SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

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Module 06

Automated tracking and VR system

Lecture 14 B

SCADA and its Application in Mining

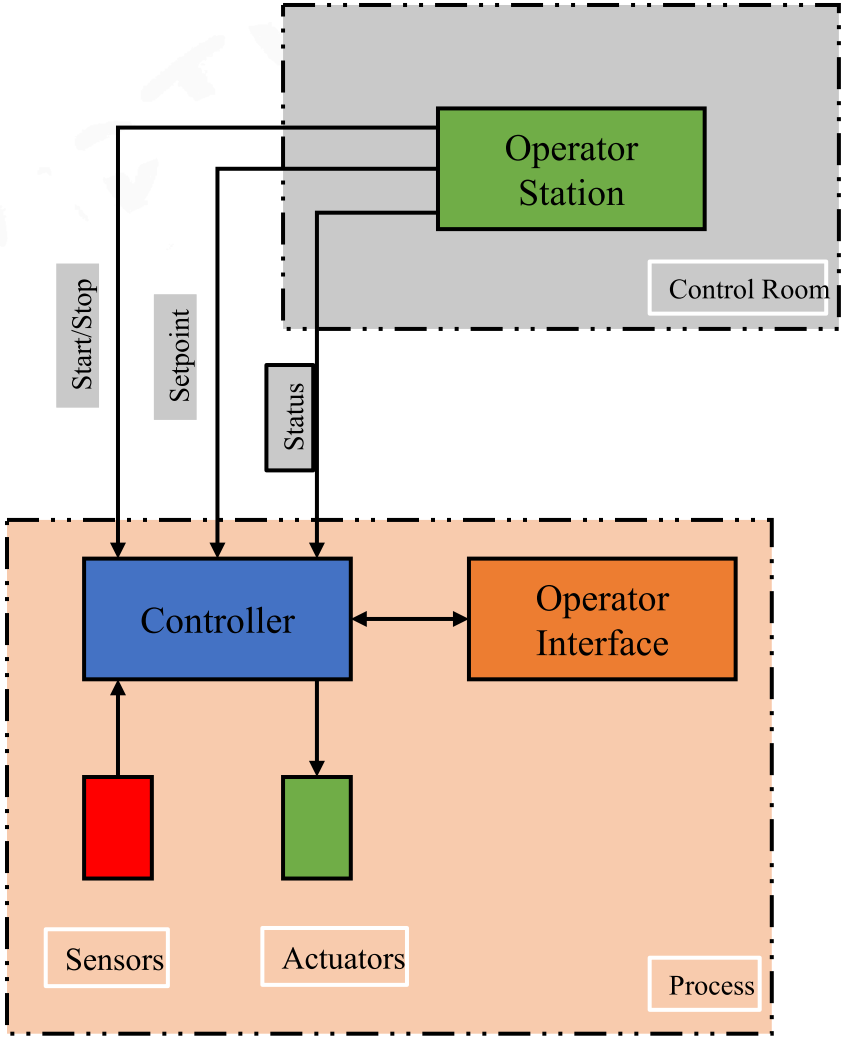
CONCEPTS COVERED

- Different control in SCADA systems
- Programmable logic controller (PLC)
- Redundant PLCs
- SCADA System Implementation
- Recent advances in SCADA
- Case study - Smart Energy Management System: Design of a Monitoring and Peak Load Forecasting System for an Experimental Open-Pit Mine

Different control in SCADA systems

Local control

- It is a system architecture where sensors, controllers, and controlled equipment are in close proximity, with each controller having jurisdiction over a specific system or subsystem.
- Local controllers are typically capable of receiving inputs from a supervisory controller to initiate or terminate locally-controlled automatic sequences or adjust control setpoints. However, the control action itself is determined within the local controller.



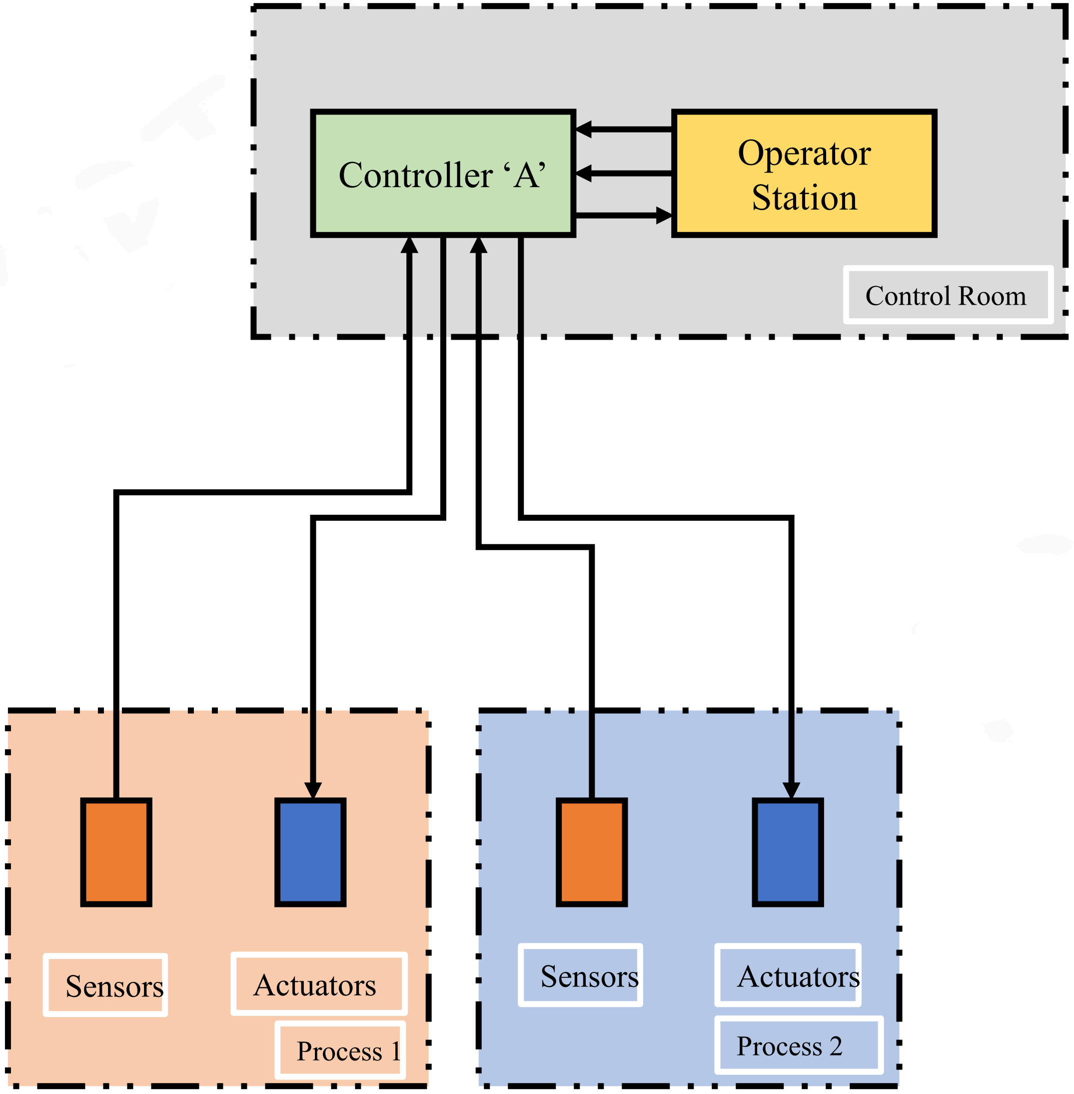
Local control system architecture

- Operator interfaces and displays necessary for system operation are also local, providing a significant advantage for troubleshooting but requiring operators to move around the facility to monitor systems or respond to contingencies.
- Examples of local control include packaged control panels accompanying chillers or skid-mounted pump packages.

