Kurdistan Regional Govermment
Kurdistan Engineer Union

APPLICATION OF IEC 61850 IN 132 KV SUBSTATIONS

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CONTENTS

A view of an Electrical Substation

C H A P T E R ONE

PROGRAMMABLE LOGIC CONTROLLER (PLC)

1.1 Introduction

Control engineering has evolved over time. In the past humans were the main method for controlling a system. More recently electricity has been used for control and early electrical control was based on relays. These relays allow power to be switched on and off without a mechanical switch. It is common to use relays to make simple logical control decisions. The development of low cost computer has brought the most recent revolution, the Programmable Logic Controller (PLC). The advent of the PLC began in the 1970s, and has become the most common choice for manufacturing controls.

PLCs have been gaining popularity on the factory floor and will probably remain predominant for some time to come. Most of this is because of the advantages they offer.

- Cost effective for controlling complex systems.
- Flexible and can be reapplied to control other systems quickly and easily.
- Computational abilities allow more sophisticated control.
- Trouble shooting aids make programming easier and reduce downtime.
- Reliable components make these likely to operate for years before failure.

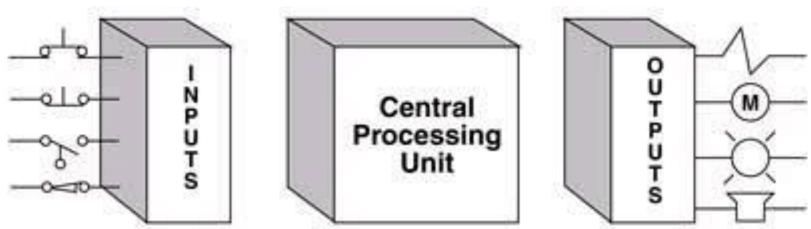
1.2 What is a Programmable Logic Controller (PLC)?

A **PROGRAMMABLE LOGIC CONTROLLER** (PLC) is an industrial computer control system that continuously monitors the state of input devices and makes decisions based upon a custom program to control the state of output devices.

Almost any production line, machine function, or process can be greatly enhanced using this type of control system. However, the biggest benefit in using a PLC is the ability to change and replicate the operation or process while collecting and communicating vital information.

Another advantage of a PLC system is that it is modular. That is, you can mix and match the types of Input and Output devices to best suit your application.

1.3 What is inside a PLC?



The Central Processing Unit, the CPU, contains an internal program that tells the PLC how to perform the following functions:

- Execute the Control Instructions contained in the User's Programs. This program is stored in "nonvolatile" memory, meaning that the program will not be lost if power is removed.
- Communicate with other devices, which can include I/O Devices, Programming Devices, Networks, and even other PLCs.
- Perform Housekeeping activities such as Communications, Internal Diagnostics, etc.

1.4 How does a PLC Operate?

There are four basic steps in the operation of all PLCs; Input Scan, Program Scan, Output Scan, and Housekeeping. These steps continually take place in a repeating loop (As shown in Fig 4.1).

Four steps in the PLC operations includes:

1.Input Scan : Detects the state of all input devices that are connected to the PLC

2.Program Scan : Executes the user created program logic

3. Output Scan: Energizes or de-energize all output devices that are connected to the PLC.

4.Housekeeping This step includes communications with programming terminals, internal diagnostics, etc...

These steps are continually processed in a loop.

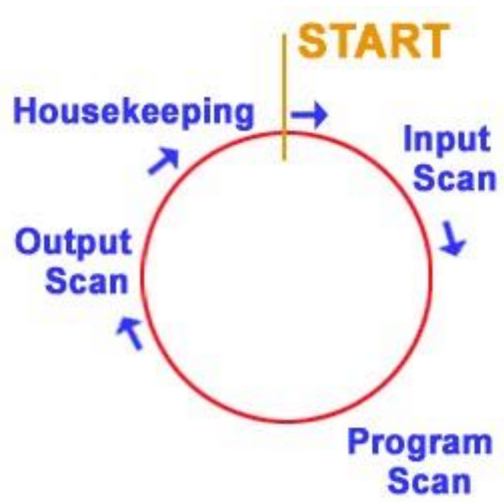


Fig 1.1 Steps in PLC operations

What programming language is used to program a PLC?

While Ladder Logic is the most commonly used PLC programming language, it is not the only one. The following table lists of some of languages that are used to program a PLC.

1.5.1 Ladder Diagram (LD) Traditional ladder logic is graphical programming language. Initially programmed with simple contacts that simulated the opening and closing of relays, Ladder Logic programming has been expanded to include such functions as counters, timers, shift registers, and math operations.

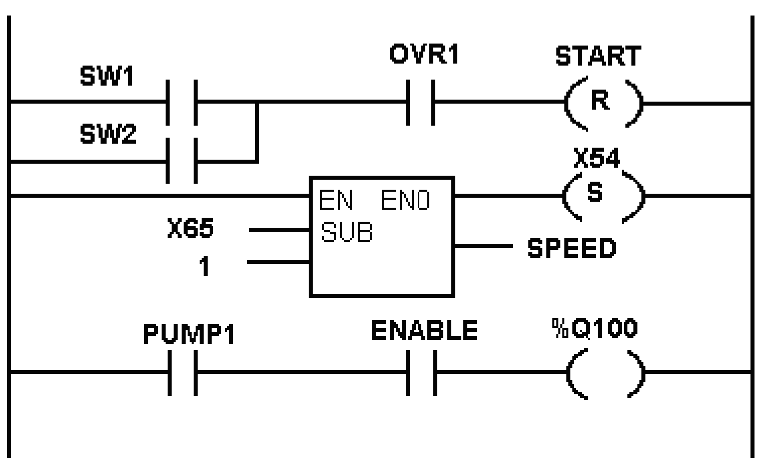


Fig 4.2 Ladder Diagram

1.5.2 Function Block Diagram (FBD) - A graphical language for depicting signal and data flows through re-usable function blocks. FBD is very useful for expressing the interconnection of control system algorithms and logic.

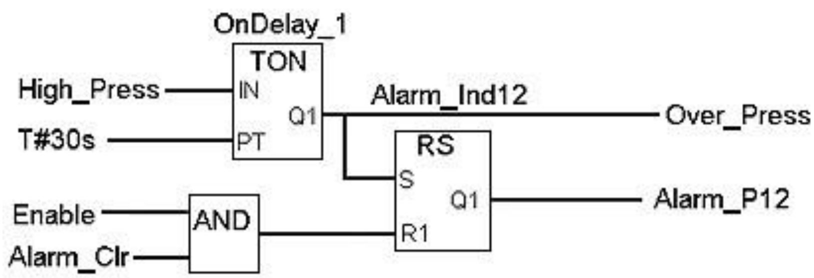


Fig 4.3 Function Block Diagram

1.5.3 Structured Text (ST) – A high level text language that encourages structured programming. It has a language structure (syntax) that strongly resembles PASCAL and supports a wide range of standard functions and operators. For example;

```
If Speed1 > 100.0 then
    Flow_Rate: = 50.0 + Offset_A1;
Else
   Flow_Rate: = 100.0; Steam: = ON End_If;
```

1.5.4 Instruction List (IL) - A low level "assembler like" language that is based on similar instructions list languages found in a wide range of today's PLCs.

```
    LD   R1
   MPC   RESET
    LD   PRESS_1

    ST   MAX_PRESS
RESET:   LD    0
       ST A_X43
```

Sequential Function Chart (SFC) A method of programming complex control systems at a more highly structured level. A SFC program is an overview of the control system, in which the basic building blocks are entire program files. Each program file is created using one of the other types of programming languages. The SFC approach coordinates large, complicated programming tasks into smaller, more manageable tasks.

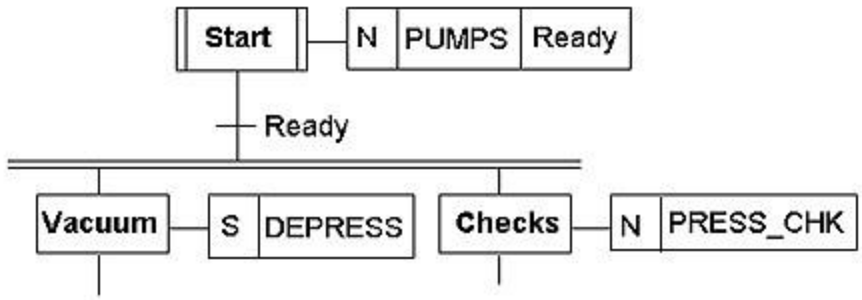


Fig 1.4 Sequential Function Chart

Programming a PLC?

