Mine Automation and Data Analytics

Prof. Radhakanta Koner

Department of Mining Engineering

IIT (ISM) Dhanbad

Week-6

Lecture-28

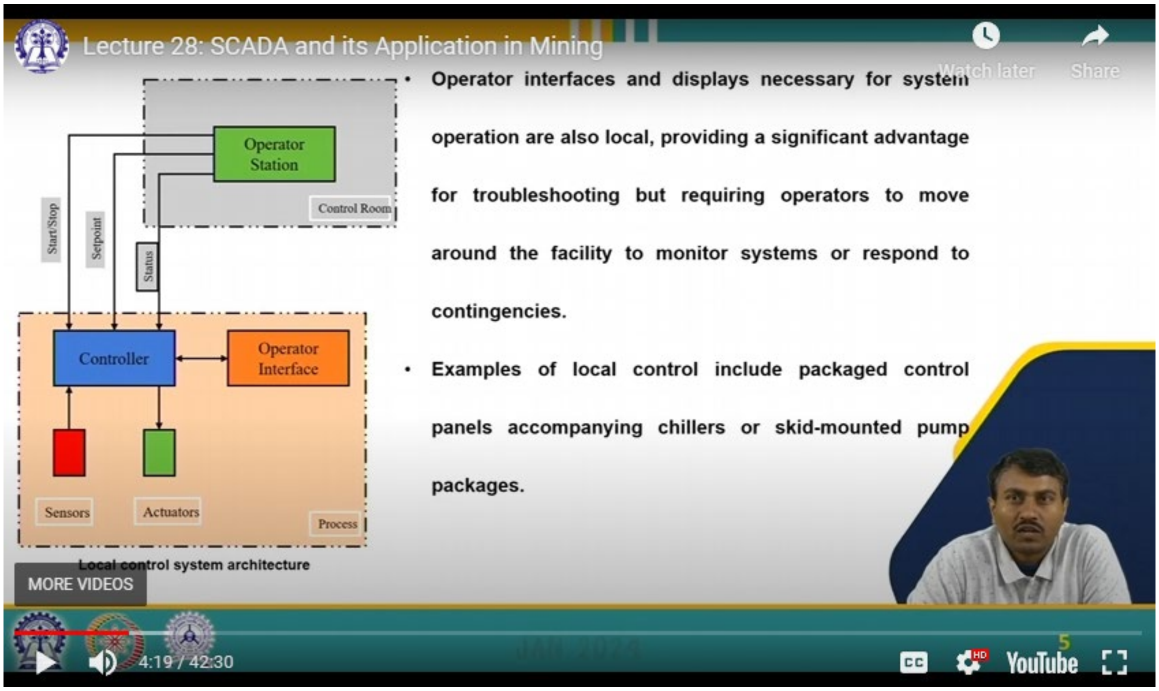
SCADA and its Application in Mining

Welcome back to my course, Mine Automation and Data Analytics. Today, in this lesson, we will discuss on SCADA control system and we will also discuss with a live example that was been implemented in an open-pit mine how this SCADA framework helps for energy utilization in an open-pit mine. So this is under the module 6 and second part of the SCADA.

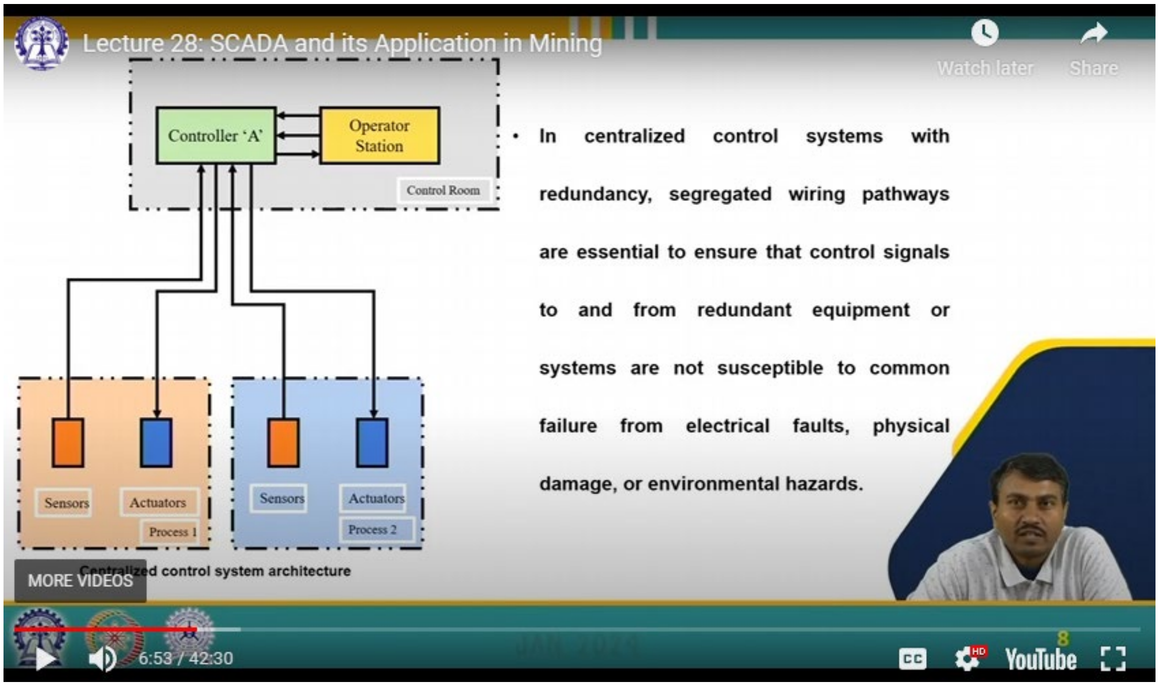
So, in this lesson, we will cover the following: the different controls in the SCADA system, the programmable logic controller that is PLC, then the redundant PLCs, the SCADA system implementation, recent advances in SCADA, and the case study that is smart energy management system design of a monitoring and peak load forecasting system for an experimental open-pit mine.

Different controls in SCADA system local control so it is a system architecture where sensors controller and control equipment are in close proximity with each controller having the jurisdiction over a specific system or subsystem. The local controller are typically capable of receiving inputs from a supervisory controller to initiate or terminate locally control automatic sequences or adjust control set points. However, the control action itself is determined within the local controller, so it is basically a local-based operation.