Centralized control

- Centralized control refers to a system where all sensors, actuators, and equipment within a facility are connected to a single controller or group of controllers situated in a common control room.
- This setup enhances operator understanding of system conditions and facilitates rapid response to contingencies by consolidating controls, operator interfaces, and indicators in one location.

- **Centralized control was prevalent in facilities like power plants using single-loop controllers or early digital controls. However, it has been largely replaced by distributed control due to the high cost associated with routing and installing all control system wiring to a central location.**
- **Centralized control systems may still be suitable for small C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance) facilities but require fully redundant processors.**

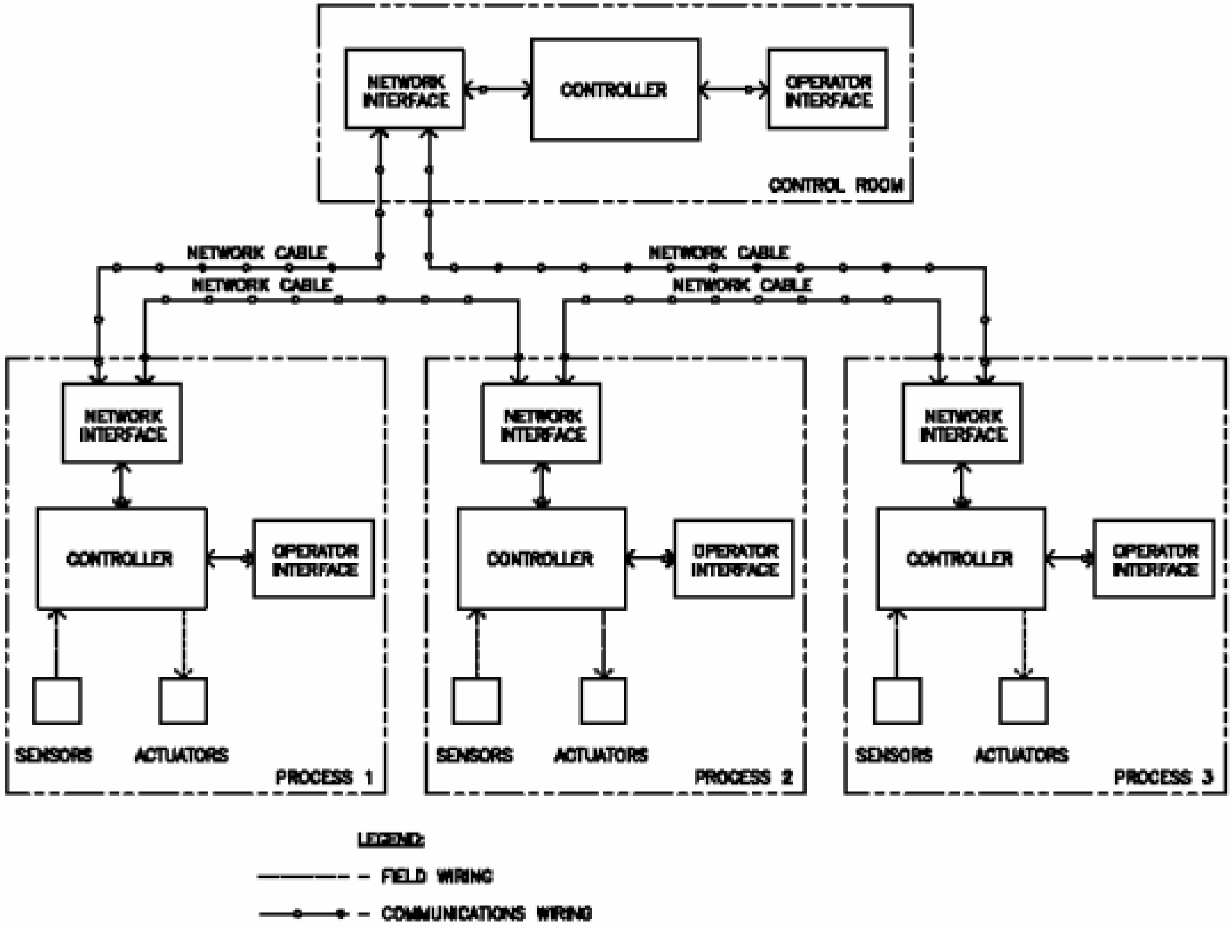


Centralized control system architecture

- In centralized control systems with redundancy, segregated wiring pathways are essential to ensure that control signals to and from redundant equipment or systems are not susceptible to common failure from electrical faults, physical damage, or environmental hazards.

Distributed control

- Distributed control system architecture, combines the advantages of both local and centralized control.
- In a distributed control system, controllers are situated locally to systems or groups of equipment but are interconnected to one or more operator stations in a central location via a digital communication circuit.


NETWORK INTERFACE
CONTROLLER
OPERATOR INTERFACE
CONTROL ROOM
NETWORK CABLE
NETWORK CABLE
NETWORK CABLE
NETWORK CABLE
NETWORK INTERFACE
CONTROLLER
OPERATOR INTERFACE
SENSORS
ACTUATORS
PROCESS 1
NETWORK INTERFACE
CONTROLLER
OPERATOR INTERFACE
SENSORS
ACTUATORS
PROCESS 2
NETWORK INTERFACE
CONTROLLER
OPERATOR INTERFACE
SENSORS
ACTUATORS
PROCESS 3
LEGEND:
– FIELD WIRING
– COMMUNICATIONS WIRING

- Control actions for each system or subsystem occur within the local controller, while the central operator station maintains full visibility of the status of all systems and input/output data in each controller.
- Additionally, the central operator station possesses the capability to intervene in the control logic of local controllers if necessary, providing enhanced control and monitoring capabilities across the entire system.

There are a number of characteristics of distributed control architecture which enhance reliability

1) Input and output wiring runs are short and less vulnerable to physical disruption or electromagnetic interference.

2) A catastrophic environmental failure in one area of the facility will not affect controllers or wiring located in another area.

3) Each local controller can function on its own upon loss of communication with the central controller.

There are also specific threats introduced by distributed control architecture that must be addressed in the design of the system:

1) Networks used for communication may become electronically compromised from outside the facility.
2) Interconnection of controllers in different locations can produce ground loop and surge voltage problems.
3) If the central controller is provided with the ability to directly drive the output of local controllers for purposes of operator intervention, software glitches in the central controller have the potential to affect multiple local controllers, compromising system redundancy.