Ladder logic is the main programming method used for PLCs. As mentioned before, ladder logic has been developed to mimic relay logic. The decision to use the relay logic diagrams was a strategic one. By selecting ladder logic as the main programming method, the amount of retraining needed for engineers and tradespeople was greatly reduced.

Modern control systems still include relays, but these are rarely used for logic. A relay is a simple device that uses a magnetic field to control a switch, as pictured in Figure 4.5. When a voltage is applied to the input coil, the resulting current creates a magnetic field. The magnetic field pulls a metal switch (or reed) towards it and the contacts touch, closing the switch. The contact that closes when the coil is energized is called normally open. The normally closed contacts touch when the input coil is not energized. Relays are normally drawn in schematic form using a circle to represent the input coil. The output contacts are shown with two parallel lines. Normally open contacts are shown as two lines, and will be open (non-conducting) when the input is not energized. Normally closed contacts are shown with two lines with a diagonal line through them. When the input coil is not energized the normally closed contacts will be closed (conducting).

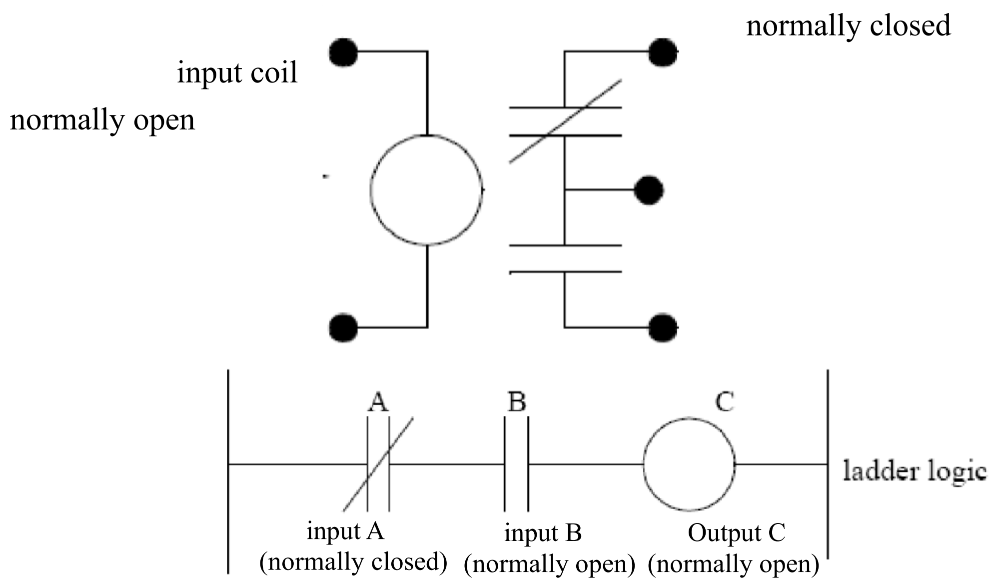
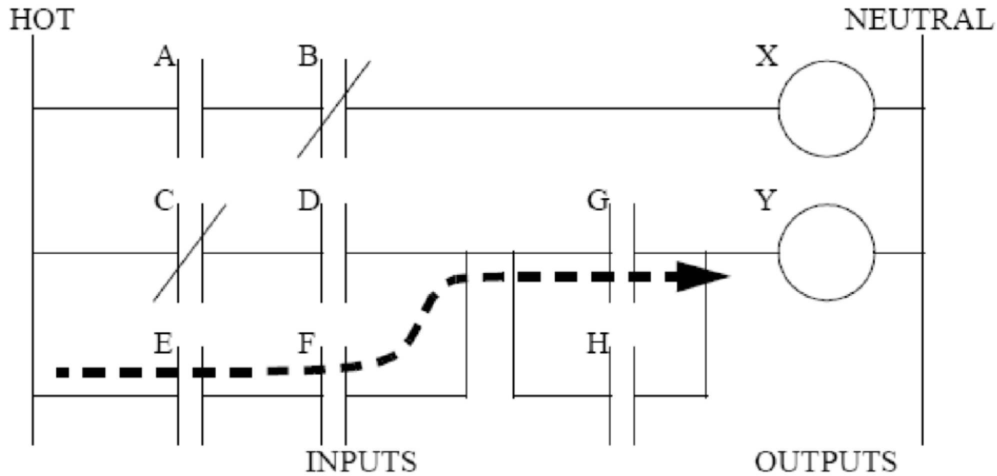


Fig 1.5 Simple Relay Schematic and Ladder logic Diagrams

In actual PLCs inputs are never relays, but outputs are often relays. The ladder logic in the PLC is actually a computer program that the user can enter and change.

The first PLCs were programmed with a technique that was based on relay logic wiring schematics. This eliminated the need to teach the electricians, technicians and engineers how to program a computer - but, this method has stuck and it is the most common technique for programming PLCs today. An example of ladder logic can be seen in Figure 4.6. To interpret this diagram imagine that the power is on the vertical line on the left hand side, we call this the hot rail. On the right hand side is the neutral rail. In the figure there are two rungs, and on each rung there are combinations of inputs (two vertical lines) and outputs (circles). If the inputs are opened or closed in the right combination the power can flow from the hot rail, through the inputs, to power the outputs, and finally to the neutral rail. An input can come from a sensor, switch, or any other type of sensor. An output will be some device outside the PLC that is switched on or off, such as lights or motors. In the top rung the contacts are normally open and normally closed. Which means if input A is on and input B is off, then power will flow through the output and activate it. Any other combination of input values will result in the output X being off.



Note: Power needs to flow through some combination of the inputs (A,B,C,D,E,F,G,H) to turn on outputs (X,Y).

Fig 1.6 A Simple Ladder Logic Diagram

The second rung of Figure 4.6 is more complex, there are actually multiple combinations of inputs that will result in the output Y turning on. On the left most part of the rung, power could flow through the top if C is off and D is on. Power could also (and simultaneously) flow through the bottom if both E and F are true. This would get power half way across the rung, and then if G or H is true the power will be delivered to output Y.

1.7 PLC Connections

When a process is controlled by a PLC it uses inputs from sensors to make decisions and update outputs to drive actuators, as shown in Figure 4.7. The process is a real process that will change over time. Actuators will drive the system to new states (or modes of operation). This means that the controller is limited by the sensors available, if an input is not available, the controller will have no way to detect a condition.

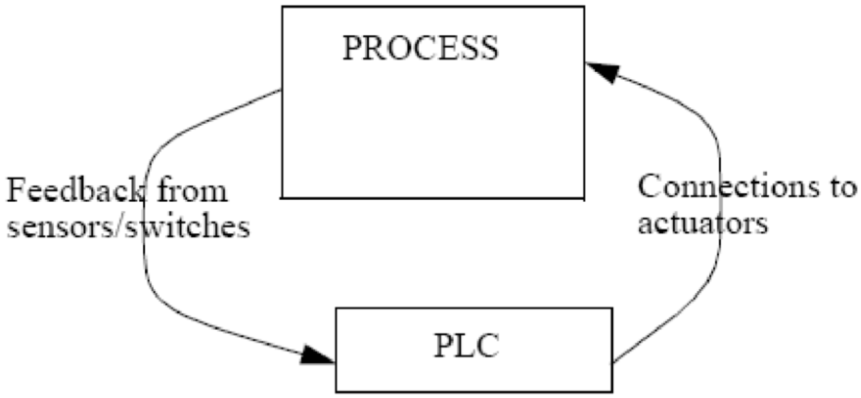


Fig 1.7 The Separation of Controller and Process

The control loop is a continuous cycle of the PLC reading inputs, solving the ladder logic, and then changing the outputs. Like any computer this does not happen instantly. Figure 4.8 shows the basic operation cycle of a PLC. When power is turned on initially the PLC does a quick sanity check to ensure that the hardware is working properly. If there is a problem the PLC will halt and indicate there is an error. For example, if the PLC backup battery is low and power was lost, the memory will be corrupt and this will result in a fault. If the PLC passes the sanity check it will then scan (read) all the inputs. After the inputs values are stored in memory the ladder logic will be scanned (solved) using the stored values - not the current values. This is done to prevent logic problems when inputs change during the ladder logic scan. When the ladder logic scan is complete the outputs will be scanned (the output values will be changed). After this the system goes back to do a sanity check, and the loop continues indefinitely. Unlike normal computers, the entire program will be run every scan. Typical times for each of the stages is in the order of milliseconds.

