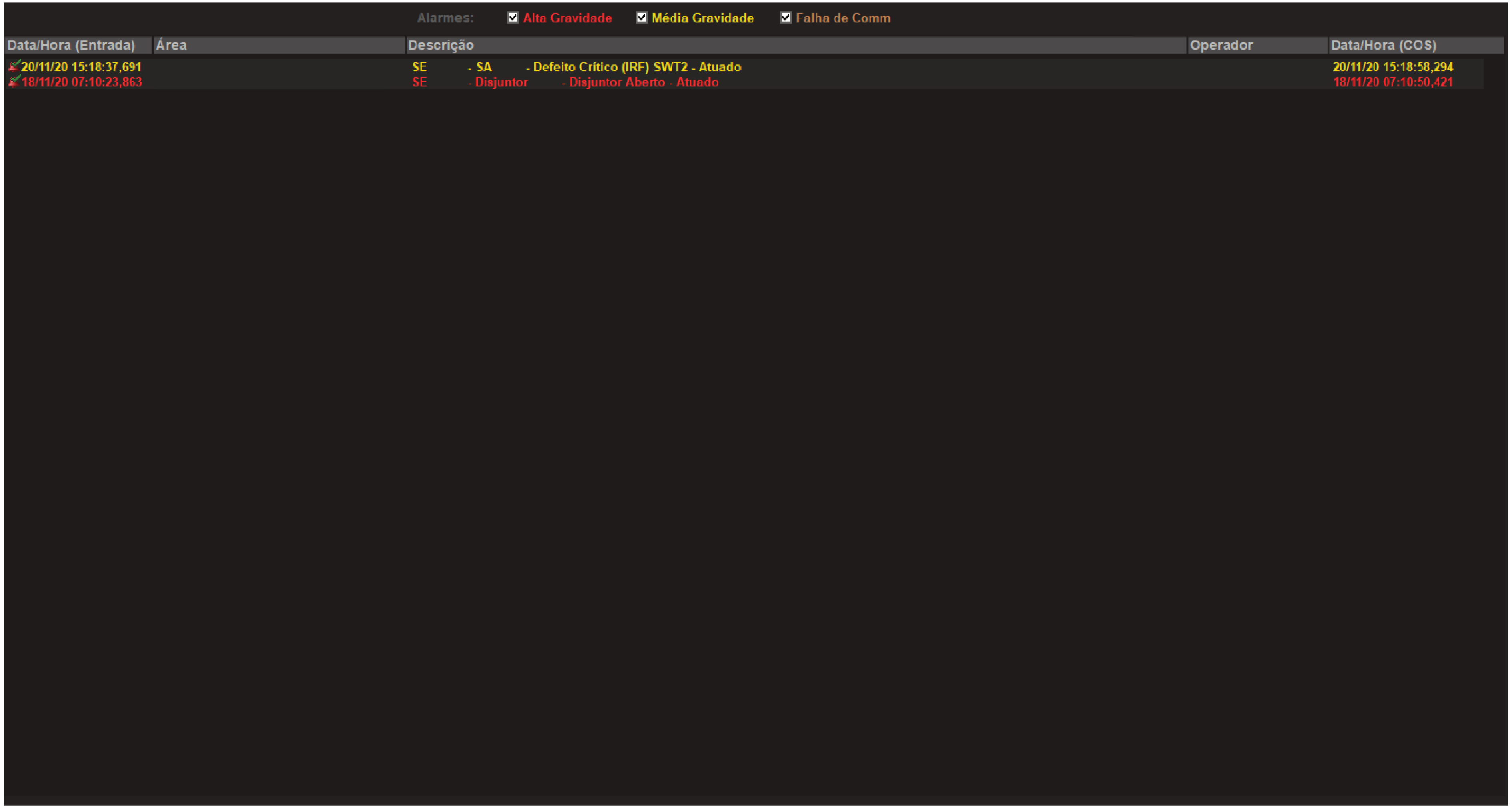


Eventos: ☑ Severidade Alta ☑ Severidade Média ☑ Severidade Baixa

Data/Hora (Entrada)	Área	Descrição	Operador	Data/Hora ( )
20/11/20 12:49:32,534		SE - Disjuntor - Fechado - Atuado	System	20/11/20 15:18:55,268
20/11/20 12:49:17,383		SE - Disjuntor - Fechado - Atuado	System	20/11/20 15:18:55,268
20/11/20 12:39:21,426		SE - Seccionadora - Fechada - Atuado	System	20/11/20 15:18:55,268
20/11/20 12:31:22,561		SE - Seccionadora - Aberta - Atuado	System	20/11/20 15:18:55,268
18/11/20 19:47:59,971		SE - Disjuntor - Fechado - Atuado	System	20/11/20 15:18:55,268
18/11/20 19:07:26,032		SE - Disjuntor - Fechado - Atuado	System	20/11/20 15:18:54,215
18/11/20 19:01:42,203		SE - Disjuntor - Fechado - Atuado	System	20/11/20 15:18:54,215
18/11/20 19:01:40,706		SE - Disjuntor - Fechado - Atuado	System	20/11/20 15:18:54,215
18/11/20 19:01:32,872		SE - GMG - Disjuntor Aberto - Atuado	System	20/11/20 15:18:54,215
18/11/20 18:58:27,936		SE - Disjuntor - Fechado - Atuado	System	20/11/20 15:18:54,215
18/11/20 19:47:59,941		SE - Disjuntor - Autorização para Abrir - Atuado	System	20/11/20 15:18:53,299
18/11/20 19:29:50,029		SE - -138kV (UCD) - CDC Chave L/R em Local - Atuado	System	20/11/20 15:18:53,299
18/11/20 19:07:26,000		SE - Disjuntor - Autorização para Abrir - Atuado	System	20/11/20 15:18:51,272
18/11/20 19:06:23,307		SE - Disjuntor - Chave L/R em Remoto - Atuado	System	20/11/20 15:18:51,272
18/11/20 19:01:41,606		SE - Seccionadora - Autorização para Abrir - Atuado	System	20/11/20 15:18:51,272
18/11/20 19:01:41,604		SE - Seccionadora - Autorização para Fechar - Atuado	System	20/11/20 15:18:51,272
18/11/20 19:01:41,599		SE - Seccionadora - Autorização para Abrir - Atuado	System	20/11/20 15:18:51,272
18/11/20 19:01:40,728		SE - Disjuntor - Autorização para Fechar - Atuado	System	20/11/20 15:18:51,272
18/11/20 18:58:27,886		SE - Disjuntor - Autorização para Abrir - Atuado	System	20/11/20 15:18:50,243
18/11/20 18:58:17,277		SE - Disjuntor - Chave L/R em Remoto - Atuado	System	20/11/20 15:18:50,243
18/11/20 18:02:11,147		SE - Disjuntor - Sincronizador Habilitado - Atuado	System	20/11/20 15:18:50,243
19/11/20 13:54:14,378		SE - Trafo - Autorização de Comando do Bay Liberado - Atuado	System	19/11/20 13:54:13,754
19/11/20 13:54:14,378		SE - TSA 13.8kV - Intertravamento Liberado Bay - Atuado	System	19/11/20 13:54:13,754
19/11/20 13:54:14,378		SE - SAGE - Autorização de Comando do Bay Liberado - Atuado	System	19/11/20 13:54:13,754