Types of distributed control systems

Plant distributed control system (DCS)

- Distributed control system architecture, combines the advantages of both local and centralized control.
- In a distributed control system, controllers are situated locally to systems or groups of equipment but are interconnected to one or more operator stations in a central location via a digital communication circuit.

Direct digital control (DDC)

Purpose:

DDC systems are utilized in the commercial building HVAC industry to oversee and regulate environmental conditions.

Components:

I. DDC systems consist of local controllers.
II. These controllers are linked to a network.
III. A central station, typically PC-based, is part of the setup.

Functionality of Central Station:

I. The central station offers capabilities for monitoring.
II. It allows for reporting.
III. Data storage is included.
IV. Programming capabilities are provided.

Optimization:

I. **The controllers are designed for cost-effective HVAC system control.**

II. **They prioritize efficiency over fast execution speeds.**

Proprietary Nature:

I. **Both hardware and control software are proprietary.**

II. **Network communication may employ either proprietary or open protocols.**

Remote terminal unit (RTU) based SCADA

Application

RTU-based systems are prevalent in the electric, gas, and water distribution industries, especially for monitoring and controlling operations across vast geographical areas.

Purpose of RTUs:

I. **RTUs are primarily developed to enable monitoring and control functions at remote and unattended sites.**

II. **Typical deployment sites include substations, metering stations, pump stations, and water towers.**

Communication:

RTUs communicate with a central station using various means such as telephone lines, fiber optics, radio, or microwave transmission.

Functionality at Monitored Sites:

I. Monitored sites are relatively small in size.

II. RTUs are primarily used for monitoring purposes, with limited control capabilities.

Proprietary Nature:

I. Both hardware and software in RTU-based systems are proprietary.

II. Data transmission to the central station may utilize either proprietary or open protocols.

Programmable logic controller (PLC)

The recommended controller for SCADA systems is the programmable logic controller (PLC). PLCs are general-purpose microprocessor-based controllers that provide

- Logic
- Timing
- Counting
- analog control with network communications

PLCs are recommended for the following reasons:

a. They were developed for the factory floor and have demonstrated high reliability and tolerance for heat, vibration, and electromagnetic interference.

b. Their widespread market penetration means that parts are readily available and programming and technical support services are available from a large number of control system integrators.

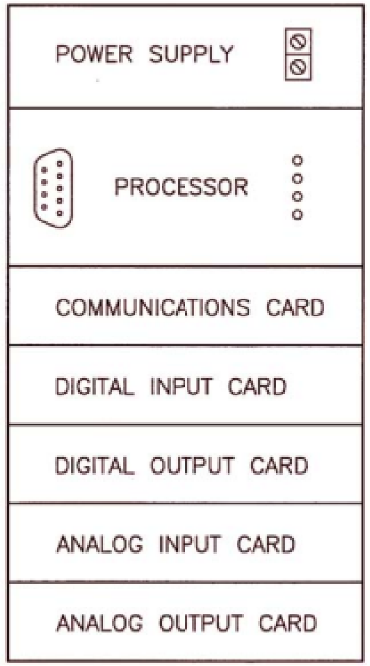
c. They provide high-speed processing, which is important in generator and switchgear control applications.

d. They support hot standby and triple-redundant configurations for high-reliability applications.

A PLC consists of the required quantities of the following types of modules or cards, mounted on a common physical support and electrical interconnection structure known as a rack. A typical PLC rack configuration is shown in the figure

Power supply

- **The power supply converts facility's electrical distribution voltage, such as 120 VAC or 125 VDC to signal level voltage used by the processor and other modules.**



Typical PLC rack

Processor

The processor module contains the microprocessor that performs control functions and computations, as well as the memory required to store the program.

Input/Output (I/O)

These modules provide the means of connecting the processor to the field devices.

Communications

Communications modules are available for a wide range of industry-standard communication network connections. These allow digital data transfer between PLCs and to other systems within the facility. Some PLCs have communications capability built-in to the processor, rather than using separate modules.

Redundant PLCs

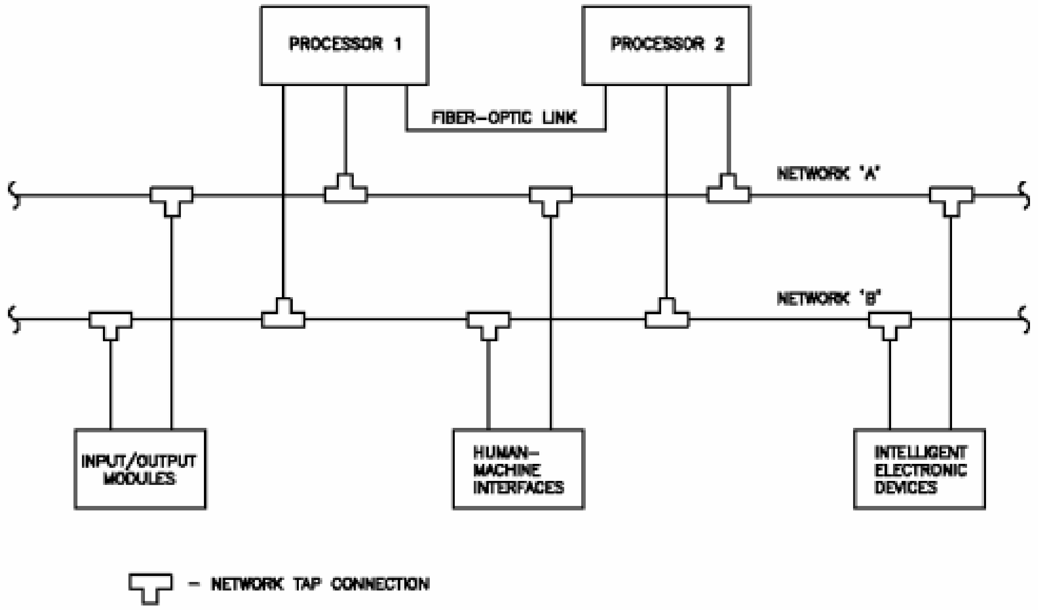
I. Redundant PLC systems may utilize a warm standby, hot standby, or voting configuration.