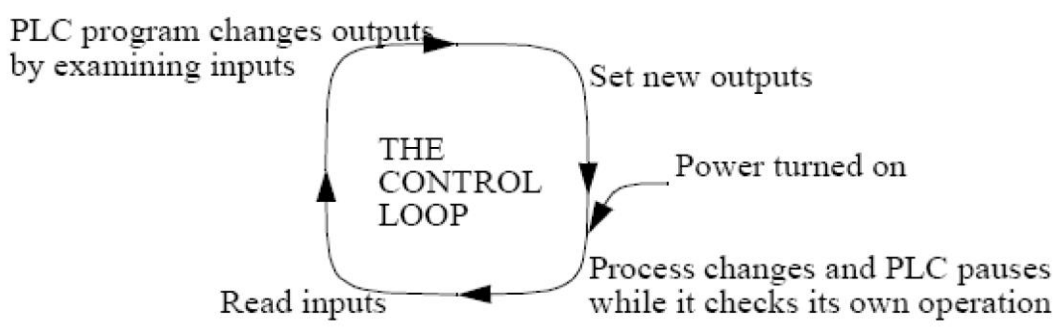


Fig 1.8 The Scan Cycle of a PLC

1.7 PLC HARDWARE

1.7.1 INTRODUCTION

Many PLC configurations are available, even from a single vendor. But, in each of these there are common components and concepts. The most essential components are:

Power Supply - This can be built into the PLC or be an external unit. Common voltage levels required by the PLC (with and without the power supply) are 24Vdc, 120Vac, 220Vac.

CPU (Central Processing Unit) - This is a computer where ladder logic is stored and processed. Central Processing Unit (CPU) is the brain of a PLC controller. CPU itself is usually one of the microcontrollers.

I/O (Input/Output) - A number of input/output terminals must be provided so that the PLC can monitor the process and initiate actions.

Indicator lights - These indicate the status of the PLC including power on, program running, and a fault. These are essential when diagnosing problems.

The configuration of the PLC refers to the packaging of the components. Typical configurations are listed below from largest to smallest.

Rack - A rack is often large (up to 18” by 30” by 10”) and can hold multiple cards. When necessary, multiple racks can be connected together. These tend to be the highest cost, but also the most flexible and easy to maintain.

Mini - These are similar in function to PLC racks, but about half the size.
Shoebox - A compact, all-in-one unit (about the size of a shoebox) that has limited expansion capabilities. Lower cost, and compactness make these ideal for small applications.

Micro - These units can be as small as a deck of cards. They tend to have fixed quantities of I/O and limited abilities, but costs will be the lowest.
Software - A software based PLC requires a computer with an interface card, but allows the PLC to be connected to sensors and other PLCs across a network.

1.7.2 INPUTS AND OUTPUTS

Inputs to, and outputs from, a PLC are necessary to monitor and control a process. Both inputs and outputs can be categorized into two basic types: logical or continuous. Consider the example of a light bulb. If it can only be turned on or off, it is logical control. If the light can be dimmed to different levels, it is continuous. Continuous values seem more intuitive, but logical values are preferred because they allow more certainty, and simplify control. As a result most controls applications (and PLCs) use logical inputs and outputs for most applications. Hence, we will discuss logical I/O and leave continuous I/O for later.

Outputs to actuators allow a PLC to cause something to happen in a process. A short list of popular actuators is given below in order of relative popularity.

Solenoid Valves - logical outputs that can switch a hydraulic or pneumatic flow.

Lights - logical outputs that can often be powered directly from PLC output boards.

Motor Starters - motors often draw a large amount of current when started, so they require motor starters, which are basically large relays.

Servo Motors - a continuous output from the PLC can command a variable speed or position.

Outputs from PLCs are often relays, but they can also be solid state electronics such as transistors for DC outputs or Triacs for AC outputs. Continuous outputs require special output cards with digital to analog converters.

Inputs come from sensors that translate physical phenomena into electrical signals. Typical examples of sensors are listed below in relative order of popularity.

Proximity Switches - use inductance, capacitance or light to detect an object logically.

Switches - mechanical mechanisms will open or close electrical contacts for a logical signal.

Potentiometer - measures angular positions continuously, using resistance.

LVDT (linear variable differential transformer) - measures linear displacement continuously using magnetic coupling.

Inputs for a PLC come in a few basic varieties, the simplest are AC and DC inputs. Sourcing and sinking inputs are also popular. This output method dictates that a device does not supply any power. Instead, the device only switches current on or off, like a simple switch.

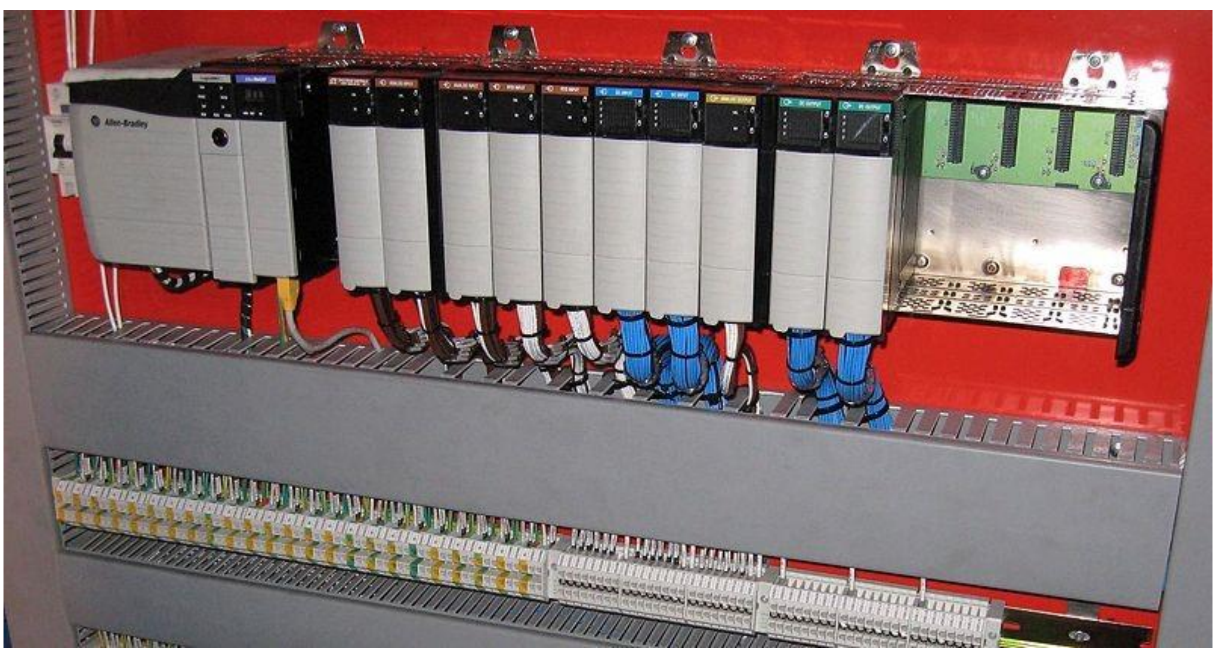
Sinking - When active the output allows current to flow to a common ground. This is best selected when different voltages are supplied.

Sourcing - When active, current flows from a supply, through the output device and to ground. This method is best used when all devices use a single supply voltage.

This is also referred to as NPN (sinking) and PNP (sourcing). PNP is more popular.

Modicon Quantum- Telemecanique
A brand of Schneider Electric

Siemens- Simatic



1.8 Some Pictures of Different PLCs

Allen Bradley

CHAPTER TWO

APPLICATION OF PLC IN SUBSTATION

2.1 Introduction

As in many other areas, the computer applications in electrical power systems have grown tremendously over the last several decades penetrating apparently all aspects of electrical power systems, including operational planning, energy management, load forecast, power quality, automated generation, transmission and distribution, etc. A system used to monitor and control equipment and processes is called **SCADA** where the acronym stands for **S**upervisory **C**ontrol **A**nd **D**ata **A**cquisition. SCADA consists of a central host (Master Terminal Unit, MTU); field data gathering and control units (Remote Terminal Units, RTUs); communication system, and a software application to monitor and control RTUs. SCADA systems may implement open or closed-loop control in conjunction with long or short distance communications.

Very few industrial plants can be left to run themselves, and most need some form of control system to ensure safe and economical operation. Figure 5.1 is thus a representation of a typical installation, consisting of a plant connected to a control system. This acts to translate the commands of the human operator into the required actions, and to display the plant status back to the operator.