19/11/20 13:54:13,385		SE - Modo de Controle Comando via (Remoto) - Atuado	System	19/11/20 13:54:12,803
19/11/20 09:02:26,620		SE - (SPS) - Chave L/R em Remoto - Atuado	System	19/11/20 09:02:26,901
19/11/20 09:02:18,666		SE - (SPS) - Automático/Manual em Manual - Atuado	System	19/11/20 09:02:18,851
18/11/20 18:34:06,412		SE - Comando Selecionar Modo de Controle via (Remoto) - Atuado	System	18/11/20 18:34:05,875
18/11/20 19:13:57,139		SE - Disjuntor - Fechado - Atuado	System	18/11/20 18:13:58,746
18/11/20 19:13:57,109		SE - Disjuntor - Autorização para Abrir - Atuado	System	18/11/20 18:13:58,746
18/11/20 19:13:25,406		SE - Disjuntor - Fechado - Atuado	System	18/11/20 18:13:28,559
18/11/20 19:13:25,382		SE - Disjuntor - Autorização para Abrir - Atuado	System	18/11/20 18:13:28,559
18/11/20 19:12:47,630		SE - Disjuntor - Fechado - Atuado	System	18/11/20 18:12:47,550
18/11/20 19:12:47,600		SE - Disjuntor - Autorização para Abrir - Atuado	System	18/11/20 18:12:47,550
18/11/20 19:12:27,649		SE - Disjuntor - Chave L/R em Remoto - Atuado	System	18/11/20 18:12:27,578
18/11/20 19:11:54,143		SE - Disjuntor - Fechado - Atuado	System	18/11/20 18:11:55,572
18/11/20 19:11:54,095		SE - Disjuntor - Autorização para Abrir - Atuado	System	18/11/20 18:11:54,517
18/11/20 19:09:26,927		SE - Disjuntor - Chave L/R em Remoto - Atuado	System	18/11/20 18:09:27,558
18/11/20 18:05:23,490		SE - -138kV (SPS) - Comando Diminuir TAP FA - Atuado	System	18/11/20 18:05:23,473
18/11/20 18:02:13,029		SE - Disjuntor - Comando Fechar - Atuado	System	18/11/20 18:02:12,494
18/11/20 19:01:41,606		SE - Seccionadora - Autorização para Fechar - Atuado	System	18/11/20 18:01:44,469
18/11/20 19:01:41,606		SE - Seccionadora - Autorização para Fechar - Atuado	System	18/11/20 18:01:44,469
18/11/20 19:01:41,599		SE - Seccionadora - Autorização para Fechar - Atuado	System	18/11/20 18:01:44,469
18/11/20 19:01:41,599		SE - Seccionadora - Autorização para Fechar - Atuado	System	18/11/20 18:01:44,469
18/11/20 18:00:47,912		SE - Disjuntor - Comando Fechar - Atuado	System	18/11/20 18:00:47,498
18/11/20 18:28:32,174		SE - Disjuntor - 43PE Chave Proteção em Transf - Atuado	System	18/11/20 17:28:34,731
18/11/20 15:50:18,998		SE - Disjuntor - Comando Fechar - Atuado	System	18/11/20 15:50:18,968
18/11/20 16:38:28,323		SE - Disjuntor - 43PN Chave Proteção Normal - Atuado	System	18/11/20 15:38:30,999
18/11/20 16:38:28,319		SE - Seccionadora - Chave L/R em Remoto - Atuado	System	18/11/20 15:38:30,999