II. Both processors have continuous access to I/O over redundant buses or networks.

III. Register data and status information are exchanged over a dedicated fiber optic link.

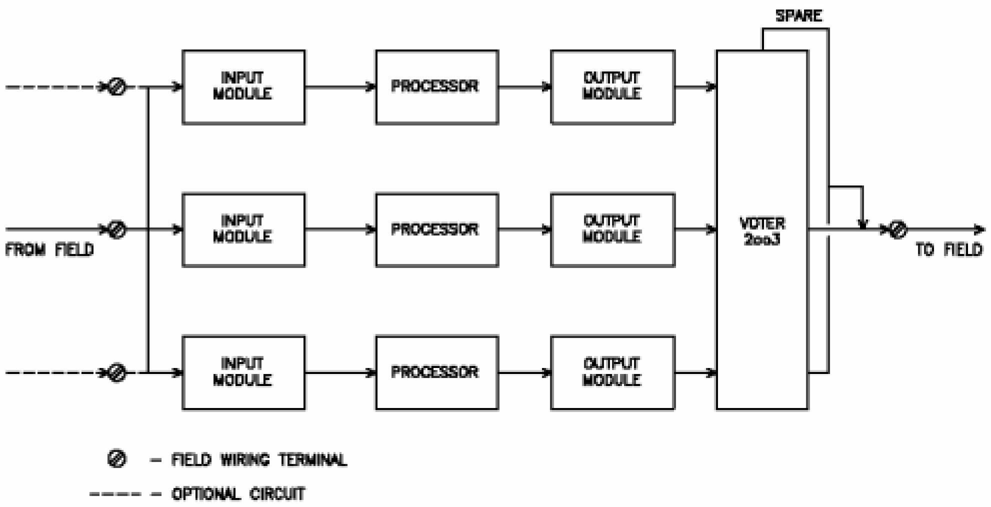
IV. In a warm standby configuration, the primary processor runs the program and controls output states. Upon primary processor failure, the standby processor takes over and runs the program.

- In a hot standby configuration, both processors run continuously with synchronized program scans over the fiber optic link. If one processor fails, the other takes control without changing output states.



Typical redundant PLC configuration

- The hot standby configuration is recommended for most SCADA applications.
- For highly critical applications, a triple-redundant voting scheme may be used.
- Three processors run continuously with synchronized scans, using shared or independent input data from redundant sensors.



Triple-redundant PLC configuration

SCADA System Implementation

Approaches to SCADA System Implementation

- **Physical replication: Creating exact physical copies of SCADA systems.**
- **Virtual-physical replication: Simulating SCADA systems in virtual environments that closely resemble physical setups.**
- **Virtual replication: Completely simulating SCADA systems in virtual environments.**
- **Hybrid replication: Combining physical and virtual elements in SCADA system replication.**

Recent advances in SCADA

Challenges in Traditional SCADA Frameworks

- Current SCADA frameworks combine characteristics of old and new features, which may compromise their security.
- Traditional SCADA systems are often inflexible, static, and centralized, limiting interoperability and exposing vulnerabilities.
- Sensor cloud-based SCADA infrastructure has been proposed as a solution to overcome these limitations, but it introduces new security concerns due to its larger exposed space.

New Approaches and Technologies

- Researchers have introduced new cloud-based frameworks capable of virtualizing sensing frameworks, processing data, and managing large amounts of sensor data.
- Proposals such as VS-Cloud focus on virtual SCADA architectures with features like dynamic sensing services management, scalability, fault tolerance, and privacy.

Integration of IoT with SCADA

- Industrial IoT (Internet of Things) is revolutionizing industrial sectors by providing enhanced automation and information sharing.
- Integrating IoT with SCADA using cloud computing services offers benefits such as predictive maintenance and fault tolerance but also introduces security vulnerabilities.
- Traditional SCADA systems integrated with IoT are more vulnerable to security threats due to the lack of proper security measures.

Concerns and Considerations

- Advantages of cloud services for SCADA include real-time monitoring, cost-effectiveness, and easy maintenance and upgrades.
- Security and performance issues are major concerns with cloud-based SCADA systems, including tracking of hackers, information leakage, latency, and privacy issues.
- Traditional communication protocols like Modbus/TCP and DNP3 lack adequate protection, increasing the risk of attacks.

- **Reliance on cloud communication exposes SCADA systems to additional security risks and vulnerabilities.**
- **Commercial off-the-shelf solutions are often used instead of proprietary solutions, further complicating security measures.**

Smart Energy Management System: Design of a Monitoring and Peak Load Forecasting System for an Experimental Open-Pit Mine

- **Digitization in the mining industry and machine learning applications have improved the production by showing insights in different components.**
- **Energy consumption is one of the key components to improve the industry's performance in a smart way that requires a very low investment.**
- **This study represents a new hardware, software, and data processing infrastructure for open-pit mines to overcome the energy 4.0 transition and digital transformation.**

- **The main goal of this infrastructure is adding an artificial intelligence layer to energy use in an experimental open-pit mine and giving insights on energy consumption and electrical grid quality.**
- **The achievement of these goals will ease the decision-making stage for maintenance and energy managers according to ISO 50001 standards.**
- **In the mining industry, technological advancements are being successfully applied to enhance the productivity and performance using the industry 4.0 concept.**
- **However, energy management and efficiency have not kept pace with these changes, which is a key element to directly optimize energy consumption and increase profitability.**

- **The objective of this work is to design a new architecture for a smart energy management system according to ISO 50001 standard for mining industry.**

- **The application was oriented to an experimental open-pit mine respecting all requirements and needs.**

- **The study presents a full design and architecture for applying a smart energy management system in mining industry regardless the situation and the technology of the control system adapted because the use of OPC data transmission this system can be implemented in different types of open pit mines.**

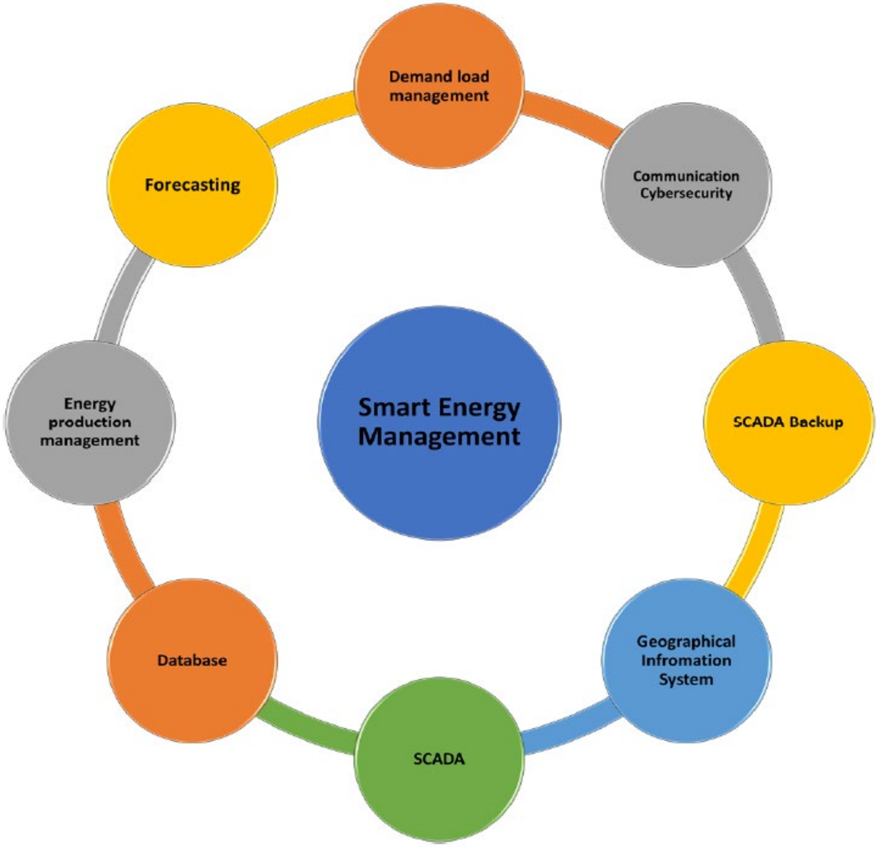
The Challenges of the Implementing the Smart Energy Management System in the Open-Pit Mine

The experimental open-pit mine was initially designed for a required function: to extract mining products and maximize the production, regardless of energy consumption and grid quality monitoring.