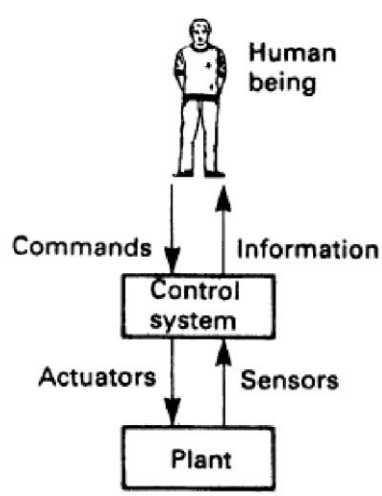


Fig 2.1 A simple view of a control system

2.2 SCADA System

SCADA (supervisory control and data acquisition system) refers to the combination of telemetry and data acquisition. SCADA encompasses the collecting of the information via a RTU (remote terminal unit), transferring it back to the central site, carrying out any necessary analysis and control and then displaying that information on a number of operator screens or displays. The required control actions are then conveyed back to the process. In the early days of data acquisition relay logic was used to control production and plant systems. With the advent of the CPU (as part of the microprocessor) and other electronic devices, manufacturers incorporated digital electronics into relay logic equipment, creating the PLC or programmable logic controller, which is still one of the most widely used control systems in industry. As needs grew to monitor and control more devices in the plant, the PLCs were distributed and the systems became more intelligent and smaller in size. PLCs and/or DCS (distributed control systems) are used as shown below. Although initially RTU was often a dedicated device, PLCs are often used as RTUs these days.

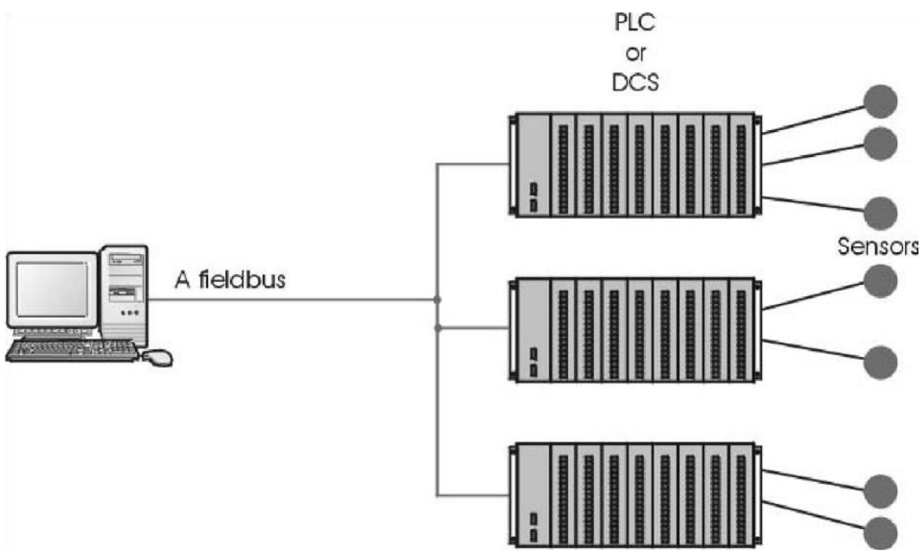


Fig2.2 PC to PLC or DCS with a fieldbus and sensors

As the requirement for smaller and smarter systems grew, sensors were designed with the intelligence of PLCs and DCSs. These devices are known as IEDs (intelligent electronic devices). The IEDs are connected on a fieldbus such as Profibus, DeviceNet or Foundation Fieldbus to the PC. They include enough intelligence to acquire data, communicate to other devices and hold their part of the overall program. Each of these super smart sensors can have more than one sensor on board. Typically an IED could combine an analog input sensor, analog output, PID control, communication system and program memory in the one device.

A SCADA System usually consists of the following subsystems:

- A Human-Machine Interface or HMI is the apparatus which presents process data to a human operator, and through this, the human operator, monitors and controls the process.
- A supervisory (computer) system, gathering (acquiring) data on the process and sending commands (control) to the process.
- Remote Terminal Units (RTUs) connecting to sensors in the process, converting sensor signals to digital data and sending digital data to the supervisory system.
- Programmable Logic Controller (PLCs) used as field devices because they are more economical, versatile, flexible, and configurable than special-purpose RTUs.
- Communication infrastructure connecting the supervisory system to the Remote Terminal Units

There is, in several industries, considerable confusion over the differences between SCADA systems and Distributed control systems (DCS). Generally speaking, a SCADA system usually refers to a system that coordinates, but does not control processes in real time. The discussion on real-time control is muddied somewhat by newer telecommunications technology, enabling reliable, low latency, high speed communications over wide areas. Most differences between SCADA and DCS are culturally determined and can usually be ignored. As communication infrastructures with higher capacity become available, the difference between SCADA and DCS will fade. The term SCADA usually refers to centralized systems which monitor and control entire sites, or complexes of systems spread out over large areas (anything between an industrial plant and a country). Most control actions are performed automatically by remote terminal units ("RTUs") or by programmable logic controllers ("PLCs"). Host control functions are usually restricted to basic overriding or supervisory level intervention. For example, a PLC may control the flow of cooling water through part of an industrial process, but the SCADA system may allow operators to change the set points for the flow, and enable alarm conditions, such as loss of flow and high temperature, to be displayed and recorded. The feedback control loop passes through the RTU or PLC, while the SCADA system monitors the overall performance of the loop.

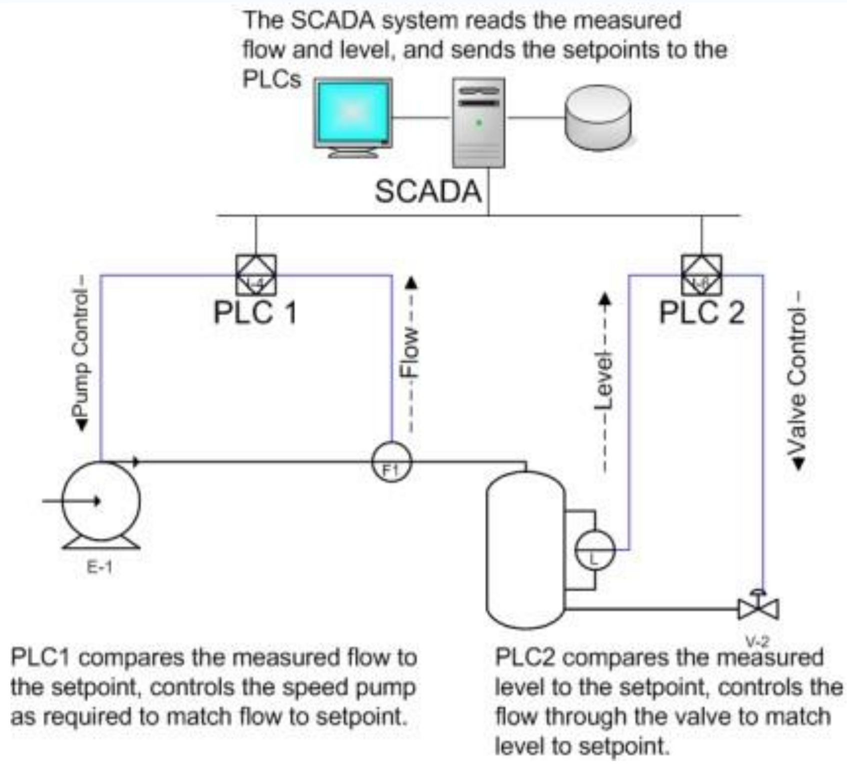


Fig. 1.3 A simple application of SCADA system

Data acquisition begins at the RTU or PLC level and includes meter readings and equipment status reports that are communicated to SCADA as required. Data is then compiled and formatted in such a way that a control room operator using the HMI can make supervisory decisions to adjust or override normal RTU (PLC) controls. Data may also be fed to a Historian, often built on a commodity Database Management System, to allow trending and other analytical auditing.

SCADA systems typically implement a distributed database, commonly referred to as a tag database, which contains data elements called tags or points. A point represents a single input or output value monitored or controlled by the system. Points can be either "hard" or "soft". A hard point represents an actual input or output within the system, while a soft point results from logic and math operations applied

met, they are activated. An example of an alarm is the "fuel tank empty" light in a car. The SCADA operator's attention is drawn to the part of the system requiring attention by the alarm. Emails and text messages are often sent

2.3 SCADA Architectures

SCADA systems have evolved through 3 generations as follows:

First Generation: "Monolithic"

In the first generation computing was done by Mainframe systems. Networks didn't exist at the time SCADA was developed. Thus SCADA systems were independent systems with no connectivity to other systems. Wide Area Networks were later designed by RTU vendors to communicate with the RTU. The communication protocols used were often proprietary at that time. The first generation SCADA System was redundant since a back-up mainframe system was connected at the bus level and was used in the event of failure of the main mainframe system.