Source: Adapted from the company's HMIs.

Figure 62 – Alarms Screen filtered by the substation's events.



Source: Adapted from the company's HMIs.

5 CONCLUSION

This report presented an approach to develop a new SCADA application and integrate it into a control center. The theoretical background presented three essential concepts that explain how substation and control center connect themselves. The first concept was about the hardware and software architecture used in the field through the SCADA systems. The second concept then provided the pathway for connecting remote points to transmit and receive data. On the other side, the third concept presented the fundamentals of the transmission system required by the control center operators to operate substations.

Next, this report explained the processes' resolution in each part of the project necessary to insert new HMIs into the control center's SCADA. The development procedures aimed to perform the functional objectives: enable the communication between the control station and substation, establish operational alarms, and store data on a database. Also, it aimed to do an interactive objective, create HMIs, to achieve the application integration.

These specific objectives were tested and validated as the project's results, which originated in 11 HMIs and 13 pop-up windows. The integration achieved its primary objective, integrating a new SCADA application to the company's control center to supervise and control the substation remotely. It allowed to attend the services of the Brazilian National Grid (known as SIN - *Sistema Interligado Nacional*) in compliance with the Brazilian Electricity Regulatory Agency (in Portuguese, *Agência Nacional de Energia Elétrica*, ANEEL) rules, and in line with the Operator of the Brazilian Grid (known as ONS - *Operador Nacional do Sistema Elétrico*) policies.

5.1 CONTROL AND AUTOMATION ENGINEERING COURSE CONTRIBUTIONS

The Control and Automation Engineering course contributions proved relevant in engaging the student's interest in the activity experienced.

The course final project discipline allowed the student to put the knowledge gained in real scenarios. The job in question is inserted in the Brazilian electric sector in the branch of electric power transmission. The Control and Automation Engineering course covered a vast area of studies, including a base in the electrical area. It enabled the student to become familiar with this segment through technical knowledge acquired in the disciplines of Electrotechnics for Automation, Electrical Machine Drives for Automation, and Electrical Circuits for Automation.

In the more specific branches of the course, the student learned about production systems, SCADA systems, communication networks, and supervisory systems programming in disciplines of Discrete Automation Systems, Automated Systems Programming, and Computer Networks for Automation.

Within the scope of measurement systems, the disciplines of Industrial Metrology and Instrumentation in Control supported an understanding of the substation's quantities and measures. In addition to presenting essential concepts of data acquisition systems and signal conditioning.

In the optional disciplines of Database Systems Fundamentals, Distributed Systems for Automation, and Corporate Systems Integration, the concepts studied are used to understand how data is stored and queried and data interoperability at a more continuous and secure data flow.

Thus, the course-specific disciplines provided automation concepts and tools that facilitated the understand and development of activities. The electrical area disciplines contributed to the energy segment's context and the technical knowledge required in power systems engineering.

Finally, inherently with the course, the student could use new computer technologies to command Elipse E3 Studio and implement new SCADA applications and its maintenance and improvements.

5.2 FUTURE WORK

The driver has an import and export option to manipulate the object in a Comma-Separated Values (CSV) file around the process resolution. It allows constructing the driver from outside of the Elipse Studio, which can be better to deal with many tags. Also, it can be used to generate alarms from the driver automatically. Future works may use alternatives development procedures through CSV files to automatically generate an object from another.

Moreover, it is essential to note that the specific objectives proposed and accomplished represent a part of what SCADA systems can provide. Future work may explore other potential features, such as generating reports to be implemented in demands similar to this work.

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