- ❑ Monitoring All Different Loads and Supplies.
- ❑ Feeding the Supervisors by Real-Time Energy Data on the Same Process SCADA View.
- ❑ Parallel Integrating Hardware Solutions to the Same Process Control System.

- Predict the Energy Demand Response Based on the State of Different Historical Scenarios
- Finding Correlations between the KPIs of Energy Consumption and Mine Production Process
- Giving Insights on the Electrical Grid Quality
- Real-Time Energy Consumption Feedback Tarrif
- Cybersecurity and Data Sharing

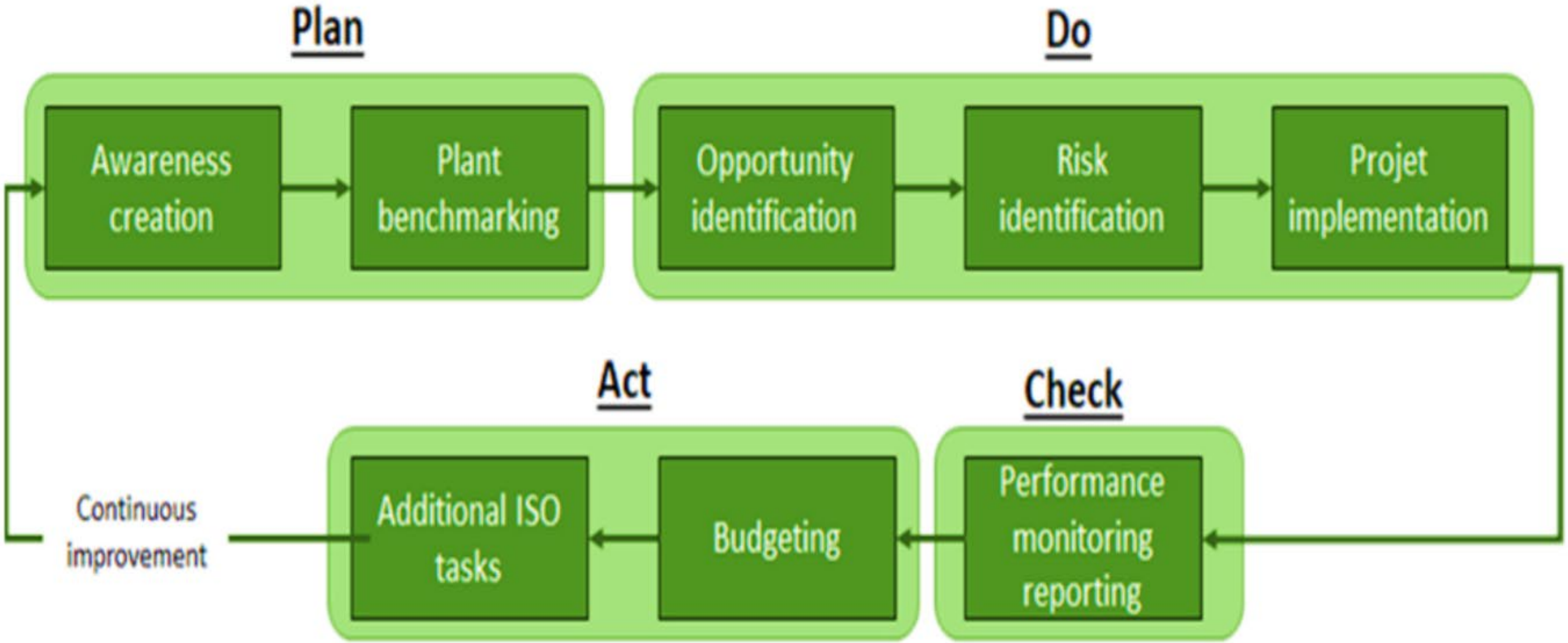
Methodology of the Integrated Smart Energy Management System



A smart energy management system general schematic.

The smart energy management system (SEMS), as shown in slide before, is a dataflow of energy consumption, generation data, between SCADA, SCADA back up for redundancy, the database, and the supervision dashboard, which shows the forecasted and predicted energy profile and demand response of the different components of the open-pit mine electrical grid.

A general PDCA schematic of the smart energy management system approach.



A scheme describing the result increasing profitability using the plan-do-check-act approach of ISO 50001.

State of Art of the Smart Energy Management Systems

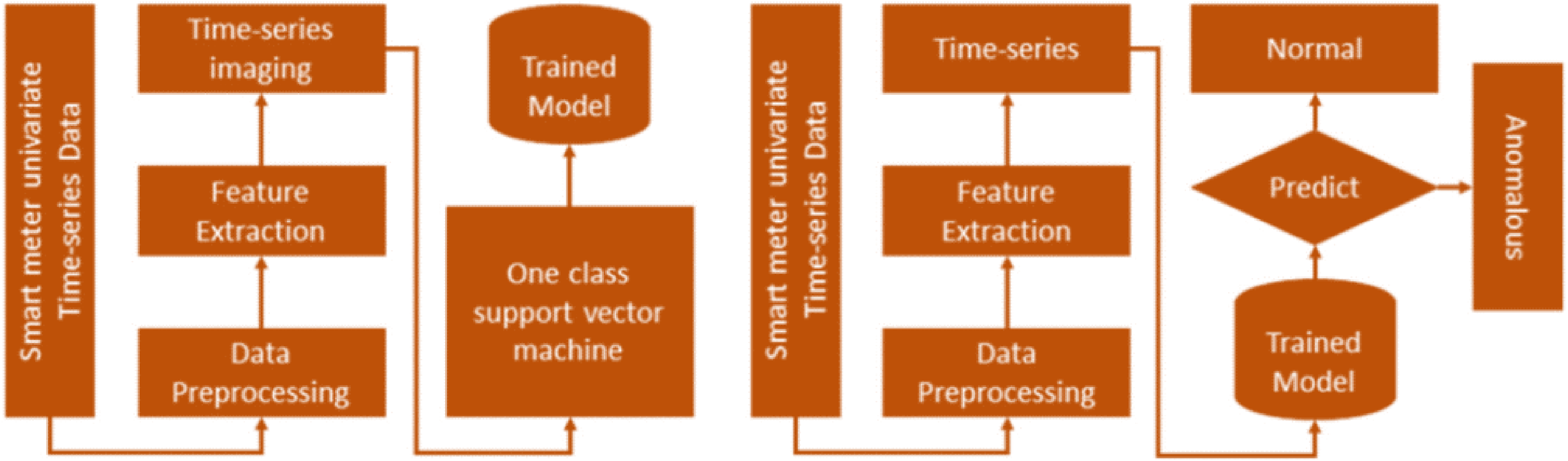
Peak Load Forecasting Models

The energy consumption prediction and peak load forecasting is an important feature in the proposed design. After collecting the data and completing the integration of hardware with the SCADA system is the phase to choose the best peak load forecasting model to validate the POC.