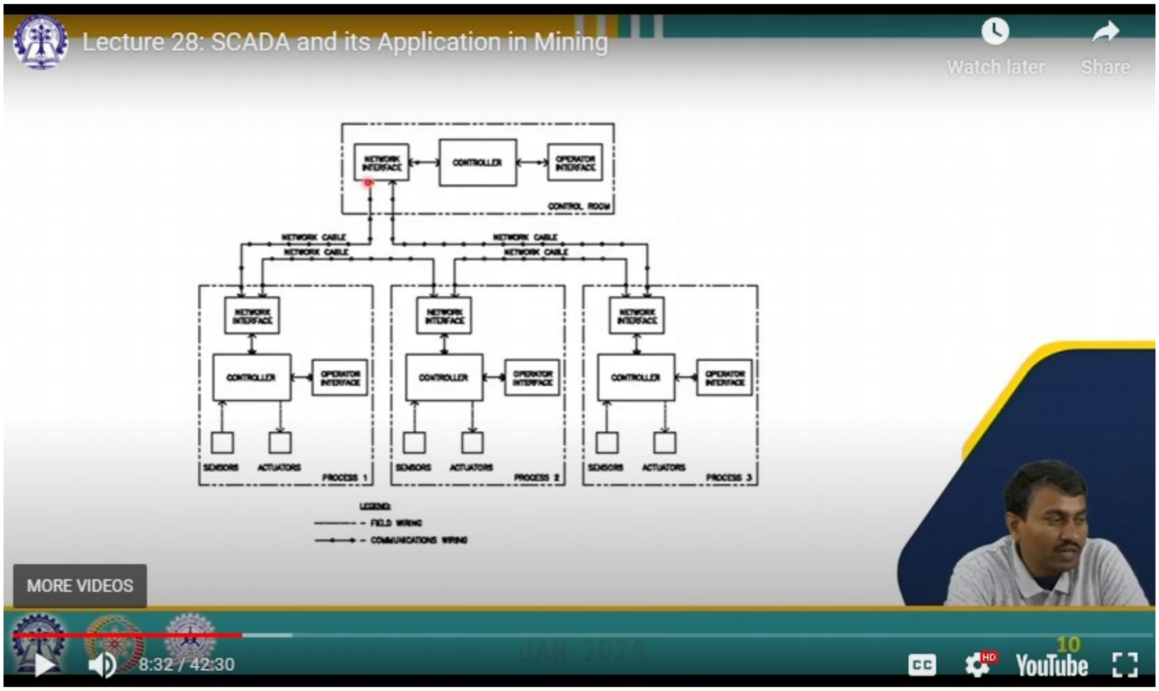
So this is a kind of figure that we can think of as a local control system in SCADA. So here at the local level sensors actuators are installed and the local level process is going on and here is the operator interface and it is a control. So it is connected to the operator station through the some start and stop command will may come there are set point in this control system and the status is also available to the operator station. So it is basically the control room so this control room and the process should be located in close proximity. This is one of the feature of the local control. So the operator interface and display necessary for system operators are also local and providing a significant advantage for troubleshooting but requiring operator to move around the facility to monitor the system or to respond to the contingencies. The example of local control include package control panel accompanying chiller 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. So this setup enhance the operator understanding of system condition and facilitates rapid response to contingencies by consolidating controls operator interfaces and indicators in one location. The centralized control was prevalent in facilities like power plant 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. The centralized control system may still be suitable for small C4ISR that is command control communication computers intelligence surveillance and reconnaissance facilities but require fully redundant processors. So, this is the typical schematic diagram of a centralized control system. Here the sensors actuator in the process it is welding to the controller another process sensor and actuator welding to the controller and operator station in control of these these two processes. So, there are some risks associated of these long wire connection to the controller so and also the cost and maintaining these kind of facilities might be challenging in different perspective in the mining industry. So in centralized control system with redundancy segregated wiring pathway are essential to ensure that control signal to and from redundant equipment or systems are not susceptible to common failure from electrical faults physical damages and environmental hazards.



Distributed control: the distributed control system architecture combines the advantages of both local and centralized control. In a distributed control system controllers are situated locally to system or groups of equipment but are interconnected to one or more operator station in a central location via a digital communication circuit. So this is the schematic diagram of a distributed control system here, one process is running, sensor actuator are connected, and there are control, so the local level controller is there to control the process one here to control the process two local level controller is installed here the to control the process three local level controller is there but all these process running independently are connected through the network cable to the network interface and here is the control room. So here in this control room, all these data that is generated and required to monitor are available to monitor from the control room and this control room, if required intervention in the process that, is also is a functionality of this system. Though, in most of, the cases controller situated at the local level can control the process based on the different set points or target fixed in the system.



So the control action 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 the local controller if necessary, providing enhanced control and monitoring capabilities across the entire system.

So there are number of characteristics of distributed control architecture which enhance reliability of these kind of control system in the SCADA framework. Number one the input and output wiring runs are short and less vulnerable to physical disruption or electromagnetic interference. Two, a catastrophic environmental failure in one area of the facility will not affect controllers or wiring located in another area. The third each local controller can function on its own upon loss of communication with the central controller because local controller is also there so local controller have the capacity to control the local process locally. So in case of disruption in the network, it can run smoothly.

There are some specific threat also in these distributed control architecture that needs some redressal in the current context. Number one the network used for communication may become electronically compromised from the outside facility. Interconnection of controller in different locations can produce ground loop and surge voltage problem. If the central controller is provided with the ability to directly drive the output of local controllers for purpose of operator intervention software glitches in the central controller have the potential to affect multiple local controller compromising the system redundancy.