Second Generation: "Distributed"

The processing was distributed across multiple stations which were connected through LAN and they shared information in real time. Each station was responsible for a particular task thus making the size and cost of each station less than the one used in First Generation. The network protocols used were still mostly proprietary.

Third Generation: "Networked"

These are the current generation SCADA systems which use open system architecture rather than a vendor controlled proprietary environment. The SCADA system utilizes open standard and protocols thus distributing functionality across a WAN rather than a LAN. It is easier to connect third party peripheral devices like printers, disk drives, tape drives due to the use of open architecture. WAN protocols such as Internet Protocol (IP) are used for communication between the master station and communications equipment. This on the other hand has put a question on the security of SCADA system which seems to be vulnerable to cyber-warfare and cyber terrorism attacks.

2.4 SCADA Hardware

A SCADA system consists of a number of remote terminal units (or RTUs) collecting field data and sending that data back to a master station via a communications system. The master station displays the acquired data and also allows the operator to perform remote control tasks. The accurate and timely data allows for optimization of the plant operation and process. A further benefit is more efficient, reliable and most importantly, safer operations.

This all results in a lower cost of operation compared to earlier non-automated systems. On a more complex SCADA system there are essentially five levels or hierarchies:

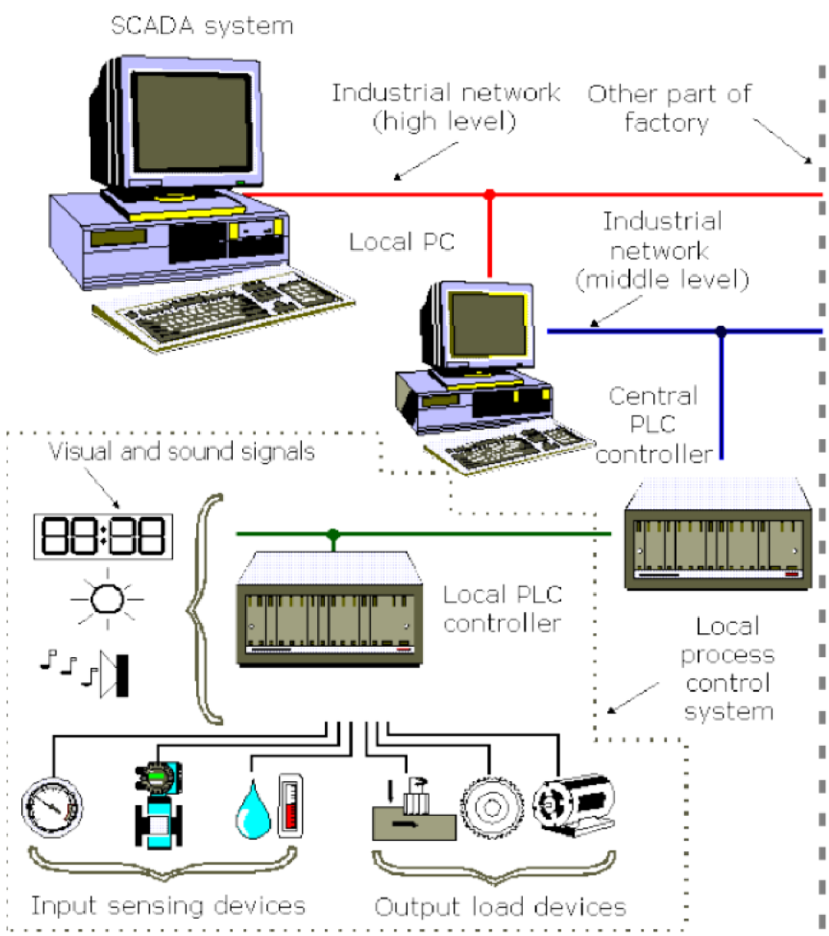
- Field level instrumentation and control devices
- Marshalling terminals and RTUs
- Communications system
- The master station(s)
- The commercial information technology (IT) or data processing department computer system.

The RTU provides an interface to the field analog and digital sensors situated at each remote site. The communications system provides the pathway for communications between the master station and the remote sites. This communication system can be wire, fiber optic, radio, telephone line, microwave and possibly even satellite. Specific protocols and error detection philosophies are used for efficient and optimum transfer of data.

The master station (or sub-masters) gather data from the various RTUs and generally provide an operator interface for display of information and control of the remote sites. In large telemetry systems, sub-master sites gather information from remote sites and act as a relay back to the control master station.

2.5 SCADA software

SCADA software can be divided into two types, proprietary or open. Companies develop proprietary software to communicate to their hardware. These systems are sold as 'turn key' solutions. The main problem with these systems is the overwhelming reliance on the supplier of the system. Open software systems have gained popularity because of the interoperability they bring to the system. Interoperability is the ability to mix different manufacturers' equipment on the same system. Citect and WonderWare are just two of the open software packages available on the market for SCADA systems. Some packages are now including asset management integrated within the SCADA system. The typical components of a SCADA system are indicated in the diagram below.



CHAPTER THREE

IEC 61850 AS A STANDARD FOR DESIGN OF ELECTRICAL SUBSTATION AUTOMATION

3.1 INTRODUCTION

A substation IEC-61850 based is an intelligent substation, with an Ethernet local area network (LAN) gathering operational and nonoperational data with human-machine interface available over a wide area network (WAN). The network includes sensors, monitors and intelligent electronic devices (IED) with peer-to-peer protocols, allowing automated digital substation buses, high speed operation, environmental monitoring, physical security and information analysis.
The other advantage of this standard is the interoperability of vendor equipments, such that spare parts from any vendor can replace original manufacturer parts. This is really a great advantage.

In short, the advantages of IEC61850 are summarized below:

- Saves time during implementation.
- Simplifies upgrading and extending the substation.
- Reduces wiring and schematics.
- Reduces cost.
- Optical fiber with high speed networks provide new opportunities for communication.
- Makes utilities less dependent on suppliers.
- Changes in the profession as complementary skills required of engineers is an advantage for young engineers.

Transformation from static structure to dynamic viewpoint, manual operation to self monitoring, and upstream control to localized automatic response is really the main outline of the benefit.

With this technology, a roomful of electromechanical device panels can be replaced with one digital panel only.

3.2 Principle

Modern electric power systems include multifunction relays, distributed programmable controllers, phasor measurement units (PMUs), and similar IEDs that are capable of producing and consuming various sorts of data for monitoring, metering, automation and control.

In existing electromechanical schemes when a multitrip lockout switch operates, the following happens:

- Unique Lockout Function:

Each protection function that performs lockout has its own lockout state, not combined with others. For example, if a transformer differential relay trips, it sets a lockout state for the breakers that isolate that transformer. If subsequent to the tripping operation, one of the breakers fails, then that breaker failure function sets a separate lockout state for the failed breaker and all the other breakers or TT channels to isolate it. The failed breaker then has two independent lockouts applied to it.

- Local Indication:

An operator must be able to determine which of these individual lockouts are in effect, so he can check on the cause and remedy for each, and sign off on corrections before resetting each one.

- Close Inhibit:

A breaker cannot be closed as long as any lockout is still in effect, even if some lockouts applied to it have been reset.

- Immunity to Relay Loss of Power:

The application of the lockout must not be dependent on the life of any particular relay, or on power to the relay. In other words, failure of the controlling relay or its DC supply cannot possibly enable closing of a locked out breaker.

- Immunity to System Loss of Power:

The memory of each of the possible lockouts must be nonvolatile. In other words, even if the entire power and closing system is de- energized and later re-energized, all the lockouts that were in effect must be remembered.

To remedy the shortcomings indicated above, we should look out for the followings:

- Remote Indication:

The lockout states are reported to SCADA and to maintenance via the LAN and remote communications.

- Single Procedure Reset:

The resetting of a particular lockout has a single procedure, all the affected breakers, channels, and other systems are reset as a group with respect to this particular lockout when that resetting procedure is applied. The operator cannot be expected to routinely go around the station finding and resetting the lockout actions at each of many target relays, breakers, or channels.

- Backup Indication and Reset:

There must be a clear backup process for identifying and clearing lockouts per above rules if the substation concentrator, computer, or humanmachine interface (HMI) are down. **–**

Lockout Restored by System

Lockout memory system must be robust in the face of relay failures and replacements. The system should have the means to align the picture of lockouts among all the relays and IEDs in the substation. If any is replaced, the system should be able to set its lockout states correctly when it is turned on, even though the replaced device was not there when the problem initially arose.