Model	Application	Year	Accuracy
Quantile regression	Electricity demand	2021	0.99
Neuro-fuzzy inference time series	Campus	2020	0.98
SVM	Hotel	2020	0.94
ANN	Ships in green ports	2020	0.85
Quantile regression	Industry	2019	0.95
Quantile regression	Grid demand load	2018	0.99

Comparative study of peak load forecasting models

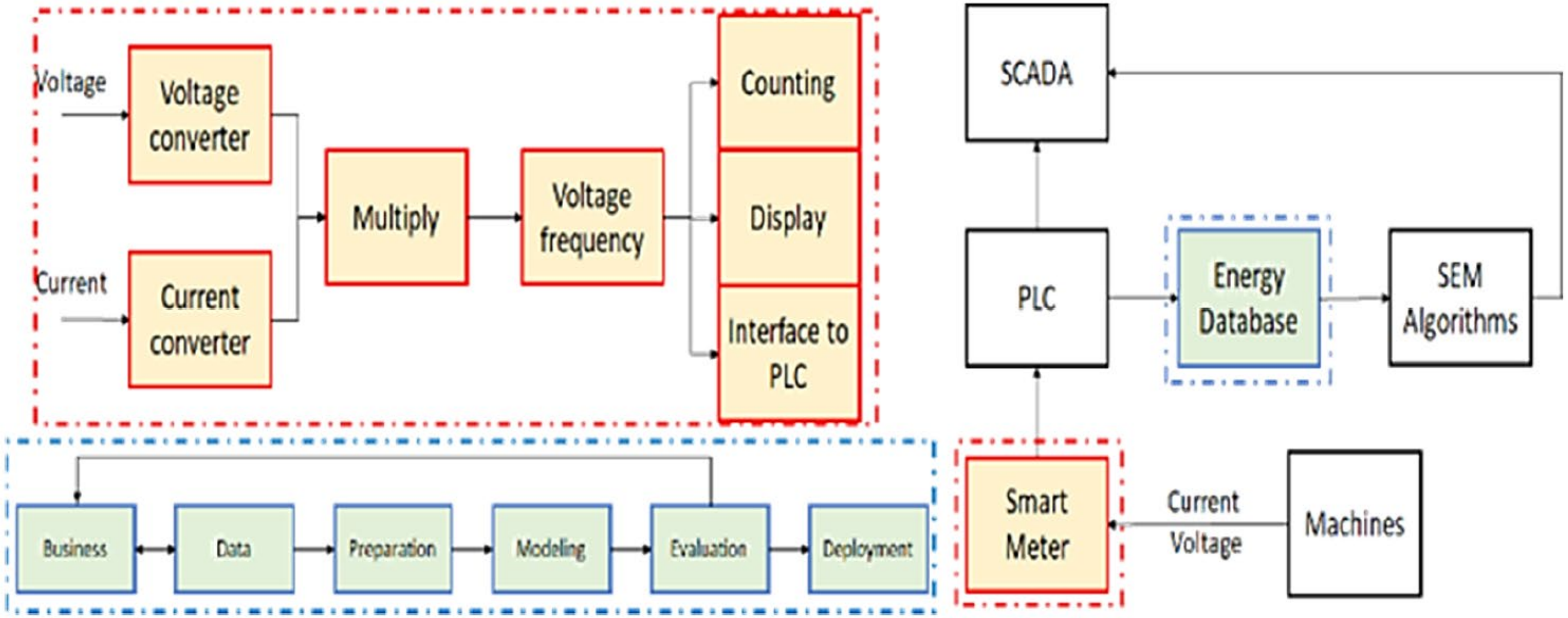
The goals, as shown in Figure, were collecting time series data from smart meters, processing the data and extracting the principal features, training the model using support vector machine, and then predicting the abnormal energy consumption behavior of each open-pit equipment.



Training and testing model to predict the normal and abnormal energy consumption for a residential smart building.

Smart Energy Meter

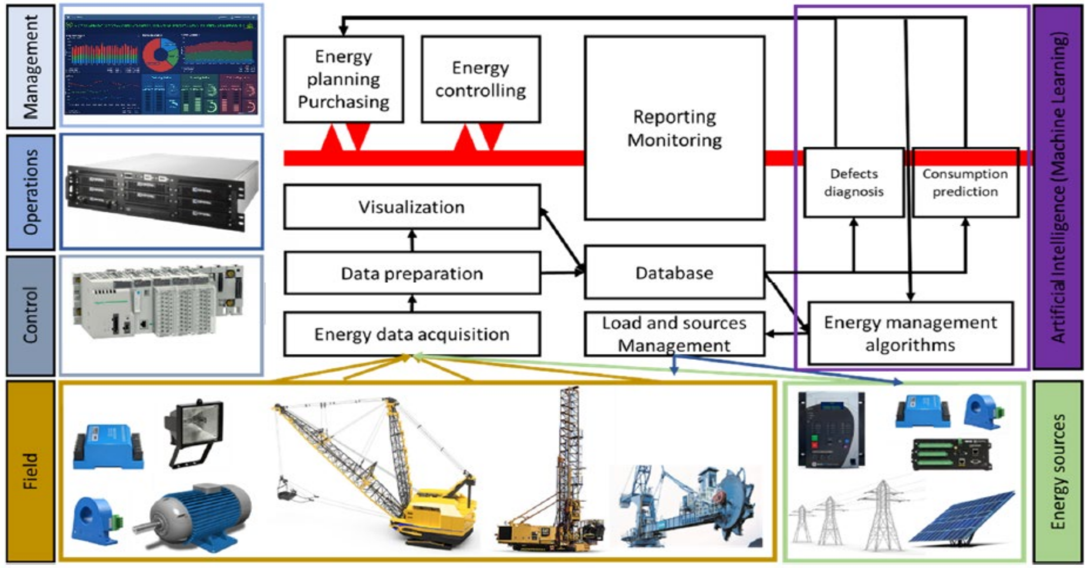
The key component in the proposed SEMS architecture in the open-pit mine application is the energy meter. In this section, we select the best energy meter that can fit perfectly with the existing SCADA architecture. We used PM8000 Schneider energy meters, which can communicate easily with the PLCs through the Modbus protocol.



A scheme of energy metering, storing, predicting and real-time monitoring for industry.

Smart Energy Management System Architecture

- The design is based on an architecture proposed in recent work, where the Smart Energy Management System (SEMS) is depicted as a data flow from various open-pit sections.
- In the field, machines and equipment like draglines, bucket wheel reclaimers, and conveyors are monitored and instrumented with current and voltage sensors.
- Sensor selection is based on factors such as accuracy, drift, linearity, phase shift, integration, and price.



Physical, software and artificial intelligence layers implementation scheme in a mining industry.