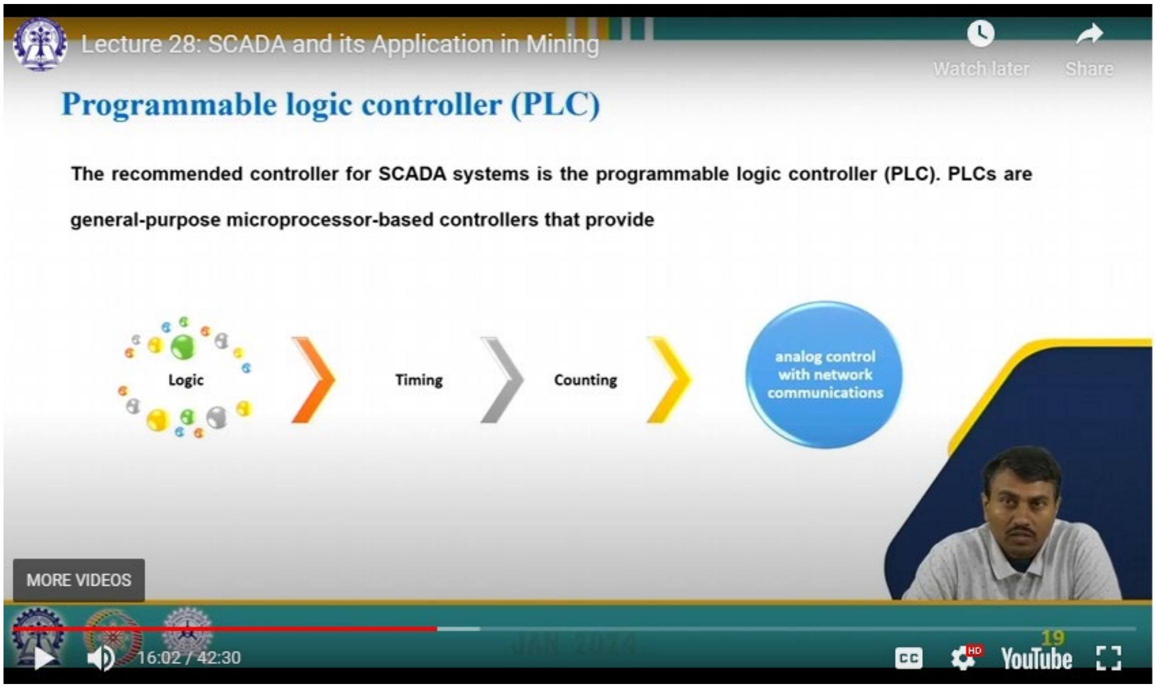
Types of distributed control systems. Plant distributed control system. Distributed control system architecture combines the advantages of both local and centralized control. In a distributed control system controller are situated locally to system or a group of equipment but interconnected to one or more operator station in a central location via digital communication service. Direct digital control purpose. DDC system are utilized in commercial building HVAC industry to overseas regulate environmental conditions. Heat ventilation and air condition facilities required in a large complexes in these kind of system DDC is a better option. Components. DDC system consists of local controllers. These controllers are linked to a network. A central station, typically PC based, is a part of the system functionality of the central station. Central station offer capabilities for monitoring. It allows for reporting and it has the facility to data storage and programming capabilities are also there in the system

Optimization. The controllers are designed for cost effective heat ventilation air conditioning system control HVAC. They prioritize efficiency over fast execution speeds. Proprietary nature. Both hardware and control software are proprietary. Network communication may employ either proprietary or open protocols.

Remote terminal unit based SCADA. Application. RTU based system are prevalent in electric gas or water distribution industries especially for monitoring and controlling operation across fast geographical areas. Purpose of RTU. RTU are primarily developed to enable monitoring and control function at remote and unattended sites and typically deployment site include substations, metering stations, pump stations and water tower.

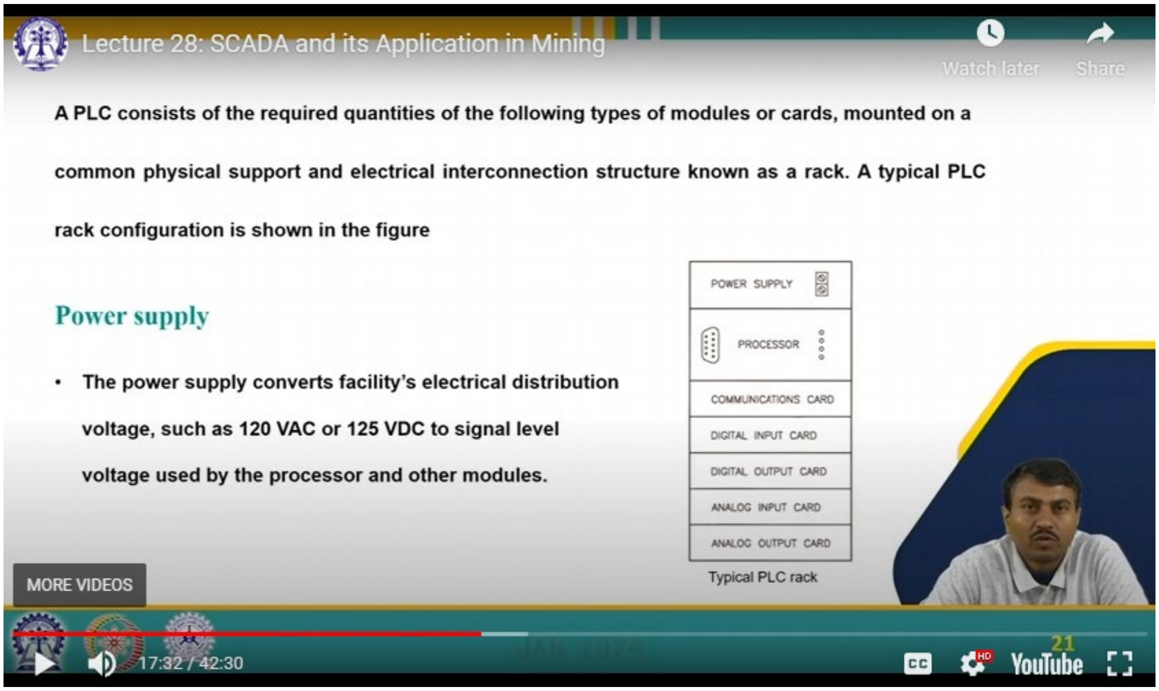
Communication. RTU's communication with the central station are using various means for example telephone lines, fiber optic cables, radio medium or through microwave transmissions. Functionality at monitor sites. Monitor sites are relatively small in size. RTU are primarily used for monitoring purpose with limited control capabilities.

Proprietary nature. Both hardware and software in RTU based system are proprietary. Data transmission to the central station may utilize either proprietary or open protocol. Programmable logic controller that is PLC. The recommended controller for the SCADA system is the programmable logic controller. The PLCs are general purpose microprocessor based controllers that provides the following options. The logic then based on the logic the timing at what time different intervention is required or time monitor for other purpose also. Then counting, then finally, the analog control with network communication.