Removal of lockout can be remotely blocked or overseen to prevent careless resetting by field personnel in a hurry. Back office applications can compile statistics on frequency, causes, time duration and handling of lockout incidents for business process reporting and improvement.

3.3 DESIGN OF IEC 61850 BASED SUBSTATION AUTOMATION SYSTEMS ACCORDING TO CUSTOMER REQUIREMENTS

3.3.1 INTRODUCTION

IEC 61850 is the global standard for Substation Automation. It allows for and open and "future proof" design, different architectures and possibilities to combine products from multiple vendors. This new standard has many new possibilities but also challenges. By using the inherent advantages of IEC 61850 it is possible to optimize more reliable and cost effective solutions. The big vendors are speeding up quite fast. In order for users and system integrators to utilize the benefits of IEC 61850 it is necessary for the generation, transmission and distribution companies to start now with the awareness and education program for their most crucial asset – people, and start the migration to IEC 61850.

For specification, design and engineering, the most important feature of IEC 61850 is its support to strong formal description of the substation and its automation system.

3.3.2 CUSTOMER SPECIFICATION

3.3.2.1 General

The customer specification has to include three areas of requirements:

A. the functionality needed
B. the performance requested
C. constraints applicable.

The *functionality* refers mainly to the given single-line diagram of the substation and the protection and control functions of the substation automation system.

The *performance* includes figures for reliability and availability.

The *constraints* may include interfaces needed for remote network control centers or remote maintenance systems. Constraints include also the geographical situation on-site, i.e. the distances between components, building space, shielding and grounding facilities, and last not least the existence of prescribed IED types.

3.3.2.2 The Single Line Diagram

The SLD shows all power equipment to be controlled and protected, and defines how this shall be done from the operator's point of view. The topology, how the power equipment is electrically connected, gives further information needed e.g. for interlocking and synchrocheck functionality.

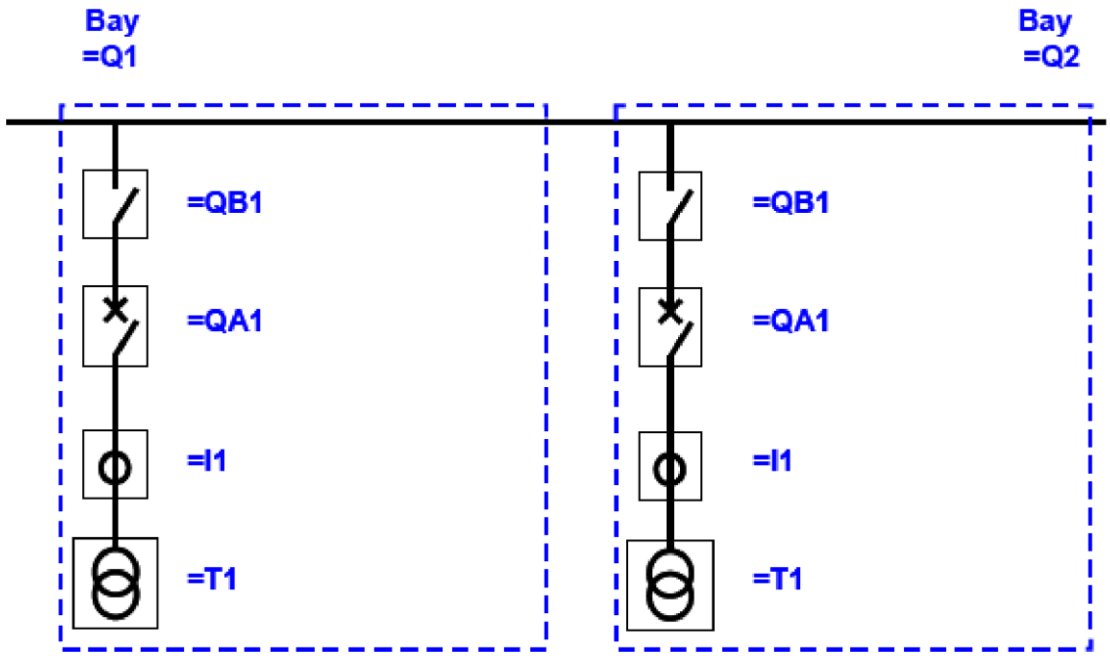


Fig. 3.1 Part of a substation single line diagram with equipment designations

3.3.2.3 Functions (Specification Method)

The functionality as given by the SLD should be specified without reference to any implementation to allow optimizing the solution. IEC 61850 offers the concept of *logical nodes* (LN) for formally defining functions. The LN is an object, which comprises at least all related mandatory data and attributes and all extensions according to the rules of IEC 61850. LNs allow defining functional requirements in a standardized way used in the SLD (see Figure 2)

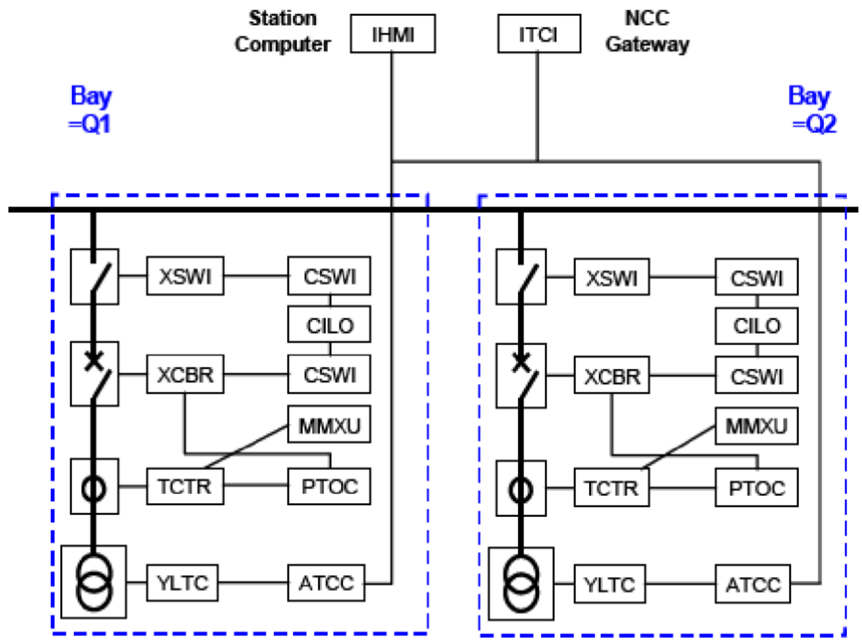


Fig. 3.2 Part of a substation single line(example)with function allocation by LN names

We have to know which power equipment and bay within the switchyard refers to what function or reverse. This may be done with help of SCL. The resulting file is called System Specification Description (SSD) file. The SSD file allows however including short text parts or references to files containing additional information into the objects of the SLD as well as into the LN definitions. With these features the degree of understandability is enhanced quite a lot compared to current verbal specification.

The LN class definitions according to IEC 61850 are given:
XCBR: *Circuit breaker*
XSWI: *Isolator or earthing switch*
TCTR: *Instrument transformer/transducer for current*
YLTC: *Power transformer*
CSWI: *Switch control*
CILO: *Interlocking*
MMXU: *Measuring unit*
PTOC: *Time overcurrent protection* ATCC:
Automatic tap changer control
ITCI: *Telecontrol interface or gateway*
IHMI: *Human machine interface, operators place*.

3.3.2.4 Performance

Performance comprises a wide range of topics such as response time, safety and reliability. These requirements guide the allocation of LNs and their related functions to devices, and strongly influence the structure of the communication system. It is up to the system designer selecting IEDs, communication configurations and function implementations which match these response times and failure modes additionally to the needed availability. Safety and availability are normally specified as probability values, together with some general rules.

3.3.2.5 Constraints

The constraints include some boundary conditions like the geographical extension and topology of the substation, the existence of building structures, switchyard kiosks, shielded rooms for the station HMI, etc. All these conditions influence the SA system architecture regarding possible IED locations and the resulting communication links. The *performance* requirements together with the given *constraints* define the final *physical architecture*.

3.4.1 THE DESIGN PROCESS

3.4.3.1 Design Steps

The general design process from customer specification to final system design is principally independent from any standard but some features of IEC 61850 influence and facilitate this process.