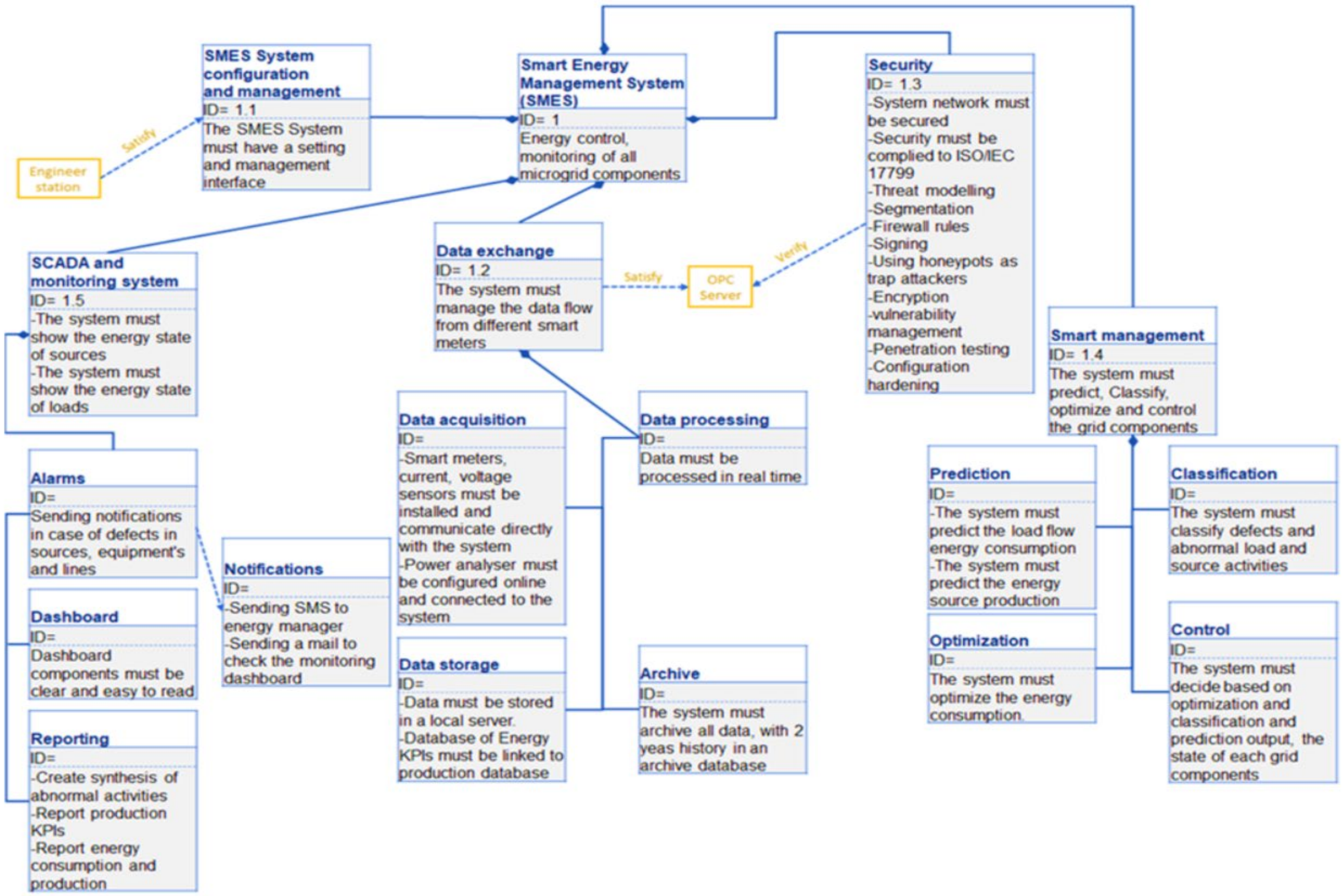
- These sensors interface with power meters, which communicate directly with Programmable Logic Controllers (PLC) in the control layer.
- The PLCs interface with the SCADA system to collect, store, and visualize the data.
- In the artificial intelligence layer of the SEMS, the database feeds algorithms for defect diagnosis and load forecasting.

Smart Energy Management System Requirements for the Open-Pit Mine

- To implement a smart energy management system in mining industry, the requirements of the system must meet the ISO 50001, ISO 50006, IEC 61557-12, IEC 62974-1 and ISO IEC 17799 standards requirements, the schematic represents the requirements diagram for this system, and it proposes a methodology on how making it smart.

- The requirements for a smart energy management system considering five important parts: SCADA and the monitoring system which contains alarms for sending notifications in case of a defects or an abnormal behavior of the grid components, a dashboard that shows the different KPIs and results of the microgrid, and a reporting system that summarize the results and generates reports automatically.

- The data exchange between different smart meters, power analyzers and the communication system, where the data acquisition processing and storage must be in real-time and automatic.



The requirements diagram for smart energy management system for mining industry.

Open-Pit Mine Application

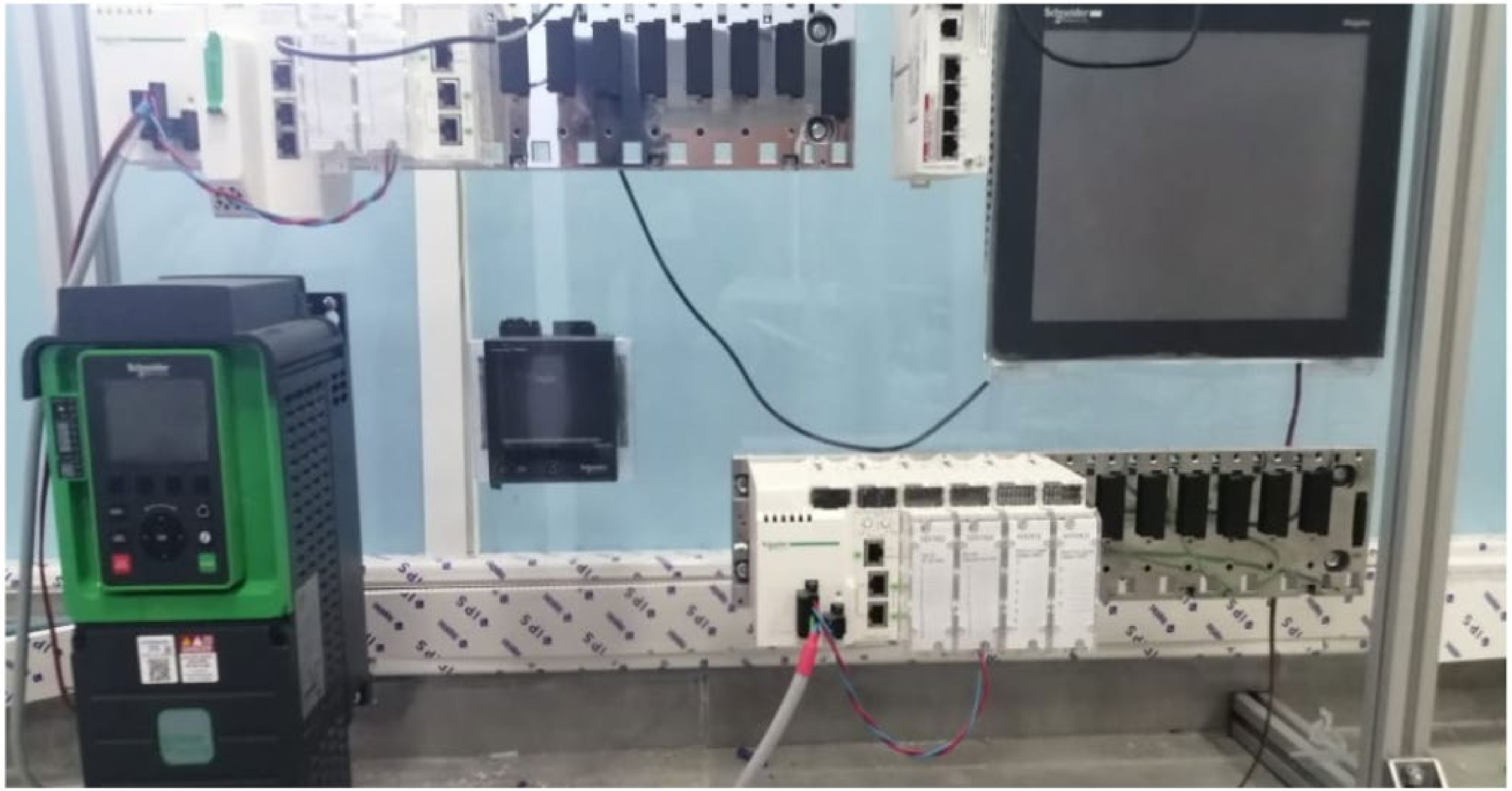
- After the design and requirements study, this section presents the current state of the smart energy management system's proof of concept at the experimental open-pit mine.
- Before implementing the architecture in the field, a test bench was designed in order to test the communication protocols, the database connection, the SCADA system, and the prediction algorithm.