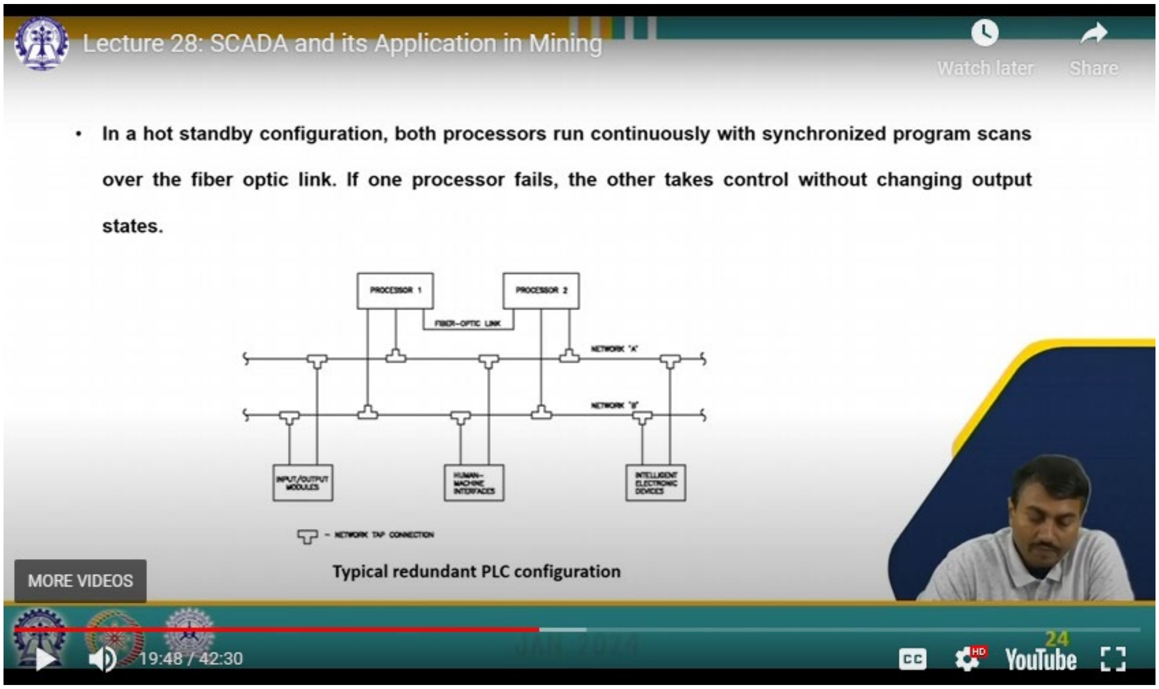
PLCs are recommended for the following reasons. They are developed for the factory floor and have demonstrated high reliability and tolerance for heat vibration and electromagnetic interference. They are widespread market penetration means that the parts are readily available and programming and technical supports services are available from a large number of control system integrators.

They provide high speed processing which is important in generator and switch gear control applications. They support hot standby and triple redundant configuration for high reliability applications. The PLC consists of required quantities of the following types of modules and cards mounted on a common physical support and electrical interconnection structure known as RAC. The typical PLC RAC configuration is like this. Here is the power supply then processor, communication card, input, output, analog input and analog output. Digital and digital output is also there. So power supply the power supply convert facility electrical distribution voltage as and when required by the processor and other modules available in these physical structure.



Processor. The processor module contains the microprocessor that performs control functions and computations as well as memory required to store the program. Input/output. These modules provides the means of connecting the processor to the field devices. Communication. Communication modules are available for a wide range of industry standard communication network connection and these allow digital data transfer between PLCs and to other systems within the facility. Some PLCs have communications capability built into the processor rather than using separate modules.

Redundant PLCs. Redundant PLC system may utilize a warm standby, hot standby or voting configuration. Both processors have continuous access to input output over redundant buses or network. Registered data and status information are exchanged over a dedicated fiber optically, and 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 processor run continuously with synchronized program scans over a hot fiber link. If one processor fails, the other takes control without changing the output state. Here if this one processor is fail another processor is connected that can take care of controlling and processing these process that is running in the bus. Hot standby configuration is recommended in most CAD applications. For highly critical applications, a triple redundant voting scheme may be used, and three processors run continuously with synchronized scans using shared or independent input data from redundant sensors. So here, these three processes run, and here is the voting configuration is there so that take care of the process. If anything happens it will, it will continuously maintain the status.



SCADA system implementation approaches to SCADA system implementation physical replication creating exact physical copies of SCADA system virtual physical replication simulating SCADA system in virtual environments that closely resemble physical setup virtual replication completely simulating SCADA system in virtual environment hybrid replication combining physical and virtual element in SCADA system replication.

Recent advances in SCADA there are some challenges also associated with the security because it is connected with different network protocols and in the age of industry 4.0 and mining 4.0 these securities to be address for getting more and more safety in this kind of control system. So, the traditional SCADA system are often inflexible, static, centralized and it has a limiting interoperability and exposing the vulnerabilities.

Sensor based SCADA framework architectures have been proposed as a solution to overcome these limitations but it introduced new security concern due to its large exposed space. Researchers have introduced new cloud-based framework capable of virtualizing sensing framework processing data and managing large amount of sensor data. Proposal such as VS-cloud focus on virtual SCADA architecture with features like dynamic sensing service management scalability fault tolerance and privacy. Integration of IOT with the SCADA.

Industrial IOT is revolutioning industrial sectors by providing enhanced automation and information theory integrating IOT with the SCADA using cloud computing based services benefits such as predictive maintenance fault tolerance but also introduce security vulnerabilities.