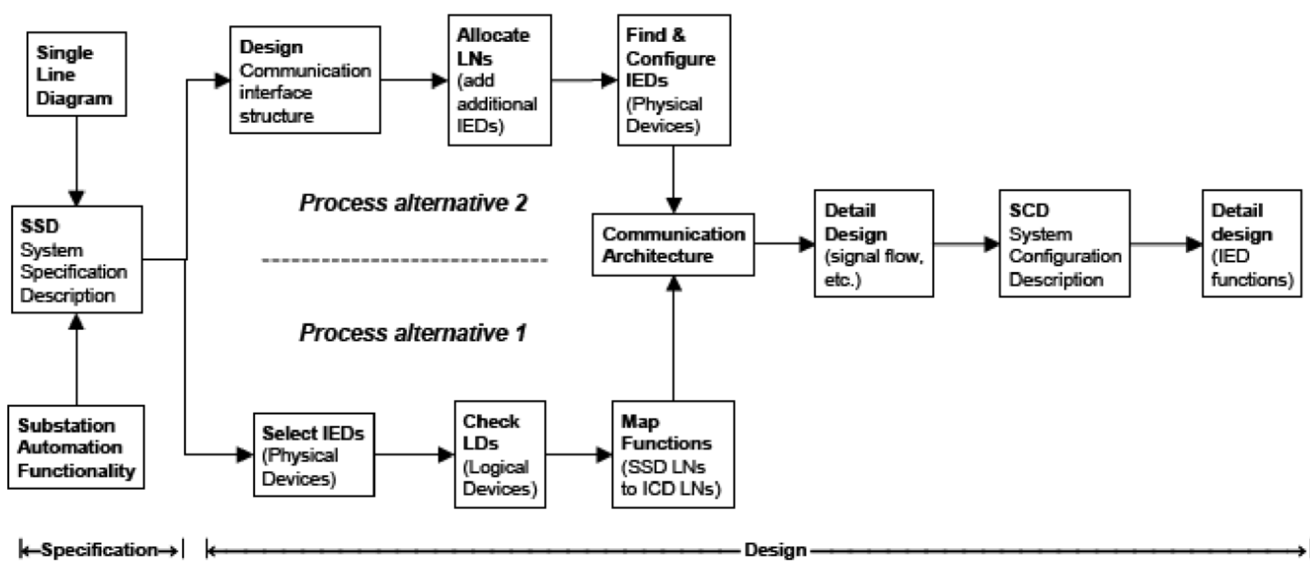


Figure 3 – Steps of the design process (process alternatives described in the text)

3.4.2 Start

The design process can either start with the functional specification, in case of IEC 61850 preferably with an SSD description, or with the boundary conditions (see Figure 3). When starting with the *functional specification*, the next step is to search for IEDs, which support the required functions. Then it has to be checked if the grouping of functions (LNs) on the found IEDs fulfills the availability and safety criteria. In the next step the boundary conditions and the availability conditions are used to design the connecting communication architecture in a cost optimal way. Now the overall system structure is known, and detail design can start. When starting with the *constraints* and *performance requirements*, this determines the minimum number of IEDs needed at the interface locations, and their main functionality. This first design step must already cover the requirements for functional redundancy.

3.4.3. Tools and formal specification

To get maximum benefit from tool support the *specification* has to be translated into the SCL based SSD (System Specification Description). The SSD is an *unambiguous input*, which enhances the quality of the specification.

3.4.4 Grouping LNs to LDs and non-functional requirements

We have to decide the geographical allocation of functions. During this allocation we have to prove that no constraints are violated and the reliability and availability goals are met. If we have a free choice of devices, we may first group functions.

1. The LNs belonging together in Logical Devices (LD).
2. combining all LDs in IEDs in such a way that a minimum number of devices results.
3. We have to find proper devices for implementing this optimized solution.

3.4.5 Example for Selection of IEDs and Allocation of Functions

In case of free selection of IEDs, the availability requirements, at least for transmission substations, end up mostly with *two devices* per bay. The selection is influenced by the process interface normally given by the switchgear. Figure 4 shows examples for both conventional hardwired interfaces in the bay IEDs and remote interfaces near the switchgear connected to the bay IEDs by the process bus. The IED allocated to the instrument transformers TCTR is called Merging Unit (*MU*) since it may merge the signals. *Switch*es are active communication nodes connecting Ethernet links.

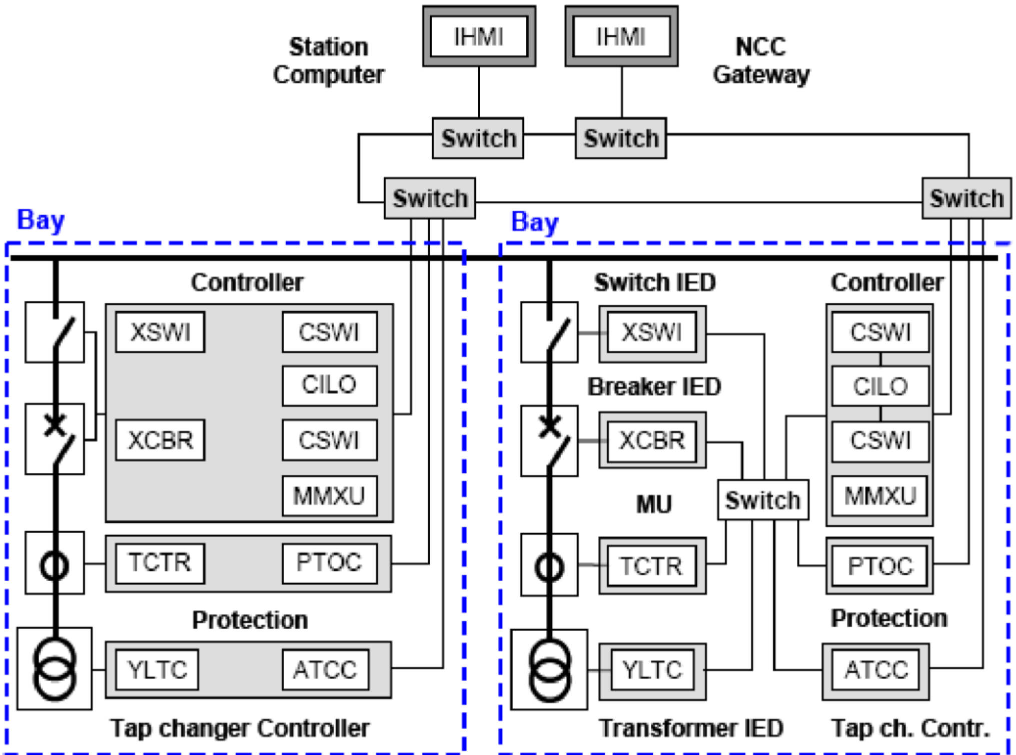


Figure 4 - Single line with allocated IEDs without (left) and with process bus.

Fig. 3.4 Single line with allocated IEDs without (left) and with process bus

3.4.6 The requirement of redundant protection

To avoid single point of failures, there have to be two process bus segments, which connect the sensor (Merging Unit IED, i.e. MU) with the protection and breaker (Breaker IED) each (see Figure 5). Each segment may contain an external or embedded switch. If any component of one segment fails, the protection of only this segment is out of order, and at least the other one is operating well. Control may be connected to any of the two switches.

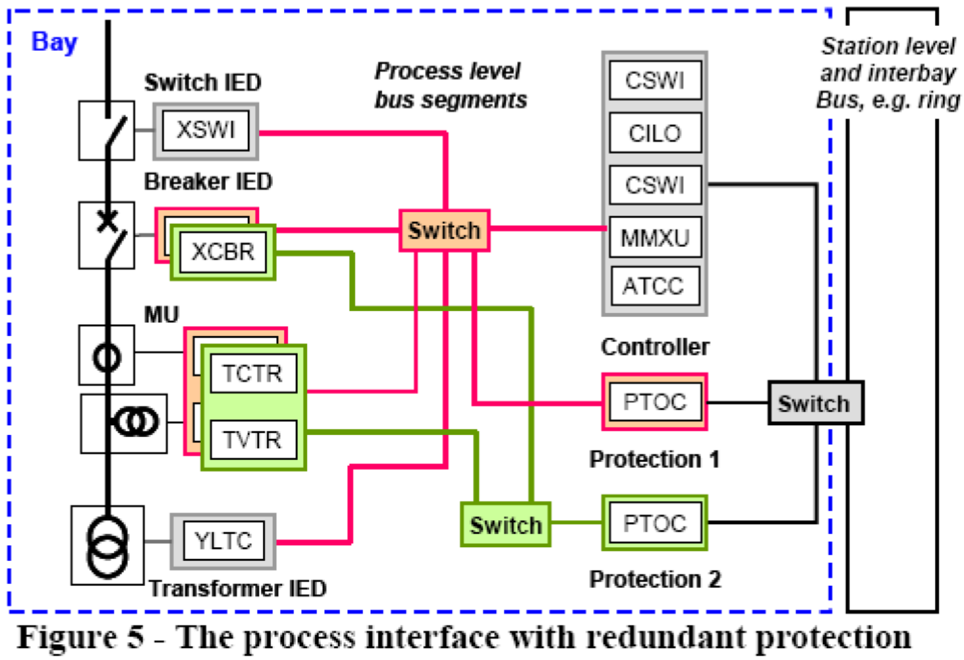


Fig. 3.5 The process interface with redundant protection

3.4.7 Communication topology

Logically, communication according to IEC 61850 takes place between LNs. In any implementation, physical communication takes place between IEDs. Multiple communication ports may exist. IEC 61850 is based on Ethernet, and Ethernet allows different physical variants. Since the standard and Ethernet is supporting both client-server relations and peer-to-peer communication, any communication topology connecting all related IEDs fulfills the functional requirements. Therefore, the final determination of the communication topology is strongly influenced by constraints, i.e. by non-functional requirements like performance, availability and others