Industrial Application in the Open-Pit Mine SEMS Architecture and Designed Test Bench

- Figure represents the test bench adding an HMI to visualize the data. The program is tested and built on the same PLC using Unity Pro XI software.

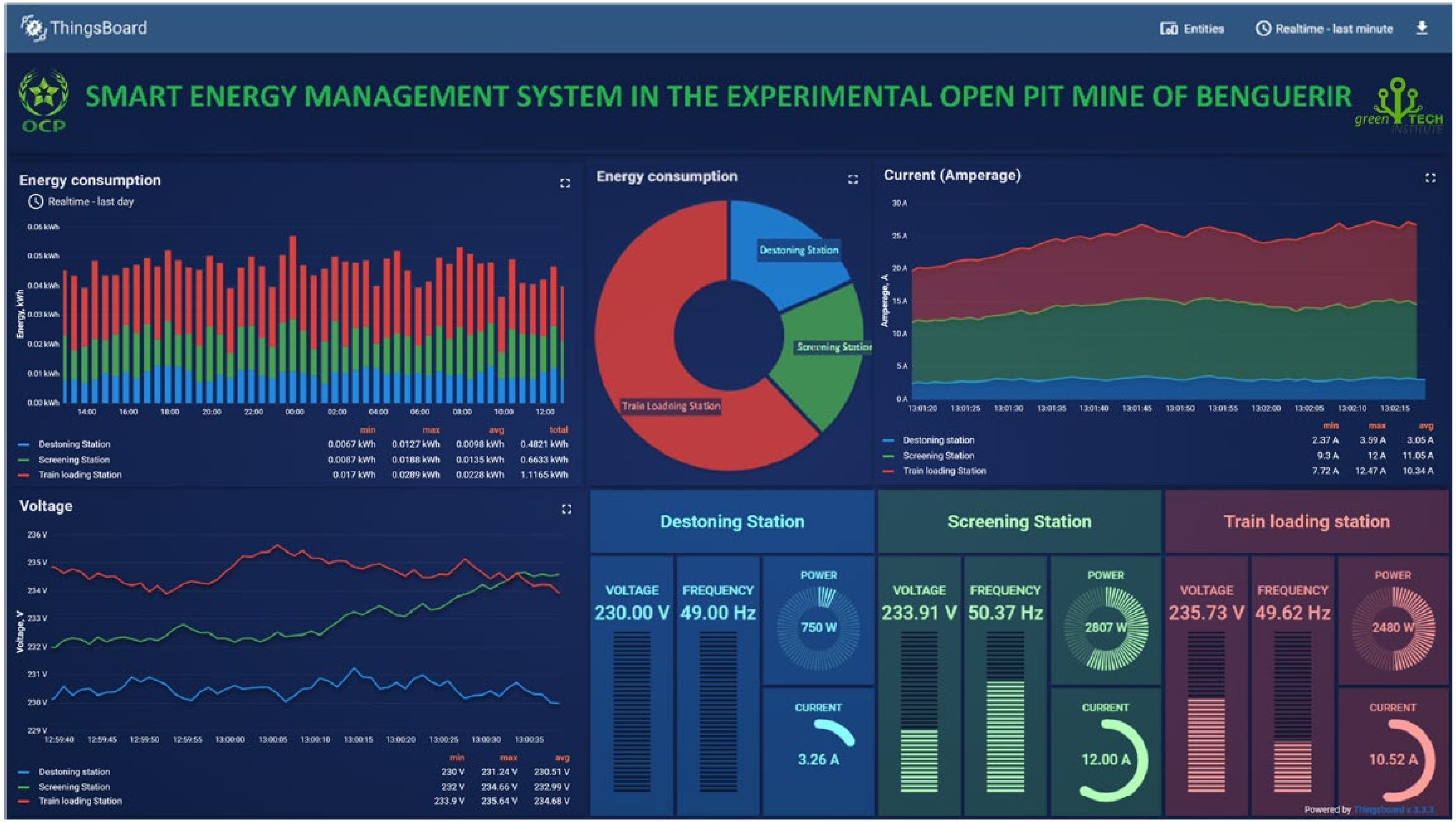
The PLC is connected to a server that contains the database, using the Python program that retrieves data from the PLC Modbus protocol and inserts them into tables as a time series dataset, which is connected to both SCADA views using Citect SCADA software and to Things Board for web browser connection.

Industrial Application in the Open-Pit Mine SEMS Architecture and Designed Test Bench



Communication test bench set up.

SCADA Views



Things Board view under design.

- **These power meters interface with programmable logic controllers (PLCs) and distributed control systems (DCS) to directly control motors and optimize energy consumption.**
- **Similar power meters are connected to renewable energy sources such as photovoltaic panels, wind turbines, electric vehicles, or other energy storage systems for a comprehensive monitoring system.**
- **A smart microgrid dedicated to the mining industry's open-pit operations is developed, integrating different communication protocols and managing energy flow.**

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CONCLUSION

- Explored the various control mechanisms employed within SCADA systems for monitoring and managing industrial processes.
- Introduced PLCs as a key component of SCADA systems, responsible for executing control logic.
- Discussed the use of redundant PLCs to enhance reliability and fault tolerance in SCADA setups.
- Explored the process of implementing SCADA systems, including hardware setup, software configuration, and integration
- Examined the latest developments and innovations in SCADA technology, including advancements in hardware, software, and communication protocols.
- Case Study - Smart Energy Management System


THANK YOU