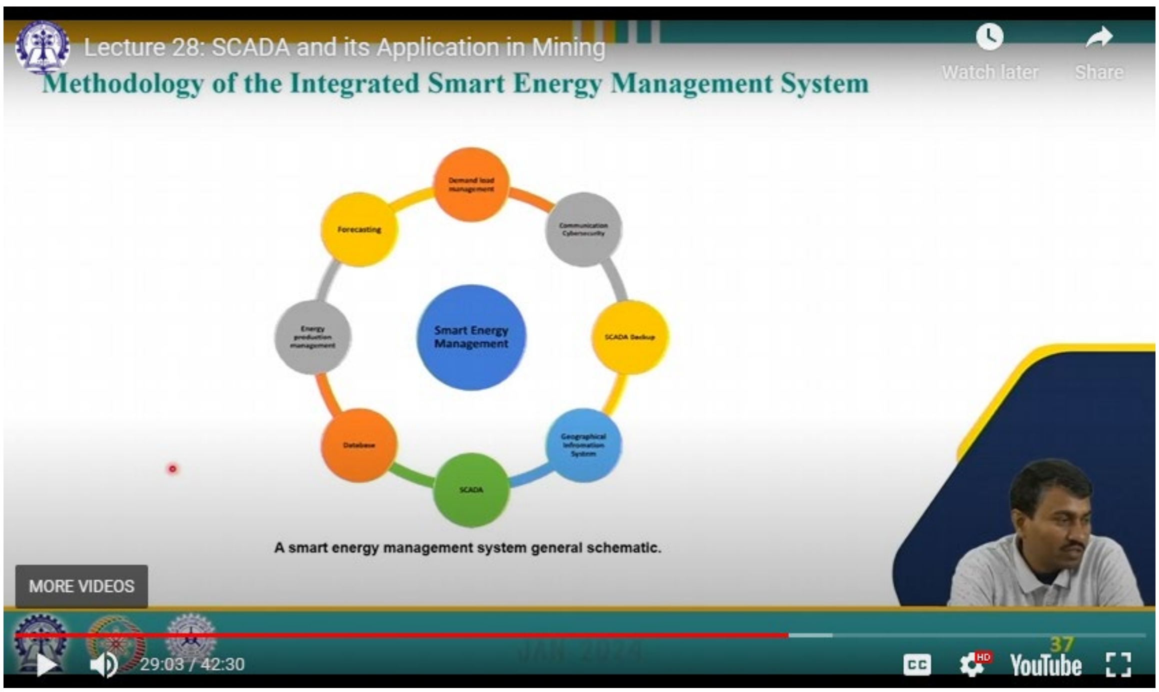
Traditional SCADA system integrated with IOT are more vulnerable to security threat due to the lack of proper security measures.

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 concern with cloud-based SCADA systems including tracking of hackers, information leakage, latency and privacy issues. The traditional communication protocols like Modbus TCP or DNP3 lack adequate protection, increasing the risk of attack. Reliance on cloud communication expose SCADA system to additional securities and vulnerabilities. Commercial of the self-solution are often used instead of proprietary solutions, further complicating the security measures.

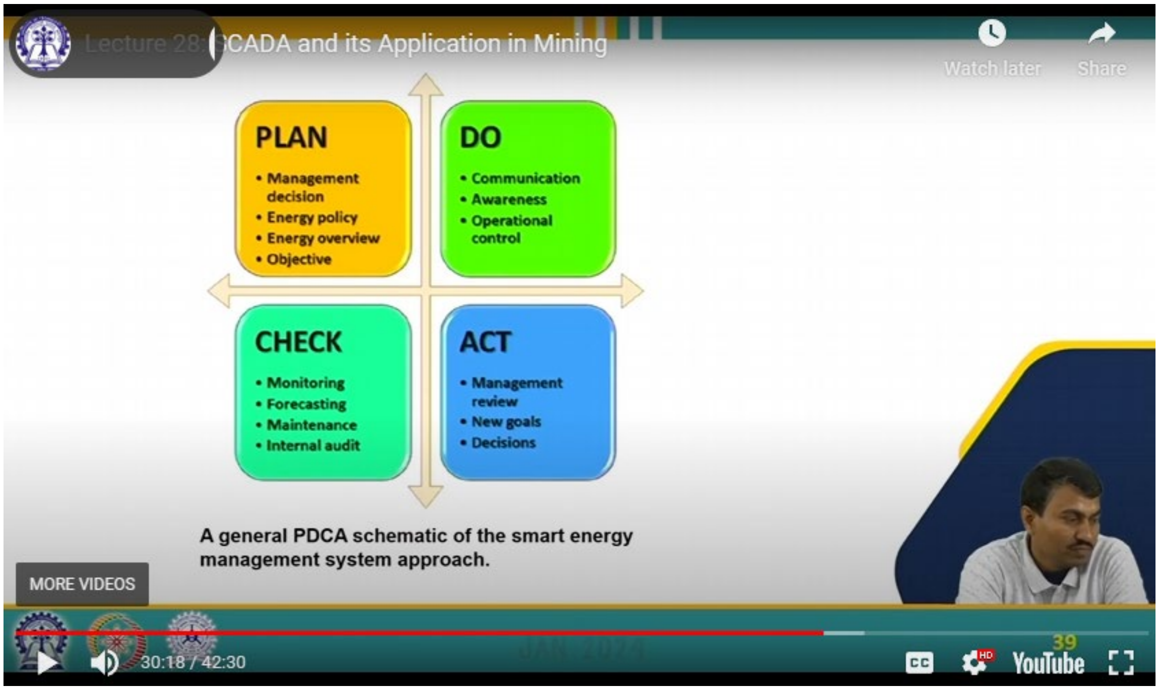
So let us focus on the case studies that is the smart energy management system design of a monitoring and peak load forecasting system for an experimental open-pit mines. So, as we understand in an open-pit mines large number of machines big machines are operating consuming and a good amount of energy, so this SCADA framework is implemented and tested for optimizing the process and that is required of the requirement of the day because energy optimization is also required to optimize the process and reduce the cost. Digitization in the mining industry and machine learning applications have improved the production by showing insight in different components. Energy consumption is one of the key component to improve the industry's performance in a smart ways that requires a very low investment. So, this study represents a new hardware software 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 insight 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 the ISO 50001 standards. In the mining industry, technological advancements are being successfully applied to enhance 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 optimise energy consumption and increase profitability. The objective of this work is to design a new architecture for a smart energy management system according to the ISO 50001 standard for the mining industry. The applications were oriented to an experimental open-pit mine respecting all requirements and needs. So this study present a full design and architecture for applying a smart energy management system in mining industry regardless the situation and technology of control system adopted because of the use of OPC data transmission this system can be implemented in different types of open-pit mines.

The challenges the experimental open-pit mines was initially designed for a required function to extract the mining product and maximise the production regardless of energy consumption and grid quality monitoring. Monitoring all different loads and supplies, then feeding the supervisory supervisor by real-time energy data on the same process scatter view parallel integrating hardware solution to same process control system predict the energy demand response on the state of different historical scenarios finding correlation between the KPIs of energy consumption and mine production processes giving insight on the electrical grid quality real-time energy consumption feedback tariff cyber security and data sharing methodology so here these are interconnected here demand and management load management then the communication cyber security then the SCADA backup then the geographical information systems SCADA database energy predictive management forecasting so these are the component of smart energy management system so this is a these are all connected together so that the schematic diagram can be understood very well.