3.4.8 The Final System

selected IEDs together with the communication architecture represent the final system. Different solutions are possible. Since all solutions have their functional and non-functional properties and their price tag, a proper trade-off can be made. In case of ordering, the high level data and communication engineering is already made.

Two extreme examples are given in what follows. They include all essential functions from the station level with its station computer and gateway to the network control center down to the process level with conventional and unconventional sensors and actuators, i.e. station bus and process bus features. According to the scope of IEC 61850, details of functions are not discussed but all related communication aspects.

3.4.9 MV system (Example)

Functional requirements are given with no redundant bay protection. The following *nonfunctional Requirements* apply: Determined hardwired process interface, switchgear cubicles at one place, prescribed combined protection-control units, average system availability, indoor switchyard with no separated control room. The *result* is a SA system with protection independent from any serial communication but with a single point of failure for the control and information exchange from station level and from remote (see Figure 6). With one switch only and one fiber link per bay, the communication system has a low price tag.

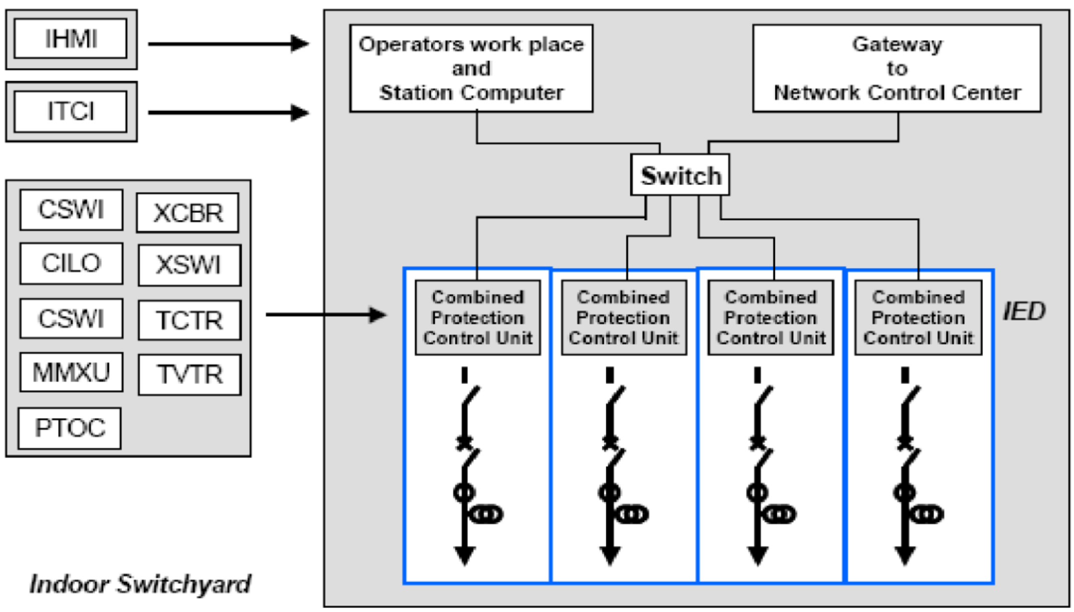


Figure 6 - Compact Substation Automation System for a MV substation

Fig.3.6 Compact Substation Automation System for a MV substation

3.4.10 HV system (Example)

Functional requirements are given with redundant bay protection (main1 and main 2). The following *non-functional requirements* apply: Determined nonconventional instrument transformers (NCIT) with serial interface via Merging Unit (MU), geographically distributed switchgear (AIS), switchyard kiosks, and high system availability.

The communication ring is safe against a single point of failure. With one switch for the operators' place, the NCC gateway and any bay, the communication at station level has a high price tag. As seen in Figure 7, the resulting solution may be applied for GIS also. The LNs allocated to the devices are found in Figure 5.

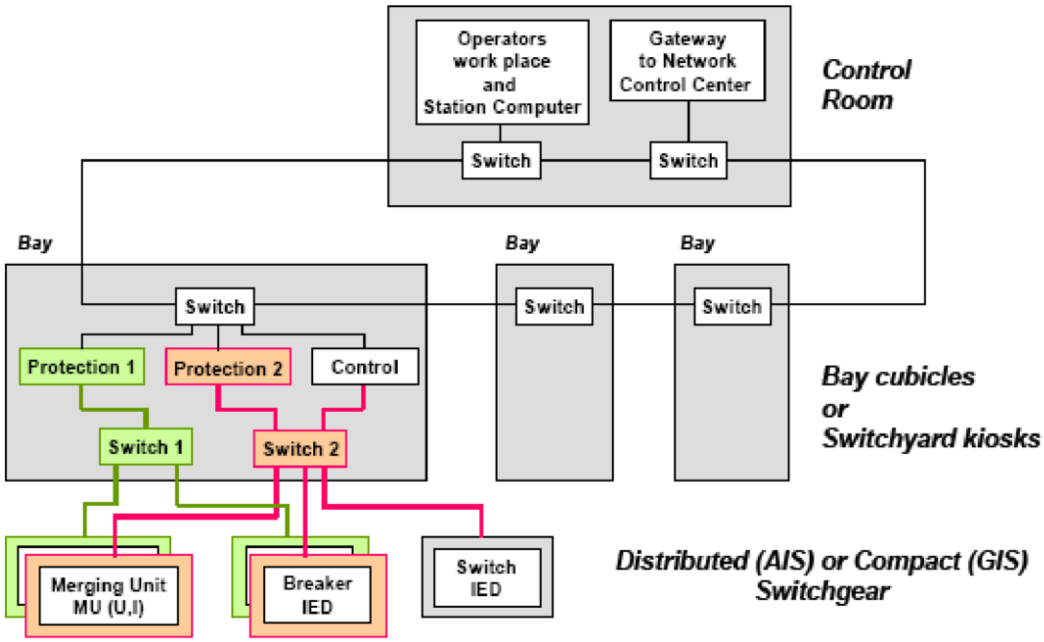


Figure 7 – Distributed Substation Automation System for a HV substation

Fig3.7 Distributed Substation Automation System for a HV substation

PLC Acronyms

The following table shows a list of commonly used Acronyms that you see when researching or using your PLC.

ASCII	American Standard Code for Information Interchange
BCD	Binary Coded Decimal
CSA	Canadian Standards Association
DIO	Distributed I/O
EIA	Electronic Industries Association
EMI	ElectroMagnetic Interference
HMI	Human Machine Interface
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
I/O	Input(s) and/or Output(s)
ISO	International Standards Organization
LL	Ladder Logic
LSB	Least Significant Bit
MMI	Man Machine Interface
MODICON	MOdular DIgital CONtoller
MSB	Most Significant Bit
PID	Proportional Integral Derivative (feedback control)
RF	Radio Frequency
RIO	Remote I/O
RTU	Remote Terminal Unit
SCADA	Supervisory Control And Data Acquisition
TCP/IP	Transmission Control Protocol / Internet Proto

Abbreviations Used

DCS	Distributed Control System
EC	European Community
ICA	Instrumentation, Control & Automation
I/O	Inputs and Outputs
LCD	Liquid Crystal Display
NWW	North West Water
PC	Personal Computer
PLC	Programmable Logic Controller
RTS	Regional Telemetry Scheme
SCADA	Supervisory Control and Data Acquisition

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