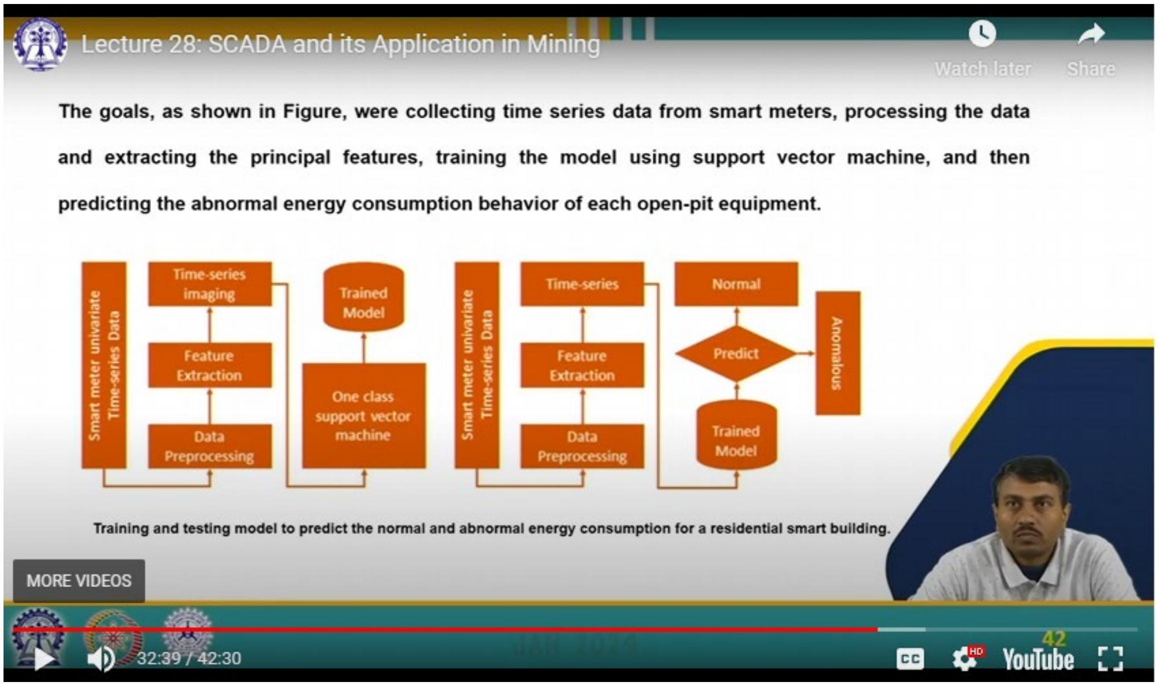
The smart energy management system that is SAMs, as shown in this slide before, is a data flow of energy consumption generation data between SCADA and SCADA backup for redundancy. The database and the supervision dashboard which shows the forecasted and predicted energy profile and demand response of different components of the open pit mine electrical grid these are basically the general management plan so there should be a plan management decision energy policies, energy overview, and objectives so for that we have to do communication awareness and operational control then we have to check these are the monitoring forecasting maintenance and internal audit and we have to act the management review new goals and decision so all are basically integrated in a PDCS schematic of the energy management system approach.



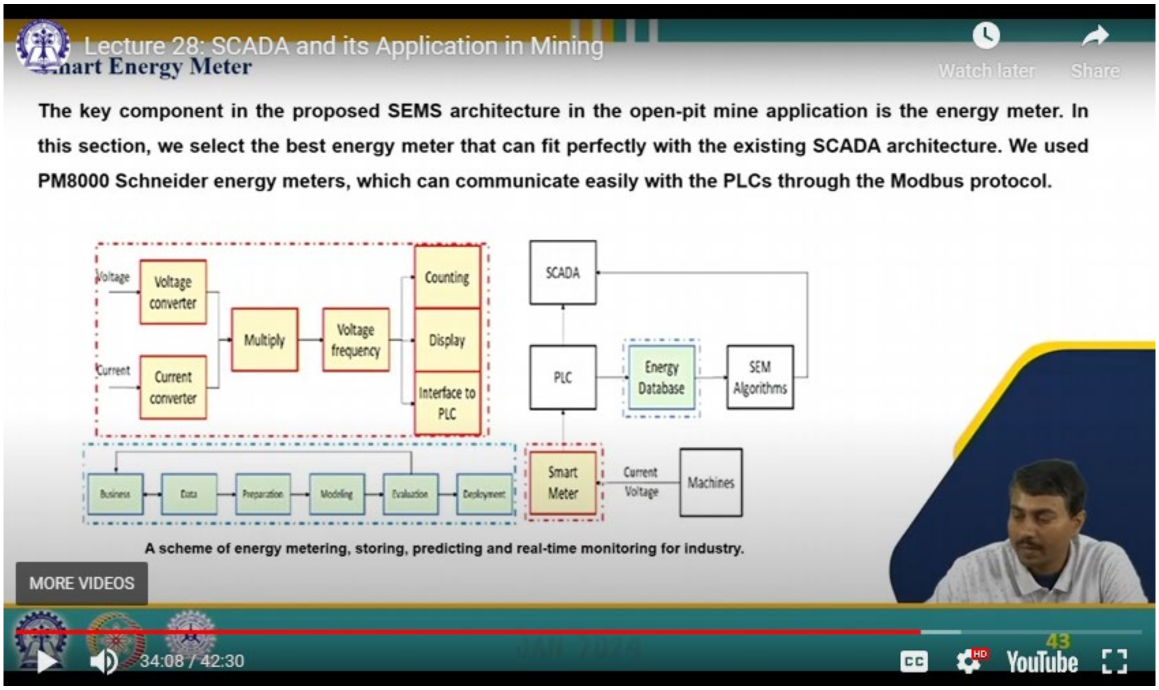
So here you can see the approach of ISO 501 50001 that basically has the plan awareness creation then the plan benchmarking, then we have to do the opportunity identification risk identification and project implementation, and with the continuous improvement we are going to act additional ISO tasks and budgeting and then we are checking the performance monitoring reporting so these are all connected together and working hand in hand one by one and complying with all these targets and objectives.

State of art of the smart energy management systems, peak load forecasting models, the energy consumption prediction and peak load forecasting 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. So these are the models been used and different accuracies been shown for this case studies. So for the number of years and, accuracy is basically not been compromised so these basically giving a very good load forecasting features with utilising different models.

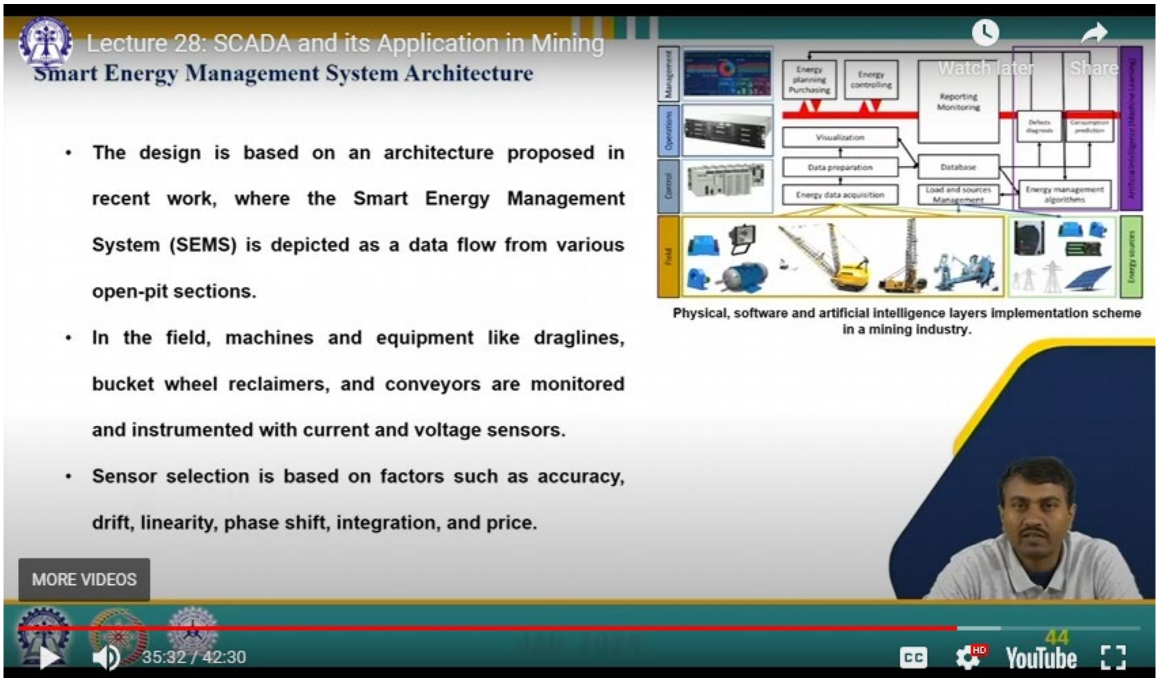
So the goals, as shown in the figure, were collecting time series data from smart meters, so these are basically different systems. This is the smart meter, then time series imaging feature extraction and data processing. So this is then trained model then trained model one class vector machines then again here it is goes on trained model predict normal and anomalies it is basically detecting the model. So, processing the data and extracting the principal features, training the model using support vector machines, and then predicting the abnormal energy consumption behavior of each open pit environment.



Smart energy meter: the key component in the proposed architecture in an open pit mine application is the energy meter. In this section, we are selecting the best energy meter that can fit perfectly with the existing SCADA architecture. We use a PM800 single energy meter, which can communicate easily with the PLC through the mod bus protocol. So here it is the voltage converter current converter, then multiply voltage frequency counting display and interface, and this is basically the smart meter that is connected to the PLC and SCADA. It is energy database and the same algorithm and this is giving it is connected to the machines and here we are basically doing controlling the business data preparations modeling evaluation and deployment. So these are basically step-by-step building blocks of implementing the smart energy meter in the experimental open pit mine.



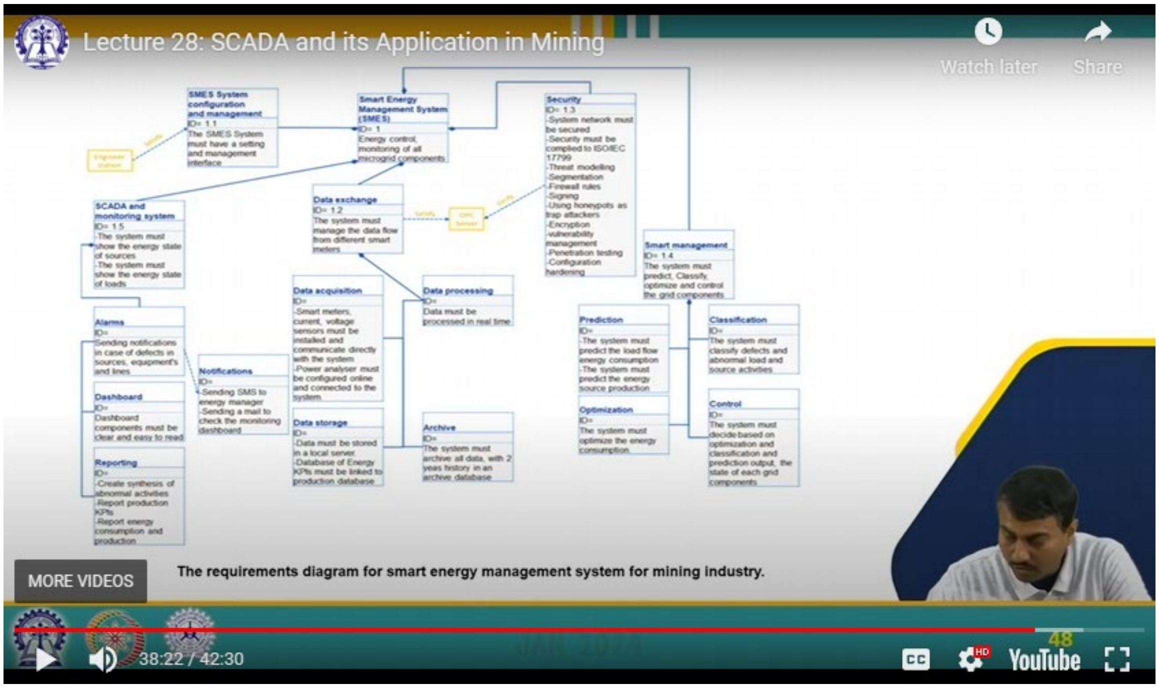
So these is basically the different applications that are running in the open pit mines dragline, shovel, driller these are electrically operated machines. So here you can see in these machines energy planning and purchasing energy controlling then reporting and monitoring then the database load and sources management energy data acquisition data preparation visualizations how much amount of energy it is consumed then energy management algorithms and then based on that they are applying some kind of models and predicting. So here it is the field level, then control, then operation, and finally the management, that is, energy planning and energy control. So, this design is based on an architecture proposed in this work where a smart energy management system is depicted as data flow from various open pit sections. So, in field machines, equipment like draglines, bucket wheel exclamers, 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.



These sensors interface with power meters, which communicate directly with a programmable logic controller in the control layer. The PLCs interface with the SCADA system to collect, store, and visualize the data. In the AI layer of the SMEs the database feed algorithm for defect diagnosis and load forecasting. To implement a smart energy management system in the mining industry the requirements of the system must meet the ISO 00001, ISO 0006, IEC 6155712, IEC 629741 and ISO IEC 17799 standard requirements, the schematic represents the requirement diagram of the study and the system. It proposed the metrology on how making it smart.

The requirement of a smart energy management system considering five important parts: SCADA, the monitoring system which contains alarm for sending notification in case of defect or an abnormal behavior of the grid components, a dashboard that shows the different KPI and result of the micro grids and reporting system that summarize the result and generate report automatically. The data exchange between different smart meters, power analyzer and the communication system where data acquisition, processing and storage must be in real time and automatic.

So, these are basically the different stages of the smart energy management system. Here is the data acquisition, then the data storage, then notification, notification according to the alarm, dashboard and reporting and here is the SCADA monitoring station. So, these are all connected with the SMEs smart energy management and here are the security smart management system prediction and classification and based from the data it is data processing then archiving and from the data exchange it is basically a study and basically verifying and based on that security management issues predicting and optimization is taken control. So all these building blocks and the blocks of the process chains are considered and all are interconnected so that a level of optimization is achieved at all the stage connected in this process so that a load forecasting system is very efficient and by that we are optimizing the energy consumption in the open pit mine.

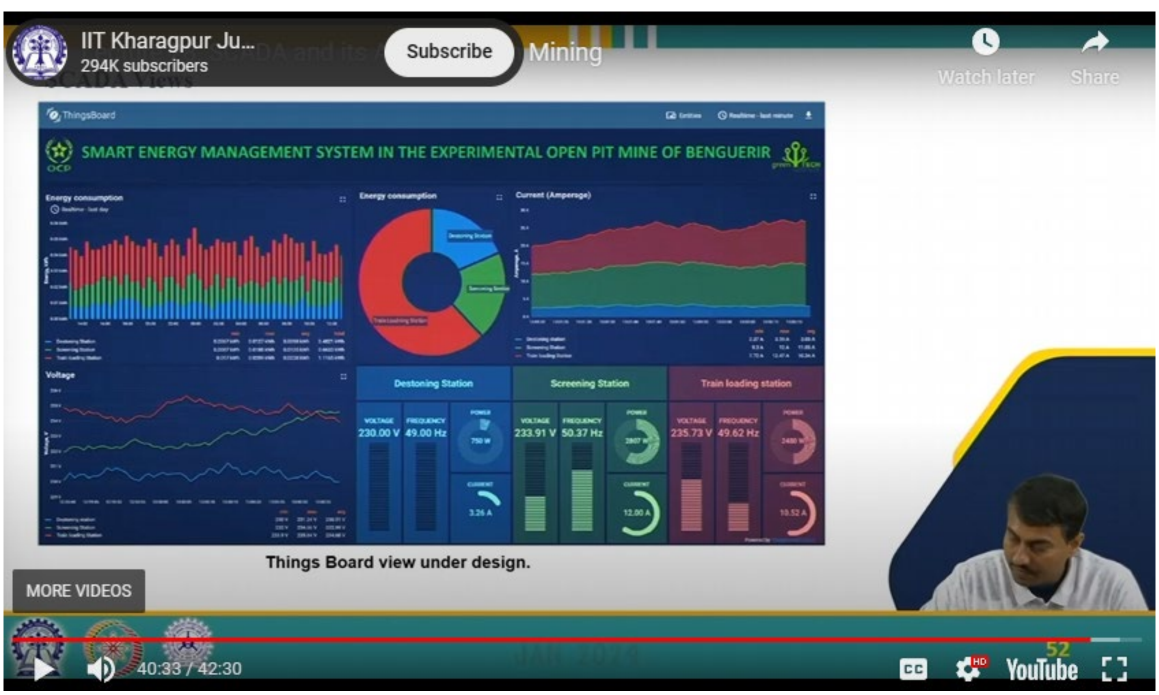


So, after design and requirement study this section present the current state of the energy management system proof of concept at the experimental open pit mine. So before implementing the architecture in the field, a test bench was designed in order to test the communication protocol, the database connection, the SCADA system, and the prediction algorithms.

So the figure present the test bench adding the HMI to visualize the data the program is tested and built on the same PLC using the unity pro xi software. The PLC is connected to a server that contains the database using Python program that retrieves data from PLC modbus protocol and insert them into tables as a time series data set which is connected to both SCADA view using Ctech SCADA software and two things board for web browser connection.

So this is basically the test bench setup for these experimental open pit mines so different hardware is been installed and tested for these whole energy management exercise.

SCADA view: this is a kind of SCADA view available so everything on the dashboard is available: the energy consumption energy consumption in percentage, then the destination station, scanning stations, the train loading stations and the current in amperes it is been visible voltage in voltage is visible. So everything in one dashboard is visible so that effective management and control over the system would be easier, and visualizing and forecasting based on this performance would also be easier, and that will enhance the efficiency and productivity of this kind of system.



These power meters interface with the programmable logic controller PLCs and distributed control system DCS to directly control motors and optimise energy consumption. Similar power meters are connected to renewable energy sources such as photovoltaic panels, wind turbine, electrical vehicles or other energy storage system for a comprehensive monitoring system. A smart micro grid dedicated to the mining industries open pit operation is developed integrating different communication protocol and managing energy flow.

So, these are the references

so let me conclude in a few sentences. We have explored the various control mechanism employed within the SCADA system for monitoring and managing industrial processes. We have introduced the PLC as a key component of the SCADA system responsible for executing control logic. We have discussed the use of redundant PLCs to enhance reliability and fault tolerance in SCADA setups. We have explored the process of implementing SCADA system including hardware setup, software configuration and integration. We have examined the development and innovation in SCADA technology including the advancement in hardware software and communication protocol and we have discussed this case study for developing a smart energy management system in an experimental open pit mine to regulate predict the load forecasting in an open pit mine.

Thank you!